REPORT OF THE INTERAGENCY AD HOC WORK GROUP FOR THE CHEMICAL WASTE INCINERATOR SHIP PROGRAM

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U.S. ENVIRONMENTAL PROTECTION AGENCY

U.S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION

U.S. DEPARTMENT OF TRANSPORTATION
COAST GUARD

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

October 8, 1980

MEMORANDUM FOR: Co-Chairmen of the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program

Mr. Russell H. Wyer
Co-Chairman, U.S. Environmental Protection Agency

Mr. Daniel W. Leubecker
Co-Chairman, U.S. Department of Commerce, Maritime Administration

Subject: Report of the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program

The serious environmental and public health problems associated with the current hazardous waste situation require that the Federal Government exercise the maximum effort to develop and establish new technologies for treatment and destruction of these wastes. Accordingly, we established the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program in February 1980 to undertake a study of at-sea incineration technology and to examine various alternatives available to the Federal Government leading to the design, construction, and operation of one or more incinerator ships.

Based upon the results of the Ad Hoc Work Group's study, as well as previous studies conducted by the Environmental Protection Agency and the Maritime Administration, we conclude that incineration at sea is an effective and environmentally acceptable technology and that an accelerated federal effort should be instituted to establish chemical waste incinerator ship capabilities in the United States. We, therefore, approve the recommendations contained in the subject report with the following comments:

1. In order to expedite essential coordination of the Program, the Ad Hoc Work Group is hereby redesignated as the Interagency Review Board for the purposes spelled out in Recommendation No. 7 of the Report.

2. The Economic Development Administration, the National Oceanic and Atmospheric Administration, the General Services Administration, and other appropriate federal agencies shall be invited to be represented on the Interagency Review Board.

3. Strong emphasis shall be placed on utilization of privately-owned U.S. flag incinerator ships as indicated in Recommendation No. 1. An evaluation of additional alternatives to promote the construction of privately-owned U.S. flag incinerator ships shall be performed on an accelerated timetable.

4. Appropriate public and private forums shall be convened that will meet the following needs: (a) assist in accelerating the Program by disseminating the results of this study, (b) dispense appropriate information on the chemical waste disposal problem and the potential for chemical waste incineration at sea, and (c) obtain comments with respect to risks, regulatory problems, and any other concerns that have caused restraint in pursuing at-sea incineration in the United States.

5. The appropriate offices of the Environmental Protection Agency and the Maritime Administration are directed to proceed with the Report's recommendations.

In conclusion, we wish to thank you, the Co-Chairmen, and all the members of the Interagency Ad Hoc Work Group for a job well-done.

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Assistant Secretary
for Maritime Affairs
U.S. Department of Commerce

DOUGLAS M. COSTLE
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U.S. Environmental Protection
Agency

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September 1980

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EXECUTIVE SUMMARY

The Environmental Protection Agency has estimated that in 1980 at least 57 million metric tons of hazardous waste will be produced in the United States. Accumulation of uncontrolled, ever increasing volumes of hazardous wastes threatens the public health and the nation's environment. The Surgeon General has indicated that toxic chemicals seeping into the environment pose a major and growing health problem that will plague the nation for years. Various United States government agencies are investigating many alternative methods for disposing of hazardous chemical wastes. Incineration at sea offers an environmentally acceptable and cost-effective method for destruction of many types of combustible chemical wastes. The following conclusions and recommendations related to at-sea incineration have been developed by the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program.

CONCLUSIONS

1. A high priority effort is required to solve the nation's hazardous waste disposal problem. Incineration at sea aboard specially designed or modified ships has been demonstrated to be an environmentally acceptable and efficient means for destruction of liquid hazardous organic chemical wastes.

2. Adequate laws and conventions to regulate the design, construction, and operation of incinerator ships presently exist, e.g., the Marine Protection, Research, and Sanctuaries Act, as amended, the Ports and Waterways Safety Act, as amended, and the Clean Water Act, as amended.

3. Federal assistance for private incinerator ship construction under the authority of the Merchant Marine Act of 1936, as amended, is currently limited to federal ship loan guarantees.

4. A U.S. flag Chemical Waste Incinerator Ship Program is not likely to develop without substantial federal assistance. Potential investors are being extremely cautious about pursuing this technology because of the lack of experience with operating incinerator ships for the destruction of chemical wastes, the need to develop a customer base for this service, and the liabilities for any mishaps in handling these toxic wastes. While there is some foreign flag operating experience, the latter two factors have inhibited foreign operators from exploiting in the United States any technological advantages they may have.

5. Two new construction conceptual ship designs, an IMCO Type I hull and an IMCO Type I/Type II combination hull, each with approximately 8,000 metric tons of waste capacity, were

determined to be optimum candidates for use at this time as a demonstration vessel for at-sea incineration of hazardous wastes. Either ship would be equipped with three liquid injection incinerators for routine destruction of 30 metric tons per hour of pumpable wastes and a single rotary kiln incinerator for experimental incineration of solid wastes. Estimated construction costs are $80 million for the Type I hull ship and $75 million for the Type I/Type II hull ship, including installed incineration equipment, for delivery in 1985. The actual cost of constructing an incinerator ship varies with the size, type, mission, sophistication, contract date, delivery date, market factors, etc. The above cost estimates are considered to be maximum; smaller, less sophisticated vessels would be priced at a comparatively lower level. Economies of scale indicate that a larger incinerator ship with higher burning rates could be a more cost-effective option if large volumes of waste for incineration are readily available and if the EPA-designated burn site can absorb, without environmental damage, the higher combustion emissions.

6. Conversions of existing ships, i.e., a Landing Ship Dock (LSD) and a T-2 tanker, were evaluated and determined to be less costly but inefficient investments compared to the optimum design new incinerator ship for the dual mission of destroying large volumes of pumpable wastes and conducting experimental solid waste incineration.

7. Land based terminals are required for supplying wastes to the incinerator ship. There are existing terminals in areas where incinerator ships are likely to operate, or new facilities may be constructed. Estimated capital costs for a new terminal facility, excluding land costs, are $31 million for availability in 1985.

RECOMMENDATIONS

1. The Maritime Administration and the Environmental Protection Agency should pursue legislative action on a high priority basis which would amend the Merchant Marine Act of 1936, as amended, (the Act) and permit substantial federal assistance and funding for the construction and operation of privately owned U.S. flag chemical waste incinerator ships. Such aid would include Construction-Differential Subsidy, Operating-Differential Subsidy, and the tax deferral benefits of the Capital Construction Fund. Federal ship loan guarantees are currently available under Title XI of the Act for construction of incinerator ships. Such vessels built with federal assistance would be designed, constructed, equipped, and operated in accordance with the requirements of the Coast Guard and the Environmental Protection Agency.

2. If viable applications for federal assistance, as proposed in Recommendation No. 1, are not received from private operators within 12 months of authorization, the Maritime Administration and the Environmental Protection Agency should evaluate other alternatives including the construction of one federally owned prototype chemical waste incinerator ship. This evaluation should include the direct private sector funding for ship construction using superfund authorities and indirect construction support through guaranteed waste destruction contracts.

3. The Environmental Protection Agency should seek federal funds for the purpose of conducting research and development aboard U.S. flag ships to advance the state of the art of at-sea incineration, in particular solid waste destruction.

4. The National Bureau of Standards should investigate the availability of durable and reliable materials for the safe storage, transport, and handling of a wide variety of corrosive hazardous chemical wastes and make appropriate recommendations.

5. The Environmental Protection Agency should conduct a comprehensive study to assess the long range requirements for at-sea treatment and destruction (for example, incineration, chemical detoxification, and thermal treatment) of hazardous wastes to determine the number of ships necessary, optimum capacity and duty cycles, total forecasted volumes and tonnages of wastes, and economic costs of system operations.

6. The Environmental Protection Agency, the Maritime Administration, and other federal agencies should conduct investigations concerning methods of encouraging and assisting state and local authorities in developing waterfront facilities to support incinerator ships.

7. An Interagency Review Board consisting of representatives from the Environmental Protection Agency, the Maritime Administration, the Coast Guard, and the National Bureau of Standards should be established to monitor all federal government activities related to legislation, funding, design, construction, and operation of U.S. flag chemical waste incinerator ships. Quarterly status reports should be prepared and submitted to the Administrator of the Environmental Protection Agency, the Assistant Secretary of Commerce for Maritime Affairs, the Commandant of the Coast Guard, and the Director of the National Bureau of Standards.

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B. U.S. Environmental Protection Agency, Design Recommendations for a Shipboard At-Sea Hazardous Waste Incineration System, TRW, Inc., EPA Contract No. 68-03-2560, Work Directive No. T5017, EPA Project Officer: D.A. Oberacker, September 1980.

C. U.S. Department of Commerce, Maritime Administration, Concept Design of U.S. Flag Vessels for the Chemical Waste Incinerator Ship Program (PD-246), September 1980.

D. U.S. Environmental Protection Agency, Design Requirements for a Waterfront Facility to Support Chemical Waste Incinerator Ships, TRW, Inc., EPA Contract No. 68-03-2560, Work Directive No. T5017, EPA Project Officer: D.A. Oberacker, September 1980.

INTRODUCTION

The United States is currently faced with a serious and massive hazardous materials disposal problem. The public health and the nation's environment are being threatened by the accumulation of uncontrolled, ever increasing volumes of hazardous wastes. The Environmental Protection Agency (EPA) has estimated that 10-15 percent of the annual production of about 344 million metric tons (wet) of industrial waste is hazardous. The organic chemical industry alone is estimated to have generated 11.7 million metric tons (wet) of hazardous waste in 1977. EPA has also estimated that 90 percent of all hazardous waste is managed by practices that will not meet the new federal standards being implemented under the Resource Conservation and Recovery Act of 1976. (1) The Agency has further stated that there are thousands of disposal sites throughout the country being improperly operated or maintained and that a large number may pose significant health problems. (2)

A safe, effective, and relatively non-polluting method for the destruction of many combustible hazardous wastes, particularly organic chemical wastes, is incineration by ships at sea. A successful application of this method of disposal has been carried out aboard several foreign flag incinerator vessels. International safety standards governing the design and operation of incineration vessels have been developed under the auspices of the United Nations Intergovernmental Maritime Consultative Organization (IMCO) and have been adopted by contracting governments to the 1972 London Dumping Convention. Both EPA and the Maritime Administration (MarAd) have conducted extensive studies and research analyses which have confirmed the environmental acceptability and potential economic viability of the thermal destruction of liquid chemical wastes at sea. (3-12)

In response to the requirements of the Marine Protection, Research, and Sanctuaries Act of 1972, as amended, to control all dumping of hazardous materials into the sea, MarAd initiated its Chemical Waste Incinerator Ship Project to provide a viable alternative to the ocean dumping of hazardous wastes. With the assistance of EPA, MarAd issued a Final Environmental Impact Statement (FEIS) concerning this Project in July 1976. (10) Subsequently, the Maritime Administration/ Maritime Subsidy Board approved the FEIS and concluded in its Final Opinion and Order (Docket No. A-131, February 22, 1979)(Appendix A), that the Project should be pursued with federal assistance. The MarAd aid plan, as currently described, involves several elements:
(a) loan guarantees to aid in the construction of incinerator ships,
(b) sale of National Defense Reserve Fleet (NDRF) vessels for conversion to incinerator ships, and (c) financial support for an incinerator ship system safety analysis.

Due to the lack of formal applications from private industry for assistance under the Chemical Waste Incinerator Ship Project and the urgent need for such ships to safely dispose of hundreds of thousands of metric tons of hazardous wastes annually, an Interagency Ad Hoc Work Group was formed in February 1980. (13, 14, 15) The first meeting of the Work Group was held at MarAd Headquarters on March 19, 1980, and was attended by representatives from EPA, MarAd, the Coast Guard, and the National Bureau of Standards. The purpose of this interagency effort has been to conduct a feasibility study which examines the various alternatives available to the federal government leading to the design, construction, and operation of (a) a federally-owned or controlled incineration ship, and (b) federally assisted, privately-owned incineration ships. The federally-controlled incineration ship would be used for research and development purposes in order to advance the state of the art of at-sea incineration as well as for disposing of hazardous wastes under federal government jurisdiction.

This document reports on the findings of the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program.

CHAPTER I

CHEMICAL WASTE INCINERATION AT SEA

The management of hazardous wastes in the United States is generally inadequate and a threat to the public health and welfare. Improper disposal practices have led to direct exposure of humans to toxic wastes, contamination of ground waters and surface waters, air pollution, damage to wetlands and other environmentally sensitive areas, explosions of landfill gas, contamination of croplands with heavy metals, and other adverse effects. Potentially the most widely significant effect is contamination of ground water. Once seriously contaminated, an aquifer is no longer useable as a drinking water source. (16)

A viable alternative to help alleviate this problem is the destruction of certain hazardous wastes, particularly organic chemical wastes, at sea in specially designed incineration ships. EPA evaluations of existing foreign flag incineration vessels have shown thermal destruction of liquid chemical wastes at sea to be an environmentally acceptable means of disposal. (3-9) The following paragraphs address the background of incineration at sea, the need for incineration ships in the United States, and the types of wastes to be destroyed.

A. BACKGROUND

Prior to the passage of the Marine Protection, Research, and Sanctuaries Act in 1972 (P.L. 92-532) (MPRSA), it was common practice to dump chemical wastes directly into the sea. With the prohibition of such disposal methods by the MPRSA and the 1972 International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention), alternative technologies for chemical waste disposal had to be developed. Land-based incineration, deepwell injection, and landfill methods have been primarily used in the United States. However, in Europe, in addition to land disposal methods, at-sea incineration technology has been developed using several incineration tank vessels. Incineration at sea is currently regulated nationally under the MPRSA and internationally under the London Dumping Convention.

One of these European incineration ships is the M/T VULCANUS, a converted cargo ship of 4768 metric tons deadweight with a waste tank capacity of 3503 cubic meters. Waste is burned in two incinerators that have a combined maximum feed rate of 25 metric tons/hour. A crew of 18 mans the ship, 12 to operate the vessel and 6 to operate the incinerators. The M/T VULCANUS meets all applicable requirements of IMCO concerning the transport of dangerous bulk chemical cargoes. See Appendix B.

The first officially sanctioned at-sea incineration operation conducted in the United States was performed aboard the M/T VULCANUS, in the Gulf of Mexico, during October 1974 through January 1975. Four shiploads, about 4,000 metric tons each, of toxic organochlorine wastes from the Shell Chemical Company, Deer Park Manufacturing Complex, Texas, were incinerated under permits granted by EPA at a federally approved incineration site 143 nautical miles (305 kilometers) southeast of Galveston, Texas, and 165 nautical miles (352 kilometers) south of Cameron, Louisiana. The site was beyond the continental shelf, in water depths of 3,000 to 6,000 feet (914 to 1,829 meters), outside all major shipping lanes; and well beyond commercial shrimping and fishing depths. The burns were monitored by EPA, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA).

The wastes, which had resulted from the production of glycerin, vinyl chloride, epichlorohydrin, and epoxy resins, were a mixture of chlorinated hydrocarbons with trichloropropane, trichloroethane, and dichloroethane predominating. The first two shiploads were each incinerated under an EPA Research Permit; the second two shiploads were burned under an EPA Interim Permit. Composition of the waste feeds was similar during the two research burns: both contained 63 percent chlorine, 29 percent carbon, 4 percent hydrogen, 4 percent oxygen, and traces of heavy metals. Combustion chamber flame temperatures ranged from 1340 - 1610 degrees centigrade. Combustion efficiencies, i.e., the percentage of hydrocarbons combusted, ranged between 99.92 and 99.98 percent. For the most part, the uncombusted hydrocarbons were not organochlorines. Efficiency of destruction of organochlorines averaged 99.995 percent. (3)

A second at-sea incineration operation took place during the period of March to April 1977 under an EPA Special Permit. Organochlorine wastes generated by the Shell Chemical Company were destroyed by the M/T VULCANUS in an incineration area located 130 miles south of Sabine Pass, Texas, in the Gulf of Mexico. A total of approximately 16,000 metric tons of wastes were destroyed in four burns. The first burn was monitored by a team of scientists and engineers from TRW Inc., Redondo Beach, California, under contract to EPA. Average waste feed rate was 22 metric tons per hour. Combustion efficiency was 99.95 percent. (5)

A third incineration at sea of organochlorine wastes occurred during the period of July 14 to September 2, 1977, on board the M/T VULCANUS under contract to the U.S. Air Force. The operation was carried out in three consecutive burns, the first under an EPA Research Permit and two under a Special Permit, at a designated area in the Pacific, approximately 200 miles west of Johnston Atoll. These burns were monitored by a team of scientists from TRW, Inc., under contract to EPA. During the first burn, an EPA observer was present. An Air Force officer, as a working member of the analytical team, was present during all three burns.

This operation required special monitoring and safety procedures because the waste was Herbicide Orange and contained 2,3,7,8-tetrachloro-dibenzo-p-dioxin (TCDD) as an impurity to the extent of an average 2 parts per million. Because of the extremely high toxicity of TCDD, special precautions were placed in effect during all loading and operating procedures on the ship.

All burns were successfully completed. Average feed rate was 14.5 metric tons per hour. Destruction efficiencies for 2,4-D and 2,4,5-T were greater than 99.999 percent. Average combustion efficiency was 99.99 percent. Average destruction efficiency of TCDD was 99.93 percent. (6)

B. NEED FOR INCINERATION SHIPS IN THE UNITED STATES

In 1978, EPA estimated that the United States annually generates about 344 million metric tons of industrial wastes, including 30 to 40 million tons of hazardous wastes. Serious environmental, public health, economic, and administrative problems and issues are associated with the management of these wastes. (16) EPA also has projected that in 1980 at least 57 million metric tons of hazardous waste will be produced nationally. (17)

Various United States government agencies are investigating many methods for disposing of chemical wastes, as part of the effort to establish safe disposal standards for the hazaradous wastes produced in this country. Organic petrochemical residues are among the most durable and difficult wastes to handle. Effective and efficient disposal methods to handle such wastes are needed immediately, because these chemicals persist once released into the environment. Abandoned landfill facilities, such as Love Canal in Niagara Falls, New York, and flagrant waste disposal abuses, such as the Valley of the Drums in Kentucky and the Chemical Control Corporation disposal site in Elizabeth, New Jersey, have demonstrated that industrial wastes have created a serious hazard to public health. The dumping of such wastes into the environment is now widely recognized as a tragic mistake that has continued for decades and will take decades to correct. (12,18)

The Resource Conservation and Recovery Act of 1976 (P.L. 94-580) (RCRA) gives the federal government powers to control hazardous waste disposal across the country in order to prevent further contamination. Establishing additional waste management facilities will be difficult. New disposal standards limit the number of acceptable sites for waste landfills, and nearby communities oppose the location of hazardous waste disposal sites in their neighborhoods. Public opposition to the siting of hazardous waste management facilities, particularly landfills, is the most critical problem in developing new facilities. (12,19)

Increasing citizen concern on location of land-based toxic waste disposal or treatment facilities is seen in regard to the Rollins Environmental Services, Inc. installation in New Jersey. Another example of the difficulties presented by public opposition to the siting of hazardous waste facilities occurred at Wilsonville, Illinois, where Earthline Corporation constructed a model secure landfill. Earthline obtained all the required State permits and began operating the site in late 1976. In April 1977, residents learned that wastes containing polychlorinated biphenyls (PCB's) from a cleanup operation in Missouri were disposed of at the site. Fearing environmental and health damages and voicing opposition to their community becoming a dumping ground for other people's wastes, residents filed suit in an attempt to force Earthline to close the site and to "restore and reclaim the area so it is safe and not an eyesore." EPA, along with 27 technical experts, testified as friends of the court in favor of Earthline's facility. Despite these efforts, the State Circuit Court ordered the facility closed in August 1978.

Incineration at sea offers an attractive alternative to present waste disposal practices for many types of combustible chemical wastes. It is the technical equivalent of land-based incineration, since 99.995 percent destruction efficiency can be achieved. An incineration ship destroys wastes away from populated areas, thereby avoiding the risk to nearby communities and reducing, or even eliminating, community opposition to its operation. Also, the acidic stack gases that the incinerator emits can be directly dispersed over the ocean surface without the elaborate "scrubbing" that is needed for acidic stack emissions from a land-based incinerator. Finally, incineration at sea for combustible, liquid chemical wastes is an industrial operation which is available now and can be implemented without much of the preliminary testing that other alternatives may require. (12)

C. WASTE TYPES - SOURCES AND CHARACTERISTICS (Appendix B)

Much of the millions of metric tons of chemical wastes produced in the United States can be assumed to be incinerable. They originate mainly from four principal industries: petroleum refining, organic chemicals, synthetic fibers and resins, and pesticides. Such wastes may be under private control or come under government jurisdiction. The volume of waste produced annually, along with waste currently stockpiled or from cleanup of old dump sites, appears to be more than adequate to support the operation of at least several incineration ships. (11) Chemical wastes may be generated from the routine operations of manufacturing processes, intermediate manufacturers, and end product users as well as from nonroutine events such as spills and accidents.

Chemical wastes which are likely to be destroyed by incineration are basically organic in nature; thus, it follows that the major locations of the manufacturing sources of wastes will largely follow the pattern of the chemical industry. Therefore, it is expected that major concentrations of sources will be along the Gulf and Atlantic Coasts. These areas are expected to have the greatest concentration of wastes from primary sources. Sources of waste involving specialty chemicals and pesticides can also be readily pinpointed because of the relatively small number of manufacturers.

Wastes from intermediate or secondary sources will be much more widely dispersed but will still tend to follow the location pattern typical of the chemical and petrochemical industries. Sources of wastes from end product users (e.g., PCB-containing electrical capacitors) can also be expected to be widely dispersed.

In classifying chemical wastes for thermal destruction, it has been found useful to categorize them on the basis of their elemental chemical composition. Within each class of compounds with the same elemental composition, subclasses may be developed based on properties (e.g., physical form, chemical composition, heat content, viscosity, etc.) which are related to specific burning characteristics. Examination of chemical waste streams shows that those suitable for thermal destruction fall into one of the following four classes:

1. C-H and C-H-O compounds, yielding CO_2 and H_2O on complete combustion,

2. C-H-N and C-H-O-N compounds, yielding CO_2, H_2O and nitrogen oxides,

3. C-H-Cl and C-H-O-Cl compounds, yielding CO_2, H_2O and HCl (gas), and

4. Other wastes including organic wastes containing both nitrogen and chlorine, organic wastes containing sulfur, organic wastes containing bromine, organic wastes containing flourine, organic wastes containing phosphorus, organic wastes containing silicon, and varied wastes not included in the first three major classes.

Wastes can come in a variety of physical forms, e.g., liquids, solids, slurries, and sludges; the ash formed from the incineration process can be nonfusible, fusible, and/or metallic.

A few of the many waste streams which could be incinerated at sea are listed in TABLE 1. The heating value for each waste stream can be either low (less than 2,800 kcal/kg), medium (2,800 to 5,600 kcal/kg), or high (greater than 5,600 kcal/kg), as the precise

TABLE 1. Candidate Wastes for Incineration at Sea

	Waste Stream Characteristics		
Hazardous Waste Stream	Constituents	Physical Form	Heating* Value
Silvex Herbicides (Recalled Products)	Esters of 2,4,-D and 2,4,5-T with TCDD contaminant	Liquid	High
Dodecyl Mercaptan Manufacturing Wastes	Mercaptons and organic sulfides	Liquid	High
Organic Chemical Capacitor, Transformer Production Wastes Containing PCB's and Alpha Methylstyrene	Waste containing PCB's and alpha methylstyrene, in capacitors	Solid	Low
Nitrochlorobenzene Manufacturing Wastes	Heavy ends and tars from orthochloronitrobenzene vacuum distillation	Tar	Medium

*High - greater than 10,000 Btu/pound (5,600 kcal/kg)
Medium - 5,000 to 10,000 Btu/pound (2,800 to 5,600 kcal/kg)
Low - less than 5,000 Btu/pound (2,800 kcal/kg)

heat content of most waste streams is not well-defined or consistent. It is important to recognize that waste stream descriptions obtained from the literature, or supplied by a plant, cannot be considered reliable until actual representative samples of the waste stream which is to be delivered have been obtained and analyzed. Refer to Appendix B for details on waste stream characteristics and suitable incineration processes.

The major category of toxic chemical waste is represented by the organic chemicals, both chlorinated and non-chlorinated, which constitute approximately 71% by weight of the total anticipated economic waste quantity for ocean incineration as of 1977. Next are petroleum refinery wastes at 15%, inorganic chemicals at 11%, and pesticides at 3%. Based on environmental quantities, excluding the inorganic chemical wastes from the economic quantities, organic wastes represent 80%, petroleum wastes 17%, and pesticide wastes 3% of the total. For the most part, the wastes are either liquids or can be handled in slurry form.

D. MARITIME ADMINISTRATION CHEMICAL WASTE INCINERATOR SHIP PROJECT

In response to the requirements of the MPRSA to control the dumping of hazardous materials into the sea, the Maritime Administration initiated its Chemical Waste Incinerator Ship Project in 1974 to provide a viable alternative to ocean dumping of hazardous wastes. Pursuant to the National Environmental Policy Act, a Final Environmental Impact Statement (FEIS) was issued in 1976. (10) Subsequently, the Maritime Administration/Maritime Subsidy Board approved the FEIS and concluded in its Final Opinion and Order (Docket No. A-131, February 22, 1979) that the Project should be pursued with federal assistance. The federal aid plan, as recommended by the Board, involves the following primary elements: (1) Title XI mortgage loan guarantees to aid in the construction of incinerator ships, and (2) sale of National Defense Reserve Fleet (NDRF) vessels for conversion to incinerator ships. It was later determined that financial support for an incinerator ship system safety analysis was also applicable to the Project.

As an initial phase of the Chemical Waste Incinerator Ship Project, MarAd contracted with Global Marine Development, Inc., for a "Study of the Economics and Environmental Viability of a U.S. Flag Toxic Chemical Incinerator Ship." (11) The study, completed in December 1978, concluded that ocean incineration of toxic chemical wastes is both economically and environmentally viable for U.S. flag ships and that the estimated number of incinerator ships required to handle the toxic wastes is four in 1983 and five in 1989 with each ship capable of carrying 12,000 metric tons of waste.

As of September 26, 1980, there have been no commercial applications to participate in the MarAd Chemical Waste Incinerator Ship Project. U.S. flag chemical waste incinerator ships are not likely to be built without additional federal assistance. Potential investors are being very cautious about pursuing this technology because of the lack of experience with operating incinerator ships for the destruction of chemical wastes, the need to develop a customer base for this service, and the liabilities for any mishaps in handling these toxic wastes.

E. COST ANALYSIS FOR DISPOSAL OF ORGANOCHLORINE WASTES

A comparative study made in 1978 of the disposal of liquid organochlorine waste by land-based incineration, at-sea incineration, and chlorolysis at a Houston, Texas location showed at-sea incineration to be the least costly option at $80 to $91 per metric ton. Comparable costs were $181 to $212 per metric ton at a centralized land-based incinerator, and $134 to $158 per metric ton by the Hoechst-uhde chlorolysis process if suitable feedstocks are available. Environmentally, maximum ground level concentrations of inorganic chlorine and organochlorine species and particulates emitted from land-based incinerators and chlorolysis are all several orders of magnitude lower than their respective Threshold Limit Values (TLVs) or are within air quality standards. The only wastewater problem identified for both disposal processes is discharges with high total dissolved solids. For at-sea incineration the maximum sea level concentration of hydrogen chloride is 4.4 mg/cu m and below its TLV of 7 mg/cu m. The maximum sea level concentration of unburned wastes is several orders of magnitude lower than the TLV of most organochlorine compounds. Water quality is not necessarily impacted by at-sea incineration. (8)

Overall, it may be concluded that land-based incineration, at-sea incineration, and chlorolysis are all viable options for the disposal of liquid organochlorine wastes. Chlorolysis should be considered if suitable feedstocks are available and the selling price for carbon tetrachloride remains relatively stable, mainly because it is a recycling process that conserves resources and causes minimum environmental impact. At-sea incineration is cost-effective for the disposal of large quantities of liquid organochlorine wastes, and the environmental risks are considered to be acceptable when properly controlled and monitored. Land-based incineration, although relatively more expensive, is suited for the disposal of other types of liquid wastes as well as solid wastes, with no restraints on the minimum accepted for disposal. (8)

CHAPTER II

ASSISTANCE PROGRAMS TO PROMOTE THE CONSTRUCTION AND OPERATION OF CHEMICAL WASTE INCINERATOR SHIPS (20)

The Marine Protection, Research, and Sanctuaries Act of 1972, as amended [1] (MPRSA), directs the Secretary of Commerce to render financial aid and other assistance to various public and private agencies and to individuals for the purpose of determining means of eliminating and minimizing the dumping of materials into the oceans [2], and to consider alternative methods of waste disposal [3]. To this end, MarAd developed the Chemical Waste Incinerator Ship Project and, with the assistance of EPA [4], published a Final Environmental Impact Statement (FEIS) [5] for the Project in 1976. The FEIS and Docket A-131 6/, which adopted the FEIS, listed three forms of MarAd support for an incinerator ship project. Title XI loan guarantees, sale of National Defense Reserve Fleet (NDRF) vessels, and a combination of the two. It is the purpose of this chapter to expand upon these three options and address other means of funding the construction and operation of incinerator ships.

The chapter is divided into the following three categories dealing with government funding mechanisms: (a) a privately owned incinerator vessel, (b) a government-owned vessel, and (c) a hybrid category involving incidents of both government and private control.

A. PRIVATELY-OWNED VESSEL

As one of the main goals of MarAd is to promote the development of the American merchant marine, funding mechanisms which encourage

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1/ P.L. No. 92-532, 33 U.S.C. 1401, et seq.

2/ Section 203, 33 U.S.C. 1433.

3/ Section 202(a), 33 U.S.C. 1442(a).

4/ The Environmental Protection Agency regulates ocean incineration of wastes under the Marine Protection, Research and Sanctuaries Act of 1972, as amended.

5/ Final Environmental Impact Statement, Maritime Administration Chemical Waste Incinerator Ship Project, MA-EIS, 7302-76-041F, July 2, 1976 (Reference 10).

6/ Docket A-131, MARAD CHEMICAL WASTE INCINERATOR SHIP PROJECT, Final Opinion and Order by the Maritime Subsidy Board and the Maritime Administration, February 22, 1979 (Appendix A).

private entrepreneurs to build and operate incinerator ships should be given top priority in any ranking of proposed actions by the Ad Hoc Work Group.

1. MarAd Programs

MarAd has several programs which should be considered in developing a comprehensive Chemical Waste Incinerator Ship Program. They are: the Title XI Loan Guarantee Program, sale of National Defense Reserve Fleet (NDRF) vessels, the Construction-Differential Subsidy Program (CDS), the Operating-Differential Subsidy Program (ODS), the Capital Construction Fund (CCF), the Construction Reserve Fund (CRF), and financial support for an incinerator ship system safety analysis through procurement of engineering and related services. The amount of new construction, operation, or other activities which can be financed is necessarily governed by obligation restrictions, available appropriated funds, eligibility standards, or other limitations applying to these programs. Therefore, within such governing terms, government assistance is to be channeled to those applications which most closely meet the purposes of the Merchant Marine Act, 1936, as amended (the "Act").

a. Title XI Federal Ship Loan Guarantees

Title XI of the Act 7/ provides for a Loan Guarantee Program whereby the "full faith and credit" of the U.S. is pledged to the repayment of principal and interest on debt obligations issued by U.S. shipowners. These guaranteed obligations are used to finance construction or reconstruction of U.S. flag ships in American shipyards and must not exceed 75 or 87-1/2 percent of the actual cost of the vessel, depending on the specific application. In addition, applicants must meet statutory requirements with respect to financial strength and the ability to operate the vessel on an economically sound basis. The program enables shipowners to obtain long term financing in the private sector at favorable terms and interest rates that are not usually available to the average shipowner.

In Docket A-131, issued on February 22, 1979, by the Maritime Subsidy Board of the Maritime Administration, it was held that Title XI guarantees could be granted to secure financing for the construction of incinerator vessels or the conversion of NDRF vessels into incinerator ships.

7/ 46 U.S.C. 1271, et seq.

b. Sale of a National Defense Reserve Fleet Vessels

The National Defense Reserve Fleet (NDRF), maintained by the Maritime Administration, is comprised of several hundred merchant ships available for use during national emergencies [8]. As these vessels lose their value for such use, due to old age, advances in technology or changes in U.S. emergency needs, MarAd may either scrap the vessels or sell the vessels by competitive sealed bids [9]. It is possible that these vessels, upon conversion, would be capable of chemical waste incineration at sea. Docket A-131 includes as one option the sale of NDRF vessels for conversion into incinerator ships and states that Title XI loan guarantees could be used to secure financing for the conversion.

c. Construction-Differential Subsidy (CDS)

The Construction Differential Subsidy Program established by Title V [10] of the Act, provides for the payment of construction subsidies to American shipbuilders in order to place the cost of constructing a vessel in the United States on a parity with foreign construction costs. The amount of subsidy awarded is the excess of U.S. shipbuilding costs over the fair and reasonable estimate of costs to construct the same vessel in a foreign shipyard. Currently the maximum amount of CDS which can be awarded is 50 percent of the U.S. construction price. CDS may also be granted for reconstruction and reconditioning of existing ships in exceptional cases.

Vessels built with CDS are subject to several restrictions including a requirement that the vessels be built for use in the foreign commerce [11] of the U.S. or in trade between foreign ports.

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[8] Merchant Ship Sales Act of 1946, 60 Stat 41, U.S.C. App. 1735, *et seq.*; Docket A-131 at 5.

[9] While the Merchant Ship Sales Act, *supra* note 8, permits MarAd to sell vessels either to an American citizen or to an alien, as a matter of public policy, preference is given to Americans.

[10] Section 501, 46 U.S.C. 1151.

[11] "Foreign commerce" or "foreign trade" is defined in section 905 of the Act, 46 U.S.C. 1244, as commerce or trade *between the United States*, its Territories or possessions, or the District of Columbia, *and a foreign country*. For the purposes of the CDS and CCF Programs, bulk cargo trading between foreign ports is also included in the definition of foreign commerce.

Recently, the consensus within MarAd has been that the proposed operations of incinerator ships do not fall within the foreign commerce of the United States, as defined in the Act, and, as a result, CDS may not be awarded for construction of incinerator ships. Modifying legislation would be required before CDS would be granted.

d. Operating-Differential Subsidy (ODS)

The Operating-Differential Subsidy Program, established by Title VI of the Act 12/, provides for the payment of subsidy to qualified U.S. flag shipping companies for the operation of ships in essential services in the foreign commerce of the United States, or in bulk cargo carrying services which may include foreign-to-foreign trading. In general, this program seeks to equalize the disparity in operating costs between those of American ships and their foreign competitors with respect to the wages of officers and crews, insurance, and maintenance and repairs not compensated by insurance.

As incinerator ships are not yet considered to be operating in the foreign commerce of the United States 13/, as required by Title VI, operating-differential subsidy is presently not available to owners of such ships. As with CDS, modifying legislation to the Act would be required before granting ODS for incinerator ships.

e. Capital Construction Fund (CCF)

The Capital Construction Fund Program 14/ was created by the 1970 amendments to the 1936 Act as a method of helping shipowners to accumulate the large amounts of capital needed to acquire, construct or reconstruct additional vessels. Once a shipowner has established a Capital Construction Fund by entering into a CCF agreement with the Secretary of Commerce, he may reduce his taxable income by making deposits into the Fund. These deposits may consist of earnings realized from the operation of an agreement vessel, net proceeds realized from the sale or disposition of an agreement vessel, insurance proceeds from the loss of an agreement vessel, earnings from the investment of amounts on deposit in the Fund, and allowances for depreciation. Qualified withdrawals from the Fund must be used to construct, reconstruct or acquire additional qualified vessels to be used in the foreign commerce, Great Lakes or noncontiguous domestic trade or in the fisheries of the United States. CCF benefits are presently not available to shipowners

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12/ Section 601, 46 U.S.C. 1171.

13/ See Section on Construction-Differential Subsidy, *supra*.

14/ Section 607.

who propose to construct or acquire incinerator vessels, because the incinerator ship trade has not been defined as being in the foreign trade. Under certain circumstances, however, the operation of an incinerator ship from the United States to fixed offshore incinerator platforms might be considered to be in the noncontiguous domestic trade for the purposes of the CCF Program 15/. As with CDS and ODS, modifying legislation would be required to allow the CCF Program to apply to incinerator ships.

f. Construction Reserve Fund (CRF)

The Construction Reserve Fund Program 16/ is similar to the Capital Construction Fund Program in that both programs offer tax deferral benefits to U.S. flag shipowners who deposit the net proceeds or net indemnity from the sale, disposition or loss of vessels into a special fund for use in constructing, acquiring or reconstructing vessels. The CCF Program offers greater tax benefits than the CRF Program by permitting shipowners to deposit amounts from current earnings into the Fund. However, the CCF Program is limited to the operation of vessels in the U.S. foreign trade, Great Lakes trade, noncontiguous domestic trade or in the fisheries. The CRF Program, on the other hand, while not sheltering earnings as does the CCF Program, is available to shipowners and operators in all forms of domestic commerce as well as the Great Lakes and foreign commerce and fisheries. The domestic commerce of the United States includes trade between ports of the United States, its territories and possessions embraced within the coastwise laws, on the Great Lakes and on inland rivers. As a result, even though the incinerator trade is presently not considered to be in the foreign commerce for the purposes of ODS, CDS and CCF, it might be considered to be in the domestic commerce for the purpose of the CRF Program. A more detailed discussion of the foreign commerce issue follows.

2. Foreign Commerce

As noted above, several of the promotional programs run by the Maritime Administration are available only to U.S. citizens who propose to operate or construct a vessel to be used in the foreign commerce of the United States. As defined in Section 905(a) of the Act 17/, "foreign commerce" or "foreign trade" is commerce or trade between the United States, its Territories or possessions, or the District of Columbia, and a foreign country. The present

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15/ See section of this chapter on Foreign Commerce.

16/ The CRF Program was established by Section 511 of the Merchant Marine Act, 1936, as amended; 46 U.S.C. 1161.

17/ 46 U.S.C. 1244, (emphasis added).

consensus with MarAd [18] holds that the proposed incinerator vessels will not operate in the "foreign commerce" of the United States because they will not travel from the United States to a foreign country. Instead, the vessels will operate between the United States and an EPA-designated burn site located in international waters.

The operations of an incinerator ship, while not considered to be in the foreign commerce for the purposes of ODS and CDS, could, in certain limited circumstances, be held to be in the noncontiguous domestic trade for the purposes of the CCF Program. As defined in section 607(k)(8), noncontiguous domestic trade is "trade between the contiguous forty-eight states on the one hand and Alaska, Hawaii, Puerto Rico and the insular territories and possessions of the United States on the other hand. . ."

A recent legal memorandum from the General Counsel's staff [19] held that offshore platforms fixed to the U.S. Outer Continental Shelf are to be considered "insular territories and possessions of the United States" for the purpose of Section 607 of the Act. A similar conclusion could be reached for permanently fixed incinerator platforms created by the conversion of abandoned drilling rigs and set up in burn sites designated by the U.S. Environmental Protection Agency within the 200 mile fishing management zone. Incinerator ships traveling from a U.S. port to the platform within the burn site could be deemed to be operating in the noncontiguous domestic trade for the purpose of the CCF Program. Such a determination would depend upon the facts of each application for assistance.

While MarAd does not presently consider incinerator traffic to be within the definition of "foreign commerce" of the United States for the purpose of the Merchant Marine Act, other agencies of the government, notably the Coast Guard and the Customs Service [20], are not likely to consider

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[18] FEIS supra note 5 at I-4.

[19] Memorandum for Assistant General Counsel, Division of Maritime Aids, from Melvin S. Eck, Attorney-Advisor, Re: CCF-Status of Fixed Platform on U.S. Outer Continental Shelf (June 12, 1980).

[20] A letter from J.P. Tebeau, Director, Carriers, Drawback and Bonds Division, U.S. Customs Service, to Mr. M.L. Neighbors, Vice President, Universal Shipping Co., Inc. (June 7, 1973), regarding the operation of the M/T VULCANUS from a U.S. port, states "No law administered by the Bureau of Customs would prohibit any vessel from transporting waste materials from a point within the United States to a point on the high seas to be destroyed. Section 883, title 46, United States Code, (the Jones Act) forbids foreign vessels from engaging in coastwise trade by transporting merchandise between points in the United States and therefore would not be applicable to the operation you describe."

such traffic to be within the protected Jones Act domestic trade where only U.S. flag ships may operate. Informal opinions by U.S. Customs Service officials have held that toxic chemical wastes which will be transported by the incinerator vessels do not constitute "merchandise" within the terms of the Jones Act, and that the burn sites are not "points or places within the U.S." for the purpose of the cabotage laws. As a result, foreign vessels 21/, unhampered by Jones Act restrictions, will be permitted to offer their services to American waste generators and to the U.S. government, while the fledgling American incinerator ship industry 22/ will be unable to qualify for MarAd subsidy aid to compete with these foreign vessels for cargoes originating in the United States. Title XI guarantees and the sale of NDRF vessels, while offering much needed assistance, are not as helpful as ODS and CDS in placing American operators in a position to compete with the more experienced European operators.

This dependence on foreign flag incinerator ships is not in the best national interest. The nation has an urgent need for incinerator vessels to safely dispose of hundreds of thousands of metric tons of hazardous wastes which are generated annually in the United States. Inadequate land-based disposal methods have endangered countless lives and the problem has reached crisis proportions in many areas of the United States 23/. The EPA has issued regulations to impose stringent requirements on waste generators for the disposal of their hazardous chemical wastes. Once the rules become effective, however, American waste generators who wish to dispose of wastes at sea will have to rely on the availability of foreign flag incinerator ships in order to meet their obligations under the new regulations. In addition, foreign flag ships will be unlikely to place a high priority on providing emergency disposal services for the federal or state governments. The ship operators will owe their primary allegiance to the flag they fly as well as to their customers who may not be in the United States, especially if the ship regularly serves clients in other countries.

21/ Foreign flag vessels currently capable of incinerating waste include the M/T VULCANUS, the K/B VESTA, and the MATTHIAS II. The VULCANUS was chartered by Shell Chemical Company, Deer Park, Texas to incinerate toxic organochlorine wastes in 1974-1975 and 1977, and the U.S. Air Force chartered the vessel to incinerate Herbicide Orange in 1977.

22/ American companies interested in constructing and operating incinerator ships include General American Transportation, Inc., At Sea Incineration, Inc., and Global Marine Development, Inc.

23/ Some of the more recent environmental tragedies involving improper disposal of hazardous wastes occurred at the Love Canal in Niagra Falls, New York, at the Valley of the Drums in Kentucky, and at Elizabeth, New Jersey where explosions and fire ripped through the Chemical Control Corporation dumpsite on April 21, 1980.

In order to alleviate this problem, MarAd could adopt one of several alternatives for promoting the domestic incinerator ship industry. These methods include: (1) determining that incinerator vessels operate in the foreign commerce and are therefore eligible for ODS, CDS and CCF, (2) determining that incinerator vessels operate in the noncontiguous domestic trade and are therefore eligible for CCF, (3) introducing new legislation which authorizes MarAd to provide subsidy assistance to owners of incinerator vessels and appropriates funds to the CDS and ODS Programs for this use, and (4) requesting Presidential approval, pursuant to Title VII of the Act, for MarAd to construct incinerator vessels for sale or charter to private individuals in the interest of national security and public health. In addition, MarAd could explore the possibility of constructing a government-owned vessel, as discussed in section B of this chapter.

3. Funding Mechanisms for a Privately-owned Vessel

a. MarAd FY 1982 Budget

In the current budget request for Fiscal Year 1982 24/ there is a provision for prospective construction of two incinerator ships at $50 million each. If these vessels are built with CDS, the cost to MarAd would be $50 million, given a 50 percent ceiling on CDS payments. At present, funds are not requested for the Program but a supplemental request for funding could be made at a later time if the use of CDS for incinerator ships were authorized. The actual cost of an incinerator ship depends on the type, size, sophistication, and delivery date of the vessel and could range from $20-80 million.

b. Authorization and Appropriations Acts

Pursuant to section 209 of the Act 25/ an authorization act is required before appropriations can be made for acquisition, construction, or reconstruction of vessels, for the CDS and ODS programs, and for reserve fleet expenses, among other items. Since an authorization bill is necessary before funds can be allocated for the Incinerator Ship Project, language can be included in the authorization bill to overcome present obstacles by defining the operation of an incinerator ship to be in an essential service in the foreign commerce of the United

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24/ Fiscal Year 1982 Maritime Administration Budget Request to the Secretary of Commerce, (June 2, 1980) at MA-9.

25/ 46 U.S.C. 1119.

States, as defined in section 905(a) of the 1936 Act. A similar approach was used in the Deep Seabed Hard Mineral Resources Act, passed by Congress on June 28, 1980, to ensure that vessels used in the recovery, processing, and transportation of hard mineral resources from the sea would be eligible for MarAd financial assistance. Section 102(c)(4) of the Act reads: "For purposes of the shipping laws of the United States, any vessel documented under the laws of the United States and used in the commercial recovery, processing, or transportation from any mining site of hard mineral resources recovered under a permit issued under this title shall be deemed to be used in, and used in an essential service in, the foreign commerce or foreign trade of the United States, as defined in section 905(a) of the Merchant Marine Act, 1936, and shall be deemed to be a vessel as defined in section 1101(b) of that Act." 26/

B. GOVERNMENT-OWNED VESSEL

In lieu of offering public assistance to private operators for construction of incinerator ships, the Maritime Administration or the Environmental Protection Agency may decide that a vessel should be constructed for the government's account for use in disposing of toxic chemical wastes and to provide emergency incinerator service in times of national crisis. There are many ways in which funding for a government-owned incinerator ship could be obtained. Perhaps the easiest way would be for the Environmental Protection Agency to request funding for the vessel as part of its anti-pollution efforts to clean up land-based toxic chemical waste dumpsites and to destroy chemical wastes under government jurisdiction. Money for design and construction of the vessel could then be transferred, by an inter-agency agreement, to MarAd pursuant to the Economy Act of 1932 or other statutory provisions.

In addition, the Maritime Administration has the authority to construct vessels for government account under the provisions of Title VII. Thirty-five Mariner vessels were constructed for the government in the early 1950's under an appropriation act which incorporated the construction terms of Title VII. After being successfully demonstrated in actual operation, these vessels were sold to private operators, thereby recovering U.S. funds.

1. Environmental Protection Agency (EPA) Vessel

The EPA can request funding for construction and operation of an incinerator vessel for its own account under the authority of the Resource Conservation and Recovery Act (RCRA) 27/.

26/ P.L. 96-283 (June 28, 1980), 30 U.S.C. 1401, 1412; 94 Stat. 553, 559.

27/ 42 U.S.C. 6901.

Section 8001 (a) [28] of RCRA authorizes EPA to cooperate with, and render financial assistance to, other federal agencies engaged in research on methods of hazardous waste management. Section 8004 [29] authorizes the EPA administrator to provide financial assistance in the form of grants to construct and to operate a full scale demonstration facility, such as the prototype incinerator vessel. In addition, EPA officials may wish to request funding for the construction of the incinerator ship under the authority given to them by the Marine Protection, Research and Sanctuaries Act of 1972 [30] (the 'Ocean Dumping Law') to regulate ocean dumping, or propose special legislation to obtain appropriations specifically for the incinerator ship project.

Once the EPA has obtained the necessary appropriations, EPA can arrange with the Maritime Administration for the construction and operation of the ship. Funds can be transferred to MarAd by an interagency agreement under the authority of the special appropriations act, provisions in RCRA [31], the Ocean Dumping Law [32], or the Economy Act of 1932 [33].

After the vessel is constructed, the Maritime Administration can bareboat charter the vessel to private owners for the EPA's account under the provisions of Section 715 of the Merchant Marine Act, 1936, as amended. Up to ten vessels can be operated and tested in any one year for the purpose of practical development, trial and testing

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[28] 42 U.S.C. 6981.

[29] 42 U.S.C. 6984.

[30] 33 U.S.C. 1401 et seq.

[31] Under RCRA, the EPA Administrator is authorized to "utilize the information, facilities, personnel and other resources of federal agencies. . . on a reimbursable basis, to perform research and analyses and conduct studies and investigations related to resource recovery and conservation and to otherwise carry out the Administrator's functions under this Act." Section 2002(a)(5), 42 U.S.C. 6912 (emphasis added). Likewise, MarAd is required to make its resources available to EPA, on a reimbursable basis, to carry out the functions of RCRA. Section 6003, 42 U.S.C. 6963.

[32] Title II of the Ocean Dumping Law directs each agency of the federal government to cooperate with the Secretary of Commerce in a comprehensive and continuing program of monitoring and research on ocean dumping.

[33] 31 U.S.C. 686.

which could include research on the economic viability of operating an incinerator ship as well as research on the seaworthiness of such a vessel.

2. Maritime Administration Vessel

The Maritime Administration may construct vessels for government account or have old vessels remodeled under the provisions of Title VII, when the national policy [34] and objectives [35] of

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[34] The national policy of the Merchant Marine Act, 1936, as amended, is declared in Section 101 of the Act (46 U.S.C. 1101).

> "Section 101. It is necessary for the national defense and development of its foreign and domestic commerce that the United States shall have a merchant marine (a) sufficient to carry its domestic water-borne commerce and a substantial portion of the water-borne export and import foreign commerce of the United States and to provide shipping service essential for maintaining the flow of such domestic and foreign water-borne commerce at all times, (b) capable of serving as a naval and military auxiliary in time of war or national emergency, (c) owned and operated under the United States flag by citizens of the United States insofar as may be practicable, (d) composed of the best-equipped, safest, and most suitable types of vessels, constructed in the United States and manned with a trained and efficient citizen personnel, and (e) supplemented by efficient facilities for shipbuilding and ship repair. It is hereby declared to be the policy of the United States to foster the development and encourage the maintenance of such a merchant marine."

[35] The objectives of the Act are stated in Section 210 (46 U.S.C. 1120) as follows:

> "First,the creation of an adequate and well-balanced merchant fleet, including vessels of all types, to provide shipping service essential for maintaining the flow of the foreign commerce of the United States, the vessels in such fleet to be so designed as to be readily and quickly convertible into transport and supply vessels in a time of national emergency. In planning the development of such a fleet the Secretary of Commerce is directed to cooperate closely with the Navy Department as to national-defense needs and the possible speedy adaptation of the merchant fleet to national-defense requirements."

the Merchant Marine Act, 1936, as amended, cannot be fully realized within a reasonable time under the provisions of Titles V (Construction-Differential Subsidy) and VI (Operating-Differential Subsidy), and the President of the United States approves of such construction.

Contracts with a private shipbuilder for the construction or reconstruction of a government vessel will be made only after advertisement and upon sealed competitive bids, and such contracts will be subject to all requirements of Title V [36]. If satisfactory contracts cannot be obtained from private shipbuilders, MarAd may have the vessels constructed or remodeled in U.S. Navy yards [37].

After construction, the vessels shall be chartered or sold as soon as practicable to private operators. MarAd can operate the vessel for its own account for a limited amount of time for research and testing under the provisions of Section 715.

Title VII was invoked in 1949-51 to authorize the construction of a prototype cargo vessel which could be adapted to mass production with a minimum of changes [38]. In addition, Congress enacted special legislation to authorize construction of 35 Mariner-type

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> "Second, the ownership and the operation of such a merchant fleet by citizens of the United States insofar as may be practicable.
> Third, the planning of vessels designed to afford the best and most complete protection for passengers and crew against fire and all marine perils.
> Fourth, the creation and maintenance of efficient shipyards and repair capacity in the United States with adequate numbers of skilled personnel to provide an adequate mobilization base."

36/ Section 703, 46 U.S.C. 1193.

37/ Section 702, 46 U.S.C. 1192.

38/ Built by Ingalls Shipbuilding, Corp., the vessel was an experimental type, C3-S-DX1, designed to be built by mass-production methods in case of emergency, but also to be an efficient and economical cargo carrier for peacetime service. United States Maritime Commission Report to Congress for the Fiscal Year Ended 1949, at 4; See Annual Report of the Federal Maritime Board and Maritime Administration, U.S. Department of Commerce, 1950 at 9.

vessels under the terms of Title VII to meet the defense needs of the nation during the Korean Conflict [39]. Both projects were intended to fulfill MarAd's goal in creating an adequate and well-balanced merchant fleet which could maintain the flow of foreign commerce in peacetime and be readily and quickly converted to transport and supply vessels in a time of national emergency [40].

As noted in the section on Foreign Commerce, the nation has an urgent need for U.S. flag incinerator vessels which has not been met by private operators. MarAd can attempt to promote the private development of incinerator ships by making the various maritime aid programs available to ship operators, as discussed in part A of this chapter, or can propose that the President's approval be requested pursuant to Title VII to construct a prototype incinerator vessel which can handle commercially-generated toxic wastes in times of peace and be quickly adapted for use by the Department of Defense in times of war or national emergency [41].

Additional funds will need to be appropriated by Congress to enable MarAd to undertake the Program, regardless of whether Congress chooses to promote the U.S. flag incinerator trade by making promotional programs (CDS, ODS) available to private operators or by authorizing government construction of a vessel.

If Congressional policy considerations dictate that emphasis be placed on the promotional programs, MarAd officials could propose that any authorization and appropriation bill which includes amounts for the CDS and ODS Programs with respect to an Incinerator Ship Program contain a proviso that if viable applications are not received from private operators within 6 months to 1 year, the money may be used by MarAd to construct a vessel under Title VII, if Presidential approval is obtained.

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[39] Annual Report of the Federal Maritime Board, Maritime Administration, U.S. Department of Commerce, 1951 at 5. Funding for the Mariner project was provided by P.L. No. 911, 81st Congress, 2nd Session.

[40] Section 210, 46 U.S.C. 1120.

[41] In 1977, the U.S. Air Force chartered the foreign flag M/T VULCANUS to incinerate Herbicide Orange in the Pacific Ocean. There were no U.S. flag incinerator vessels available to handle the task.

C. HYBRID (GOVERNMENT/PRIVATE) VESSEL

If a government vessel is built, under the provisions of Title VII, MarAd has the authority, under section 715 of the Act, to operate the vessel under a general agency agreement or bareboat charter for the purposes of practical development, trial and testing. As noted above, the testing can include research on the economic viability of operating an incinerator ship as well as research on the mechanics of operating such a ship. These charters and general agency agreements must be reviewed annually for the purpose of determining whether conditions exist to justify continuance of the charter or agreement.

Once the period of trial and testing is completed, however, MarAd has the obligation to arrange, as soon as practicable, to offer the vessel for sale, or charter to private operators 42/. Preference in the sale of vessels will be given to U.S. citizens 43/ and charter is by sealed competitive bids 44/, unless the vessel was constructed specifically to develop a certain essential trade route in which case MarAd may charter the vessel under Section 714 to the present U.S. flag operator on the trade route, without advertisement or competition 45/. However, as an incinerator vessel will in all likelihood be treated like a bulk cargo-carrying vessel rather than a liner vessel, the vessel will not be destined for operation on a specific trade route and, therefore, Section 714 will not apply. If the vessel is chartered, the federal government will have title to the vessel but the private bareboat charterer will control the vessel's daily operations.

42/ Section 704 and 705.

43/ Section 7, Merchant Marine Act, 1920; 46 U.S.C. 866.

44/ Section 706, Merchant Marine Act, 1936, as amended, 46 U.S.C. 1196.

45/ Section 714, 46 U.S.C. 1204.

CHAPTER III

SAFETY AND CONTROL MEASURES (9,10)

Chemical waste incinerator ships designed and built in the United States and flying the U.S. flag are subject to the extensive safety and pollution prevention requirements administered by the U.S. Coast Guard (USCG), the American Bureau of Shipping (ABS), the Environmental Protection Agency (EPA), and the Intergovernmental Maritime Consultative Organization (IMCO). These standards and regulations have been established under the authority of national legislation and international conventions. In addition, the Maritime Administration (MarAd) has its own requirements for the safe operation and pollution control of ships built in the United States with federal assistance. The most important of these design, construction, and operating requirements for U.S. flag incinerator ships are those of the Coast Guard, which apply to the bulk chemical tank vessel, and those of EPA, which apply to the incinerator system. The regulations of both agencies reflect the international standards established under the auspices of IMCO. This chapter provides a brief overview of the authoritative and regulatory controls applicable to chemical waste incinerator ships. For more information in this regard, refer to references 9 and 10.

A. INTERNATIONAL CONVENTION ON THE PREVENTION OF MARINE POLLUTION BY DUMPING OF WASTE AND OTHER MATTER

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972 London Dumping Convention) was negotiated in London in November 1972, and came into force on August 30, 1975. Under the provisions of the Convention, nations agree to regulate all ocean dumping through national administrative authorities. Dumping is not allowed without a permit. The disposal of wastes or other matter directly arising from or related to the exploration, exploitation, and associated offshore processing of seabed mineral resources is not covered by the provisions of the Convention.

The Convention requires each contracting nation to regulate the dumping of all material loaded in its ports for the purpose of being dumped at sea or loaded on a vessel or aircraft of its flag or registry in the territory of a nation not a party to the Convention. Participating nations are further required to maintain records concerning the nature and quantities of material which they permit to be dumped and the circumstances of such dumping. They must report this information periodically to IMCO, the organization responsible for administration of the Convention. Contracting parties are also to promote the disposal and treatment of wastes and other measures to prevent or mitigate pollution caused by dumping.

Incineration at sea of wastes is regulated at the international level under the 1972 London Dumping Convention. The Convention has been amended to include mandatory regulations and recommendatory technical guidelines on the control of incineration of wastes and other matter at sea.

B. INTERNATIONAL AGREEMENTS PERTAINING TO MARITIME SAFETY AND TO PROTECTION OF THE MARINE ENVIRONMENT

In addition to the foregoing international agreement, the following international conventions and codes dealing with maritime safety and with protection of the marine environment, primarily from vessel source pollution, apply to chemical waste incinerator ships:

1. The International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL).
2. Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL Protocol).
3. International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969.
4. Protocol Relating to Intervention on the High Seas in Cases of Marine Pollution by Substances Other Than Oil, 1973.
5. International Convention on Safety of Life at Sea, 1974 (SOLAS).
6. Protocol of 1978 Relating to the International Convention on Safety of Life at Sea, 1974 (SOLAS Protocol).
7. IMCO International Maritime Dangerous Goods Code, as amended.
8. IMCO Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, as amended.
9. International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers, 1978.

All of the above conventions and codes are administered by IMCO.

C. MARINE PROTECTION, RESEARCH, AND SANCTUARIES ACT OF 1972 (P.L. 92-532) (MPRSA)

This Act, enacted on October 23, 1972, provides for the regulation of ocean dumping, research on ocean dumping and other man-induced changes to the ocean ecosystems, and the designation, acquisition, and administration of marine sanctuaries. Titles I and II address ocean dumping.

Title I of the MPRSA provides for a regulatory scheme to control all materials transported from the United States for the purpose of dumping into ocean waters. In addition, the Act controls the dumping of material originating outside of the United States, if that dumping takes place in ocean waters subject to the jurisdiction or control of the United States. Finally, consistent with the declared policy, the Act also regulates the activities of federal departments and agencies transporting material for dumping into ocean waters, regardless of the location from which the transportation is initiated.

Title I requires that no person, regardless of his nationality, may depart a United States port with material intended for dumping anywhere in the world's oceans, unless he has first obtained a federal permit. The MPRSA also has a total prohibition against the dumping of radiological, biological, and chemical warfare agents, or any high-level radioactive wastes. These hazardous substances may not be dumped or transported for dumping, and no permit can be issued for their disposal.

Title II Section 201 of the Act directs the Secretary of Commerce to work with the Coast Guard and to initiate a comprehensive and continuing program of monitoring and research regarding the effects of ocean dumping, and, in consultation with other agencies, to initiate a comprehensive and continuing research program with respect to possible long range effects of pollution, overfishing, and man-induced changes of ocean ecosystems. A major purpose of these research and monitoring activities is clearly intended to provide scientific findings, evaluations, and conclusions that are relevant to defining use conflicts that could influence the decisions to grant or deny dumping permits. In requiring annual reports to Congress, the Act provides a convenient and timely mechanism for documenting these efforts.

Title II Section 203 requires the Secretary of Commerce to conduct and encourage research, investigations, experiments, training, demonstrations, surveys, and studies for the purpose of determining means of minimizing or ending all dumping of materials within five years of the effective date of the Act. (The MarAd Chemical Waste Incinerator Ship Project (Appendix A) is in response to this Title II requirement).

The EPA has permit granting authority with respect all ocean dumping except dredged material; this permit authority includes incineration at sea. The dumping of dredged material requires a permit from the U.S. Army Corps of Engineers. The EPA Ocean Dumping Regulations, 40 CFR Parts 220-230, describe the procedures relating to the application for, issuance of, and denial of permits for ocean dumping. Criteria for evaluation of permit applications are also included. The categories of permits issued are: general, special, emergency, interim, research, and incineration at sea. EPA regulates incineration at sea in a manner consistent with the intent of the Ocean Dumping Convention and the MPRSA.

D. NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (P.L. 91-190) (NEPA)

The purposes of this Act are: to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere, and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the nation; and to establish a Council on Environmental Quality (CEQ).

Section 102(2)(C) of NEPA and the amended CEQ Guidelines, as published in the Federal Register of November 29, 1978, require all federal agencies to include, in every recommendation or report on proposals for legislation and other federal actions significantly affecting the quality of the human environment, a detailed statement on the environmental impact of the proposed action. Underlying the preparation of such environmental impact statements is the mandate of both NEPA and Executive Order 11514 of March 5, 1970, that all federal agencies, to the fullest extent possible, direct their policies plans and programs to protect and enhance environmental quality.

EPA conducts environmental impact assessments for all disposal sites and publishes environmental impact statements (EIS's) prior to designating a site for incineration at sea. This constitutes compliance with the EPA regulations on ocean dumping. The EPA published a Final EIS for an incineration site in the Gulf of Mexico (4) and is currently preparing an EIS for the Atlantic site, commonly known as the "106 industrial waste site."

E. RESOURCE CONSERVATION AND RECOVERY ACT OF 1976 (P.L. 94-580) (RCRA)

The purpose of RCRA is to provide technical and financial assistance for the development of management plans and facilities for the recovery of energy and other resources from discarded materials, for safe disposal of discarded materials, and to regulate the management of hazardous waste. The Act requires the Administrator of EPA to promulgate regulations establishing performance standards for the treatment, storage, and disposal of hazardous waste.

EPA published in the Federal Register of May 19, 1980, the final rules concerning the hazardous waste management system (40 CFR Parts 260-265). The regulations address: general information concerning the hazardous waste management system, identification and listing of hazardous waste, standards applicable to generators of hazardous waste, standards applicable to transporters of hazardous waste, and standards and interim status standards for owners and operators of hazardous waste treatment, storage, and disposal facilities.

Although the provisions of this Act are applicable to incineration at sea, this method of hazardous waste disposal is adequately regulated under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA) and, because of the interrelationship between the MPRSA and the Ocean Dumping Convention, regulations developed under RCRA are not being used to control incineration at sea. However, RCRA does regulate land-based transport and storage of hazardous wastes permitted to be incinerated at sea, as well as the land-based alternatives to incineration at sea, and promotes resource recovery.

F. PORTS AND WATERWAYS SAFETY ACT OF 1972 (P.L. 92-340) (PWSA)

The PWSA is intended to promote the safety of ports, harbors, waterfront areas, and navigable waters of the United States. It consists of two sections.

Title I of the PWSA gives the Secretary of the Department in which the Coast Guard operates the authority to take means to prevent damage to, or the destruction or loss of, any vessel, bridge, or other structure on or in the navigable waters of the United States, or any land structure or shore area immediately adjacent to those waters; and to protect the navigable waters and the resources therein from environmental harm resulting from vessel or structural damage, destruction, or loss.

Title II provides for the establishment of comprehensive minimum standards of vessel design, construction, alteration, repair, maintenance and operation to prevent or mitigate the hazards to life, property, and the marine environment. These standards apply to all vessels documented under the laws of the United States or entering the navigable waters of the United States.

The PWSA was amended during 1978 by the Port and Tanker Safety Act of 1978 (P.L. 95-474). This new law provides a stringent and comprehensive program dealing with the design, construction, operation, equipping, and manning of all tank vessels using U.S. ports to transfer oil and hazardous materials. The design, construction, and equipment requirements contained in this law are, for the most part, in agreement with the results of the 1978 International Conference on Tanker Safety and Pollution Prevention. This Conference resulted in the adoption of Protocols for two of IMCO's most important Conventions, 1973 MARPOL and 1974 SOLAS.

Incineration vessels must comply with the design, construction, and operation requirements issued by the U.S. Coast Guard under the PWSA, as amended. Of particular importance are the Coast Guard rules for chemical carriers (46 CFR Part 153) which implement the IMCO Bulk Chemical Code. (21) These Coast Guard requirements, as well as the IMCO Bulk Chemical Code, are based upon the philosophy of relating cargo containment features of vessel design, construction, and operation to the hazards of various chemicals. The key provisions of these requirements as they relate to dangerous cargoes specify three different levels of vessel construction, containment system, and containment system location within the vessel:

> Type I - a containment system to transport products which require maximum preventive measures to preclude their release;
>
> Type II - a containment system to transport products which require significant preventive measures to preclude their release;
>
> Type III - a containment system to transport products which require moderate preventive measures to preclude their release.

These three containment systems specify the location of the cargo tanks and piping within the ship and place minimum requirements for damaged and intact vessel stability. These assignments to containment system types take into account the nature and severity of the product's hazards if released.

The highest standard of cargo containment, Type I, is placed on those cargoes that on release could have the most wide-reaching effect beyond the immediate neighborhood of the vessel. No portion of the Type I cargo containment system may be located closer than one-fifth the vessel beam from the side of the vessel or a distance equal to one-fifteenth the vessel beam above the vessel keel. The vessel with a Type I containment system must be designed to withstand prescribed damages (two-compartment standard of subdivision and damage stability throughout its length). In addition, to prevent the large-scale release of Type I cargo in event of rupture of the containment system, the size of each tank is limited to 1,250 cubic meters.

Cargoes with significant hazards, but whose release would not have far reaching effects, are carried in Type II containment systems. A Type II containment system must be located a minimum distance of 760 mm from the vessel side and one-fifteenth the vessel beam above the vessel's keel. These requirements should provide cargo protection against groundings and low-energy collisions. In addition, each vessel greater than 150 meters long must have a two-compartment standard of subdivision and damage stability throughout its length. Vessels less than 150 meters must meet a two-compartment standard of subdivision and damage stability in the cargo containment portion of each vessel and a one-compartment standard for the engine room. To prevent the large-scale release of a Type II cargo, the individual tank size is limited to 3,000 cubic meters.

A Type III containment system is prescribed for products with lesser hazards. No separation of the cargo containment system from the ship's hull is required. However, increased damage stability, in excess of that required for a typical tanker, is required. Vessels greater than 125 meters with a Type III containment system must be able to survive damage to any location except either bulkhead of an aft machinery space.

G. FEDERAL WATER POLLUTION CONTROL ACT AMENDMENTS OF 1972 (P.L. 92-500) (FWPCA)

In Section 311 of this Act, Congress declared that it is the policy of the United States that there should be no discharge of oil or hazardous substances into, or upon, the navigable waters of the United States, adjoining shorelines or upon, or into, the waters of the contiguous zone.

Some essential features of the Act relating to spills include a revolving fund for cleanup operations, a national contingency plan for control of spills of oil and hazardous polluting substances, and authority to remove polluting spills of oil and hazardous substances. In addition, the President shall issue regulations consistent with maritime safety and with the marine and navigation laws: (a) establishing methods and procedures for removal of discharged oil and hazardous substances and (b) establishing procedures, methods and requirements for equipment to prevent discharges of oil and hazardous substances from vessels and from onshore facilities and offshore facilities.

The Clean Water Act of 1977 (CWA) (P.L. 95-217) further amended the FWPCA with respect to liability for oil and hazardous substance spills. Most notably, the CWA extends U.S. national jurisdiction for water pollution control to the ocean beyond the contiguous zone where fisheries and other natural resources of the U.S. may be adversely affected.

EPA rules to implement the FWPCA, as amended, are contained in Title 40 of the Code of Federal Regulations. Of particular importance with respect to incinerator ships are: 40 CFR Part 110 - Discharge of oil, 40 CFR Part 112 - Oil pollution prevention, 40 CFR Part 116 - Designation of hazardous substances, and 40 CFR Part 117 - Determination of reportable quantities of hazardous substances.

H. INTERVENTION ON THE HIGH SEAS ACT, AS AMENDED (P.L. 93-248)

The purpose of this Act is to implement the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties and Marine Pollution by Substances Other than Oil. The Act authorizes the Department of Transportation (U.S. Coast Guard) to prevent, mitigate, or eliminate pollution or threat of pollution on the sea by oil and other substances which results from a ship collision, stranding or other incident of navigation.

In the event that an incineration vessel, while transporting hazardous wastes, became involved in a marine disaster, the U.S. may take appropriate measures to eliminate an imminent danger to U.S. coastlines or related interests of the United States.

I. COAST GUARD REGULATIONS

As noted previously, the Ports and Waterways Safety Act of 1972 and its amended version, the Port and Tanker Safety Act of 1978, give the Coast Guard, U.S. Department of Transportation, the authority to regulate vessels and facilities handling hazardous materials. The Coast Guard also has responsiblities under the Federal Water Pollution Control Act, as amended. Coast Guard regulations are contained in the Code of Federal Regulations: Title 33 - Navigation and Navigable Waters and Title 46 - Shipping. Related regulations of the Materials Transportation Bureau, U.S. Department of Transportation, are contained in Title 49 - Transportation. Regulations which are particularly applicable to the safety and pollution control characteristics of chemical waste incinerator ships are:

1. Title 33, Chapter I

   a. Subchapter K - Security of Vessels
      e.g. Part 124 - Control over movement of vessels

   b. Subchapter L - Waterfront Facilities, Security Zones, and Regulated Navigation Areas
      e.g. Part 126 - Handling of explosives and other dangerous cargoes

   c. Subchapter O - Pollution
      e.g. Part 151 - Oil pollution regulations
      Part 153 - Control of pollution by oil and hazardous substances, discharge removal
      Part 154 - Large oil transfer facilities
      Part 155 - Vessel design and operations
      Part 156 - Oil transfer operations
      Part 157 - Rules for protection of the marine environment relating to tank vessels carrying oil in bulk
      Part 159 - Marine sanitation devices

   d. Subchapter P - Ports and Waterways Safety
      e.g. Part 161 - Vessel traffic management
      Part 162 - Inland waterways navigation regulations
      Part 164 - Navigation safety regulations

2. Title 46, Chapter I

   a. Subchapter D - Tank Vessels
   b. Subchapter E - Load Lines
   c. Subchapter F - Marine Engineering
   d. Subchapter I - Cargo and Miscellaneous Vessels
   e. Subchapter J - Electrical Engineering
   f. Subchapter O - Certain Bulk Dangerous Cargoes
      e.g. Part 153 - Safety rules for self-propelled vessels carrying hazardous liquids.

3. Title 49, Chapter I

   a. Subchapter C - Hazardous Materials Regulations
      e.g. Part 176 - Carriage by vessel

Coast Guard regulations pertaining to vessels carrying hazardous liquids in bulk are contained in 46 CFR Part 153. The regulations list the substances which are covered. New substances proposed for shipment are evaluated by the Coast Guard on the basis of their hazards, and the minimum carriage requirements are developed before they are permitted to be shipped. Currently, products proposed for shipment on incinerator ships also undergo this same evaluation before they are permitted to be carried.

In the interest of maintaining uniform international standards, requirements for vessels carrying hazardous liquids in bulk are developed by the Intergovernmental Maritime Consultative Organization (IMCO). The IMCO Subcommittee on Bulk Chemicals (BCH) developed the IMCO Bulk Chemical Code which is the basis for requirements in 46 CFR 153. The Subcommittee is currently developing special requirements for ships engaged in incineration at sea. Vessels built before final requirements are finalized should be built to comply with interim guidelines which have already been developed and approved by IMCO. The interim guidelines must be used in conjunction with the Bulk Chemical Code.

The Ports and Waterways Safety Act also gives the Coast Guard authority to develop requirements for facilities transferring hazardous materials. Regulations are currently under development and will generally apply to facilities where substances to be incinerated are transferred to vessels. The Coast Guard Captain of the Port has the overall responsibility of ensuring that hazardous materials are transferred, loaded, and transported through the port in a safe and environmentally acceptable manner.

J. MARITIME ADMINISTRATION STANDARDS

MarAd has developed standard specifications to provide guidance for merchant ship designers preparing detailed ship specifications. Significant improvements in ship design, construction, and equipment for the purposes of safety and pollution prevention have been integrated into ships built with MarAd financial assistance. In this regard, MarAd's Standard Specifications for Merchant Ship Construction include sections for: (a) invoking compliance with regulatory body requirements; (b) contributing to the overall physical safety potential of the vessel; (c) enhancing the safe navigation and operation of the vessel; and (d) mitigating marine pollution. All MarAd supported ships must comply with all applicable portions of Coast Guard regulations and those of other regulatory agencies named in each individual ship specification and in the MarAd standard specifications.

K. SAFETY AND CONTROL MEASURES SUMMARY (10)

U.S. flag chemical waste incinerator ships are subject to the stringent requirements of the Coast Guard, the Environmental Protection Agency, the Maritime Administration, and the Intergovernmental Maritime Consultative Organization. Each U.S. flag incinerator ship would have the following fundamental characteristics: (a) highly automated, safe, and reliable; (b) operated by a highly trained crew; (c) an efficient user of all energy generated; and (d) designed and equipped with all vital safeguards and controls, such as accurate incinerator monitoring equipment, double bottom and double sides, and advanced navigation and communication aids. The Coast Guard and MarAd have primary control over the design, construction, and equipment of each ship; the Environmental Protection Agency has jurisdiction over the incinerator system design and operation and related matters.

CHAPTER IV

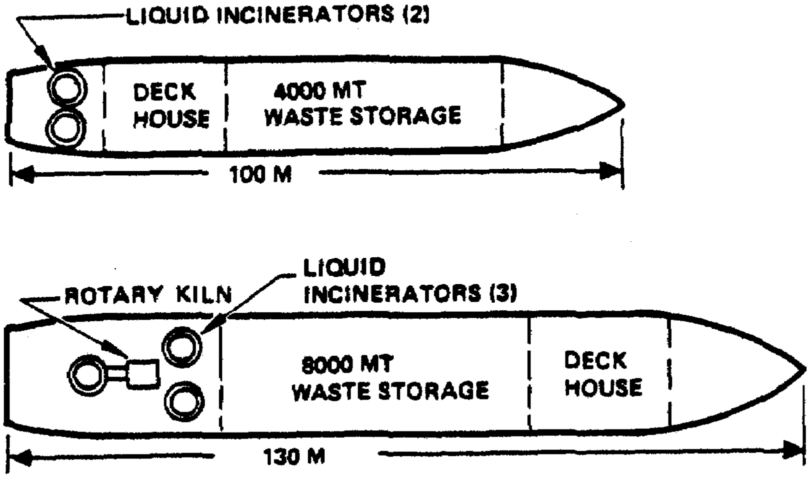
INCINERATOR SHIP CONCEPTUAL DESIGN

U.S. flag incineration ships can serve two broad functions: first, they can be used for the destruction of hazardous wastes in EPA-designated burn sites which minimizes the risk to public health and the environment; second, they can provide safe platforms to conduct EPA research and development efforts in hazardous waste incineration. This chapter discusses the fundamental characteristics of chemical waste incinerator ships. Detailed presentations concerning shipboard incineration systems and incinerator ship conceptual designs, including estimated costs, are contained in Appendices B and C.

A. INCINERATION SYSTEM/SHIP INTEGRATION (Appendix B)

The ship layouts in FIGURE 1 indicate some of the ways that incineration systems can be integrated on board ships to provide desired incineration capacity and operational time at sea. Ships of two different capacities are depicted with liquid injection incinerators installed aft. These incinerators are intended for high rate *destruction of hazardous wastes at sea. A rotary kiln incinerator* is also installed on the larger ship for research purposes. Rotary kilns are the most universal incinerators available, capable of destroying liquids, slurries, tars, and solids, separately or combined. Athough widely used on land, rotary kilns have not been used on ships, and would require modifications for shipboard operation. The rotary kiln in conjunction with a liquid injection incinerator is the most versatile combination for thermal destruction of a wide variety of hazardous wastes.

FIGURE 1. Incineration System/Ship Integration



The smaller ship shown in FIGURE 1 - 100 meters long with 4,000 metric tons waste capacity - is approximately the capacity of the VULCANUS, which has two stern-mounted incinerators. Liquid wastes are pumped from the tanks to each incinerator burner. At a waste feed rate of 10 metric tons/hour for each incinerator, this ship would require slightly over eight days of continuous burning to dispose of 4,000 metric tons of liquid waste. The bridge and deckhouse are shown immediately forward of the incinerators, as on the VULCANUS. A location farther forward near the bow would be preferable for the safety of the crew.

The large ship of FIGURE 1 has 8,000 metric tons of waste capacity and is 130 meters in length. This ship layout is similar to the conceptual designs described in Appendix C. Three liquid incinerators burning 10 metric tons/hour each would dispose of 7,200 metric tons of liquid waste in ten days. A rotary kiln of 1.5 metric tons/hour solid waste capacity is shown connected to one of the liquid incinerators, which is utilized as an after burner. Solid wastes are stored in bulk containers, which are transported by conveyer to the kiln. Automated equipment lifts the bulk containers and discharges the solid wastes into the kiln through a sealed hopper. Ash from solids incineration is stored and returned to land for analysis and disposal. The deckhouse for this ship is located forward of the waste tanks, near the bow of the ship.

These ship layouts indicate some of the ways that incineration systems can be integrated on board ships. Optimization studies to determine the size of incinerator ships, the number of incinerators/ship, and the incineration time versus loading and transit times can be made. Economies of scale indicate that larger incinerator ships with higher burn rates could be more cost-effective than the ships shown in FIGURE 1.(22) This possible advantage for larger ships is contingent upon the ready availability of large volumes of waste for incineration and the ability of the EPA-designated burn sites to absorb without environmental damage the higher combustion rates.

A dedicated laboratory on each incinerator ship is required to provide operational safety through detection of waste constituents in the shipboard environment and for verification of waste combustion efficiency. Environmental monitoring of at-sea incineration is also required to assure personnel safety and to protect the environment.

B. ALTERNATIVE DESIGNS FOR CHEMICAL WASTE INCINERATOR SHIPS (Appendix C)

Among the proven technologies of the maritime industry, alternative approaches to the transportation and incineration of chemical wastes include:

1. A monohull vessel outfitted with incinerators aft and deckhouse forward. Such designs are discussed in Appendix C and include new construction and conversion design options.

2. An integrated tug-barge system, where the cargo carrying incinerating barge and the propulsion tug are separable. For this unit, the tug and barge could be built separately and simultaneously, thereby shortening the construction period. Also, in an emergency, it would be possible to uncouple the tug from the barge and set the barge to drift or under tether. The integrated tug/barge design reverses the general arrangements of conventional ships, locating the incinerators at the barge's forward end, with the propulsion plant, the tug, at the stern. While incinerating waste, the tug pulls the barge to provide maximum separation between the exhaust plume and the crew.

3. A barge carrying ship, where fully loaded waste containing barges are loaded onto the ship. The barges can be loaded outside the harbor limits as long as sea conditions permit. The ship, which is the incinerator platform, would generally remain outside the heavily trafficked port area while the waste containing barges are delivered to it by tugs.

4. A tethered tug-barge combination which provides ample separation between the incineration platform and the propulsion platform.

C. CONCEPTUAL DESIGNS FOR U.S. FLAG INCINERATOR SHIPS

Appendix C presents conceptual designs for U.S. flag incinerator ships. Each ship design has a full-bodied cargo ship hull with extensive auxiliary processing systems to handle and incinerate hazardous chemical wastes. The vessel designs must conform with all applicable Coast Guard regulations, such as 46 CFR Part 153 - Safety Rules for Self-Propelled Vessels Carrying Hazardous Liquids, and with the IMCO Code for Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk. Two new construction designs are presented, as well as an NDRF conversion. Since EPA is interested in advancing the state of the art of hazardous waste disposal, each ship design incorporates a demonstration plant for solid waste handling and incineration at sea as well as a high capacity industrial plant for transporting, pumping and incinerating liquid wastes at sea. The designs require that a land-based terminal exists to support the operation of incinerator ships.

The concept design study of Appendix C presents two new ship alternatives and discusses alternative technologies for use as an incinerator ship. Each ship is outfitted with three liquid injection incinerators and one experimental solid waste rotary kiln incinerator, plus the auxiliary equipment and the cargo systems needed to support the incineration plant. The new vessels should be able to burn a total of 7200 metric tons of liquid waste and 360 metric tons of containerized solid waste during ten days of continuous burning.

Both designs must conform to the highest standard of marine chemical cargo protection and containment. The PD-246A can carry a full load of the most hazardous chemical cargoes, those rated Type I according to the IMCO Bulk Chemical Code. Very few chemicals now require Type I protection, so that the PD-246A is a conservative design. The other new ship design, the PD-246B, is a combination Type I/Type II ship, which carries the same amount of waste cargo in a slightly smaller hull. Most candidate chemicals for incineration at sea are Type II chemicals that could be adequately protected by this hull design. The Type I cargoes could be carried only in the ship's centerline tanks.

In addition to the new ship designs, a conversion alternative, PD-246C, was evaluated using a Landing Ship Dock (LSD) as the baseline ship for a Type I hull chemical waste incinerator ship. However, because the available space for the liquid cargo tanks is flanked by the existing propulsion plant, the LSD has been determined to be inappropriate for use as a liquid waste incinerator ship equivalent to either of the new ships. The LSD may still be useful as a research platform for solid waste incineration at sea, as the containerized solid cargo can be safely handled within the cargo well space. Another conversion may be possible for an equivalent incinerator ship, but the extensive modifications needed for most older ships, such as T-2 tankers, would make the converted vessel an inefficient investment for this mission.

The estimated cost and construction schedule for a single ship of each new ship design, for delivery in 1985, including installed incineration equipment, are as follows:

DESIGN	NEW TYPE I	NEW TYPE I/II
NAME	PD-246A	PD-246B
LENGTH	129.5m (425'-0")	121.9m (400'-0")
BEAM	25.0m (82'-0")	23.8m (78'-0")
DEPTH	13.4m (44'-0")	12.5m (41'-0")
COST ($ millions)	80	75
SCHEDULE (mos.)	30	30

Estimated annual operating costs for either vessel are $15 million based upon information obtained from industry.

CHAPTER V

ENVIRONMENTAL ASSESSMENT

Incineration at sea has been shown to be a technically and environmentally acceptable alternative to land-based disposal of hazardous wastes. (3-12) The principal environmental considerations incident to the operation of a chemical waste incinerator ship are: accidental discharge or spillage of hazardous waste cargo and the effects of the incinerator emissions. In addition, there are other potential pollutants from the operation of the ship itself, such as fuel oil, sewage, garbage and domestic wastes, and stack emissions from the machinery plant. This discussion will summarize the major environmental factors to be considered when operating a chemical waste incinerator ship--all of which are addressed by national and international regulations and programs. Refer to references 3-12 for additional information.

A. ACCIDENTAL DISCHARGE OR SPILLAGE (9,10)

A chemical waste incinerator ship is a specialized bulk chemical carrier designed and operated to safely transport and dispose of hazardous chemical wastes. Due to the special design and operation of incinerator ships, tank cleaning and deballasting operations are not pollutant sources. Potential for environmental pollution does exist due to accidents--both from faulty transfer operations and from vessel casualties. Such accidents could occasion moderate or serious consequences, depending in large measure upon where the discharge occurred and the quantity and type of wastes released. For instance, a major spill near shore which affects an estuary would destroy many organisms, including benthic forms, and would contaminate the area for a substantial period of time. A large spill on the continental shelf or beyond could have significant short-term impacts on local organisms. However, the actions of waves and currents would greatly disperse the contaminant, and the large volume of oceanic water would dilute the contaminant. Therefore, the long-term impacts at the site would be significantly reduced.

There are three primary reasons for polluting accidents during transfer (loading) operations: mechanical failures, design deficiencies, and human error. The human error factor increases as the number of incompatible chemical cargoes increases. Vessel casualties which could cause chemical waste pollution are grounding, collision, ramming, fire, explosion, structural failure, and mechanical breakdown--any one of which, if serious enough, could result in the vessel capsizing or sinking. Due to the extensive safety and control measures required in connection with the design and operation of incineration ships and the related land-based terminals, the potential for accidental spillage of chemical wastes would be minimized.

In order to reduce the potential for polluting discharges of oil and hazardous substances, the Coast Guard conducts surveillance flights over ports and coastal waters. Specific coastal surveillance areas are determined by the pollution potential expected as a result of vessel density studies and historical spill data. The Federal Water Pollution Control Act, as amended, requires those responsible for spills to report them; and non-spilling industries and the public are encouraged to report spills in order to augment this mandate.

The Coast Guard promulgates and enforces regulations that protect the environment from chemical carrier pollution. These regulations fall into several categories: (a) standards for design, equipment, construction and operation of vessels; (b) cargo containment and fire protection requirements; (c) navigating equipment necessary for safe operation; (d) cargo transfer regulations; and (e) procedures for notifying the proper authorities if a spill occurs. In addition, the Coast Guard Captain of the Port (COTP) is responsible for general port safety and enforcement of pollution prevention regulations. The COTP staff daily inspects vessels, facilities, and anchorages. The purpose of these inspections is to safeguard vessels, waterfront facilities, the harbor, and the port by enforcement of hazardous material and related safety regulations. The COTP is also responsible for establishing, coordinating, and, if necessary, implementing emergency contingency plans in the event of a major casualty or spill in the port.

B. INCINERATOR EMISSIONS (9)

One of the key considerations for minimizing the environmental impact of incineration at sea is proper selection by EPA of the site for treatment and disposal. Of equal importance are the regulation of incinerator emissions, the control of operating procedures, and the requirements for equipment and devices to minimize malfunctions of the incinerator ship system. Such matters are currently addressed by federal regulations and international agreements.

1. Incineration Site Designation

Sites for at-sea incineration are selected to minimize the interference of waste disposal activities on the marine environment, particularly avoiding areas of existing fisheries or shellfisheries, regions of heavy commercial or recreational navigation, and areas of mineral extraction or special scientific importance. Disposal site evaluation studies are conducted which are based on EPA criteria. The results of these studies are presented in support of the site designation in the form of an environmental assessment of the impact of using the site for disposal. An environmental impact statement is prepared for each site designation where such a statement is required by EPA policy.

2. Incinerator Emission Products

Wastes which are incinerated at sea on an industrial or commercial basis are principally organic chemicals. Such wastes are usually liquid, although certain organic solids may be candidates because they are soluble in liquid waste or in fuel oil. In addition, the wastes may be "wet" or emulsified in water. The incineration of solid organic wastes has not been conducted successfully at sea to date and is planned on a research and development basis by EPA. This research and development work will be part of EPA's program to implement new and improved management techniques for hazardous waste management.

In general, the wastes are organochlorine compounds whose principal combustion products are CO_2, H_2O, and HCl. Other acceptable wastes are hydrocarbons or oxygenated organic compounds, provided that they are combustible and do not contain prohibited materials. Principal combustion products from these non-chlorinated materials are CO_2 and H_2O.

A basic characteristic of at-sea incineration is that the combustion products of the waste go directly from the stack of the incinerator into the air and the ocean without any further treatment. (Emission control devices are being considered by EPA for future research and development work, however.) The stack emissions contain the major products of combustion - CO_2, H_2O, and HCl; certain minor constituents of the waste; whatever unburned waste which remains; and any organic materials which may have been synthesized during the incineration process. Trace metals which may have been present in the waste appear in the effluent gases as particulates. Phosphorus, sulfur, and much of the combined nitrogen appear as P_2O_5, SO_x, and NO_x. Certain other minor constituents caused by equilibrium conditions in the furnace and stack, i.e., CO, Cl_2, and H_2, may also be present to the extent of 10^{-5} to 10^{-8} mole fractions. In general, organic waste of high inorganic content, such as heavy metals, are not suitable for at-sea incineration.

3. Incinerator Efficiencies

Combustion efficiency (CE) and destruction efficiency (DE) are two parameters often used to describe an incinerator's effectiveness in disposing of organic wastes. The combustion efficiency for a certain burn is based on measurements of CO and CO_2 concentrations of the hot gases leaving the combustion chamber and is given by the following expression:

$$CE(\%) = \frac{(CO_2) - (CO)}{(CO_2)} \times 100$$

Destruction efficiency is basically a measure of the difference between the amount of waste being fed to the incinerator and the amount of waste contained in the exiting gas stream. A variety of sampling, analysis, and calculation procedures can be used to determine the destruction efficiency of a particular burn. (5,6)

Combustion efficiencies of 99.99 percent and destruction efficiencies of 99.999 percent have been demonstrated on the M/T VULCANUS.(6) National and international standards require both the combustion efficiency and the destruction efficiency to exceed 99.9 percent. The flame temperature of the liquid injection incinerators is maintained at all times above 1250°C during the incineration of organochlorine wastes.

4. Impact on Air Quality

Some largely local impacts on air quality from at-sea incineration occur in the burn site. Among these are the large output of hydrogen chloride with far lesser amounts of carbon monoxide, chlorine, and unburned hydrocarbons. At 99.96 percent destruction efficiency of the waste, the maximum predicted concentration of organochlorines would be approximately 2.75 micrograms/cubic meter of exhaust gas. In the 1977 Gulf burn aboard the M/T VULCANUS, the maximum air concentration of hydrogen chloride found downwind of the ship was 10 parts/million. Most frequently, values ranged from 0-5 parts/million.(5) Sea level concentrations of hydrogen chloride generally were in the range of 1-2 parts/million several kilometers downwind during the 1974 burn. (3) These low atmospheric concentrations of hydrogen chloride posed no hazard to birds or personnel in the area. The concentrations of carbon monoxide and chlorine in the atmosphere are negligible.

Within 5-10 miles of the incinerator ship, acid rain from incineration could equal or exceed that normally produced when rain washes out the naturally occurring acidic sulfur (SO_x) and nitrogen (NO_x) as well as chloride in seawater spray. In this case, the acid rain would be neutralized immediately by the natural carbonates in the ocean.

Beyond ten miles, any hydrogen chloride remaining in the air would be so diluted that it would be insignificant compared to naturally occurring acidic components of the atmosphere. Aerial monitoring of at-sea incineration in 1974 showed that the maximum concentration of hydrogen chloride in the air five miles downwind was on the order of 0.1 parts/million. This concentration is much lower than the Threshold Limit Value (TLV) for humans in the workplace of 7 milligrams/ cubic meter. Eight miles downwind the concentration was below detection limits (0.005 parts/million). This concentration is lower than the concentration of other acidic components allowed under the most stringent air standards for either SO_x or NO_x.

At any greater distance than ten miles, the effect would be even less with continued dispersion and neutralization of the hydrogen chloride which contacts the ocean or reacts with naturally occurring ammonia in the atmosphere. For these reasons, the acidity of rainfall on coastal locations would not be increased due to at-sea incineration in EPA-designated burn sites.

5. Impact on Water Quality

The ability of seawater to assimilate hydrogen chloride without measurable change is well known. Analysis of seawater samples for organochlorines during organochlorine burns resulted in values below the 0.5 parts per billion limit of detection. In addition, surface water samples collected during burns showed no significant differences in trace metals between test and control stations under normal meteorological conditions.

A "worst case" condition would be the rapid fallout of HCl caused by rainfall. If rainfall occurred in the immediate vicinity of the incinerator vessel, it is estimated for a typical organochlorine waste (63 percent chlorine) that the maximum fallout of HCl would be between 30 and 60 grams/square meter of ocean surface. A depression of pH would occur but would have only short-term and local effects since neutralization would occur within the first few meters of the water column. If the rain occurred directly downwind at a distance of 5-10 miles from the incinerator vessel, acid rain would be neutralized immediately by the natural buffering capability of the ocean. At distances greater than 10 miles, acidity due to input of HCl from incineration of organochlorines would be neutralized by ambient ammonia in the atmosphere.

CHAPTER VI

WATERFRONT FACILITIES FOR STORAGE, PROCESSING, AND TRANSFER OF WASTES

An incinerator ship service requires a land-based support network consisting of waterfront storage tanks, waste processing and handling equipment, a laboratory for waste analysis, and a cargo transfer terminal, plus an inland transportation system to haul wastes. (12) See Appendix D for design and operational requirements for such a shoreside facility.

Storage facilities may be leased tank capacity in an existing chemical tank farm. Storage capacity should be several times the capacity of one incinerator ship in case incineration operations are disrupted. A well-established incinerator ship service would very likely require new terminal construction, though leased tank capacity in several ports may still be necessary. When a dedicated facility is built, it will require the capability for: dedrumming wastes, slurrying of powdered and soluble solid wastes, and loading of solid wastes into sealed fiber or bulk material containers. (12, Appendix B)

Inland delivery networks to the ship's loading terminal must be established. To haul the wastes safely, special trucks, railcars, or barges would be used. These vehicles and vessels could be owned by the ship operator or may be leased. Barges, for example, should be able to discharge their liquid waste cargo directly into the ship's tanks, just as fuel oil barges load ships when they are at dock or at anchor. (12)

The following section describes the waterfront facility design and function. The remainder of this chapter then discusses several current regulatory programs and activities which specifically address the land-based handling of hazardous materials and hazardous wastes.

A. DESIGN AND FUNCTION OF WATERFRONT FACILITY

The purposes of the waterfront facility are the following:

- Receive liquid and solid hazardous wastes either by land or by waterborne barge transport
- Analyze, blend, shred, and containerize or package the materials as appropriate for incineration at sea
- Load the waste aboard ship in a safe and efficient manner

- Remove and receive residues from the incinerator ship for analysis and disposal either on land or at sea, in the case of incineration of wastes producing a collectable residue during disposal

A preliminary design has been developed for this facility and is described in Appendix D. Also summarized in this appendix are the results of a survey of existing terminal facilities which could be used for hazardous materials.

Several design criteria were used in the preliminary design and will also apply for subsequent design stages. The facility must accommodate wastes in almost any physical form and in several types of containers, some of which may be older, corroded, and possibly leaking. Ideally the facility would service three transportation modes for delivery of wastes: truck, rail and barge. The facility must consecutively accommodate up to two incinerator ships, each of which is on a two-week cycle. The required waste storage capacity of the facility is as follows:

Liquid Waste	30,000 m^3 (181,000 bbl)
Solid Waste	1,800 m^3 (64,000 ft^3)

The facility must also provide for preparing and blending wastes for optimum transfer and combustion, and for unloading ash residue from the incineration process from each ship.

The ideal site for the facility would be located where potential environmental impact is minimal, transportation time for the various modes are minimal, and topography is convenient. Structural standards must be carefully followed, and these are normally 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 reach soil, water, or air. In general these criteria are specified by federal regulations.

Liquid waste, solid waste, and ash residue from incinerators 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, along with the tanker decontamination rinse, will also be blended and pumped to the storage tanks.

Solid waste arriving at the site will be unloaded at the unloading rack, prepared for incineration by shredding, and placed in bulk material containers (BMC) to be loaded on the ship.

The 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.

The waterfront facility is designed to prevent emissions of hazardous materials; to contain spills, leaks and other accidents; and to minimize harm to personnel in the event of accidents. Planned measures include the following:

- Collection and disposal systems for vapors from waste transfer
- Detailed material balance audits
- Dry break valves which prevent spillage during disconnecting
- Aboveground plumbing and convenient access to fittings
- Use of corrosion resistant materials
- Pipes sloped away from points of potential discharge
- Complete fire prevention and control systems
- Security provisions including guards and continuous fencing around facility
- Special training in hazardous wastes for personnel
- Effluent and media monitoring in and around facility
- Dikes around liquid storage areas

The facility is expected to require approximately 75,000 square meters (18 acres) of land and will require a staff of approximately 40 to operate on a two-shift schedule.

Capital costs for the installed facility (excluding dock rental and land costs) are estimated to be $19 million in 1980 dollars. Land costs will vary greatly depending on the location and are expected to be in the range of $5 to $20 million. The operating costs, including labor, maintenance, depreciation, power and ash disposal, are estimated to be $4 million annually. This excludes insurance costs and potential land and dock rental costs. Insurance premiums are estimated to be $3 million to $6 million annually. In case the land and dock will not be purchased, lease costs will be at least $300,000 annually.

The survey of existing terminal facilities in the United States found that 139 ports and 1,221 terminal docks, piers or wharves on the East, Gulf, and West coasts of the continental U.S. have sufficient water depth and space to receive the incinerator ship. These terminals are concentrated primarily in the states of Texas, New Jersey, Louisiana, California and New York. Most terminals are privately owned. These owners feel that compliance with regulations not yet finalized is the major determinant of their ability to handle hazardous wastes. The technical feasibility to handle these wastes is a secondary question. Several military depots appear to have capability for handling both liquid and solid hazardous wastes and this possibility should be explored further.

None of the bulk liquid terminal operators thought it advisable to provide solid waste service at a bulk liquid terminal, primarily because of differences in the handling characteristics of the wastes. Although separate facilities for liquid and solid wastes are not necessarily a recommendation of this report, it is suggested that this apparent concern be investigated further.

B. ENVIRONMENTAL PROTECTION AGENCY REGULATIONS FOR THE HAZARDOUS WASTE MANAGEMENT SYSTEM

The EPA published in the Federal Register of May 19, 1980, the final rules concerning the hazardous waste management system (40 CFR Parts 260-265). This rulemaking is in response to the Resource Conservation and Recovery Act (RCRA) of 1976 which directs EPA to promulgate regulations to protect human health and the environment from improper management of hazardous waste.

A brief summary of this regulatory action follows.

Rulemaking 40 CFR Part 260 sets forth definitions which appear in Parts 261 through 265 and contains provisions which are generally applicable to all of these regulations.

Rulemaking 40 CFR Part 261 identifies four characteristics of hazardous waste to be used by persons handling solid waste to determine if that waste is hazardous waste. In addition, it lists 85 process wastes as hazardous wastes and approximately 400 chemicals as hazardous wastes if they are discarded. Persons who generate, transport, treat, store, or dispose of hazardous wastes identified or listed in this regulation must comply with all applicable requirements of Section 3010 of RCRA. Part 261 also sets forth the criteria used by EPA to identify characteristics of hazardous wastes and to list hazardous wastes.

Rule 40 CFR Part 262 sets standards applicable to generators of hazardous waste. The hazardous waste generator standards require a generator to determine if the waste is a hazardous waste and then to prepare manifests for the shipment of all such wastes sent off-site for treatment, storage, or disposal. For these shipments, the generator must also package, label, mark and placard the waste according to Department of Transportation and EPA rules. The generator must also keep records, report those shipments which do not reach the facility designated on the manifest, and submit an annual summary of their activities.

The 40 CFR Part 263 regulations establish standards for transporters of hazardous waste. The hazardous waste transporter standards require each transporter of regulated wastes to obtain an EPA identification number, comply with the manifest system initiated in 40 CFR Part 262, deliver the entire quantity of hazardous waste to the designated treatment, storage, or disposal facility, and keep records of the transportation of hazardous waste. Additionally, each transporter is to take certain actions in the event of a discharge of hazardous waste, e.g., clean up the hazardous waste discharge, notify the National Response Center, and report in writing to the Materials Transportation Bureau.

The regulations under 40 CFR Part 264 include the first phase of the standards which will be used to issue permits for hazardous waste treatment, storage, and disposal facilities. Included are requirements respecting preparedness for and prevention of hazards, contingency planning and emergency procedures, the manifest system, and recordkeeping and reporting. Also included are general requirements respecting identification numbers, required notices, waste analysis, security at facilities, inspection of facilities, and personnel training. Additional Part 264 regulations will be promulgated.

The regulations of 40 CFR Part 265 establish requirements applicable during the interim status period regarding preparedness for and prevention of hazards, contingency planning and emergency procedures, the manifest system, recordkeeping and reporting, ground-water monitoring, facility closure and post-closure care, financial requirements, the use and management of containers, and the design and operation of tanks, surface impoundments, waste piles, land treatment facilities, landfills, incinerators, treatment units (thermal, physical, chemical, and biological), and injection wells. In addition, there are included some general requirements respecting identification numbers, required notices, waste analysis, security at facilities, inspection of facilities, and personnel training.

EPA also published with these final rules two proposals to modify 40 CFR Part 265 concerning the financial requirements for hazardous waste management systems and the requirements for hazardous waste disposal by underground injection.

C. MATERIAL TRANSPORTATION BUREAU RULES FOR TRANSPORT OF HAZARDOUS WASTES AND HAZARDOUS SUBSTANCES

The Materials Transportation Bureau, Department of Transportation, published in the Federal Register of May 22, 1980, a final rule (49 CFR Parts 171, 172, 173, 174, 176, 177) concerning identification numbers, hazardous wastes, hazardous substances, international descriptions, improved descriptions, forbidden materials, and organic peroxides. The purpose of this regulation revision is to accomplish the following: (1) adopt a numerical identification system for hazardous materials transported in commerce; (2) adopt regulations pertaining to the transportation of hazardous wastes; (3) adopt regulations pertaining to the identification of, and discharge notification for, hazardous substances; (4) list certain forbidden materials by name and revise general criteria applicable to forbidden materials; (5) provide proper shipping names for organic peroxides; (6) require inclusion on shipping papers of the technical names of certain hazardous components of materials covered by "not otherwise specified" entries; and (7) provide for optional use of certain United Nations shipping descriptions.

The principal objective of this rule, as it pertains to the use of identification numbers, is to improve the capabilities of emergency response personnel, such as firemen and policemen, to quickly identify hazardous materials and to assure the accurate transmission of information to and from the scenes of accidents involving hazardous materials.

D. COAST GUARD WATERFRONT FACILITIES REGULATIONS (23)

The Coast Guard is revising and developing regulations for waterfront facilities handling hazardous commodities (33 CFR Subchapter L). The new regulations are being developed in a number of packages, each package basically devoted to a different type of facility as follows: general facility requirements, bulk liquid facilities, liquefied gas facilities, container/break bulk/explosives facilities, bulk solid facilities, and other facilities. The Coast Guard presently has regulatory responsibilities for a total of 2,216 waterfront facilities; this regulatory authority will be expanded to approximately 4,890 waterfront facilities in 275 ports and harbors of the United States when the new rules take effect.

The new waterfront facilities regulations seek to promote safety and to minimize environmental pollution. The regulations deal with design, construction, equipment, fire protection, operations, maintenance, security, and personnel qualifications and training. When new facilities handling hazardous commodities on the waterfront are built or when existing facilities are significantly modified, in-depth environmental impact statements will be ordered.

The new regulations will apply to many more commodities than those presently listed as cargoes of particular hazard by the Coast Guard. Specifically, waterfront facilities handling quantities beyond stated threshold limits of the following materials will be subject to the regulations: oil of any kind or in any form (including, but not limited to petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredge spoils) and all of the articles, materials, chemicals or cargoes referred to in the following regulatory publications: 46 CFR Subchapter D (bulk liquids and gases), 46 CFR Subchapter O (bulk dangerous cargoes),46 CFR Part 148 (bulk solid hazardous materials), 49 CFR Subpart 172.101 (packaged hazardous materials), 33 CFR Subpart 124.14 (cargoes of particular hazard), and 40 CFR Part 116 (hazardous substances).

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APPENDIX A

to

REPORT OF THE INTERAGENCY
AD HOC WORK GROUP
FOR THE
CHEMICAL WASTE INCINERATOR
SHIP PROGRAM

(SERVED)
(February 22, 1979)
(MARITIME ADMINISTRATION)
(MARITIME SUBSIDY BOARD)

U.S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION

DOCKET NO. A- 131

MARAD CHEMICAL WASTE INCINERATOR SHIP PROJECT

In the matter of environmental review of the Maritime Administration Chemical Waste Incinerator Ship Project, including review of the Final Environmental Impact Statement - Maritime Administration Chemical Waste Incinerator Ship Project, NTIS Report No. MA-EIS-7302-76-041F issued on July 2, 1976, under the National Environmental Policy Act of 1969.

FINAL OPINION AND ORDER

Samuel B. Nemirow, Maritime Subsidy Board Chairman; C.G. Caras, Member, James S. Dawson, Jr., Alternate Member, and Acting Assistant Secretary for Maritime Affairs Samuel B. Nemirow

I. INTRODUCTION

The Maritime Subsidy Board and Assistant Secretary for Maritime Affairs herein present the decision and action to be taken on the Maritime Administration (MarAd) Chemical Waste Incinerator Ship Project (Project) under the National Environmental Policy Act of 1969 (NEPA) 1/ NEPA requires federal agencies, in connection with "major Federal actions significantly affecting the quality of the human environment," to produce a detailed statement pertaining to the environmental implications of the proposed actions and to act using all practicable means so as to protect and enhance the nation's environment.2/

In fulfillment of this requirement, a detailed Environmental Impact Statement (EIS) concerning the MarAd Chemical Waste Incinerator Ship Project was developed. The

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1/ 42 U.S.C. §§4321 et seq. It should be noted that actions which will be taken under this project involve two types of authority: (1) delegated authority to the Board to make contracts for the sale of vessels, and (2) authority of the Secretary of Commerce under the Merchant Marine Act, 1936, as amended, delegated to the Assistant Secretary of Commerce for Maritime Affairs. In the interest of avoiding repetition, we shall speak to the "Board" as embracing all authorities within the Maritime Administration.

2/ 42 U.S.C. §4331(b), 4332.

"Final Environmental Impact Statement — Maritime Administration Chemical Waste Incinerator Ship Project," designated NTIS Report MA-EIS-7302-76-041F, was issued by the Department of Commerce on July 2, 1976. The final EIS reflects the comments of various governmental and private organizations concerned with environmental quality.3/ In the Board's view, this final EIS was prepared in accordance with all statutory and regulatory requirements and reflects consideration of all relevant environmental consequences.4/

The Board herein reviews the environmental implications of the MarAd Chemical Waste Incinerator Ship Project, and alternatives to the project, as noted in the final EIS, and indicates environmental protection actions to be taken relative to the project.

3/ For a partial listing of those who have generously given of their efforts in this regard, note page "c", Volume I and pages iii and iv of Volume II to the EIS.

4/ Congress intended under NEPA that a detailed EIS would assure that agency decisionmakers had before them and considered an analysis setting forth the environmental implications of proposed action and alternative courses of action. Calvert Cliff's Coordinating Committee, Inc. v. AEC, 449 F. 2d 1109, 1114 (D.C. Cir. 1971). See also 42 U.S.C. §4332(2)(c).

II. THE MARAD CHEMICAL WASTE INCINERATOR SHIP PROJECT

The MarAd Chemical Waste Incinerator Ship Project was developed in response to The Marine Protection, Research, and Sanctuaries Act (P.L. 92-532) enacted on October 23, 1972 (Act). The Act provides for the regulation of ocean dumping, research on ocean dumping and other man-induced changes to the ocean ecosystem, and the designation, acquisition, and administration of marine sanctuaries. In part, the Act directs the Secretary of Commerce to work in conjunction with other federal agencies in an effort to minimize the environmental consequences of ocean dumping. Specifically, Title II, Section 203 of the Act requires the Secretary of Commerce to conduct and encourage studies for the purpose of determining means of minimizing or ending all dumping of materials within five years of the effective date of the Act.

The environmentally safe disposal of chemical wastes is a serious international problem. In 1973 it was estimated that approximately 10 million tons of non-radioactive, hazardous waste are generated yearly in the United States.

The rate has been increasing over the years roughly parallel to the increases in the chemical industry — a rapidly growing field. Disposal of these wastes, particularly by direct ocean dumping, is becoming increasingly intolerable from an environmental standpoint. One effective alternative to ocean dumping is incineration at sea. Successful disposal of combustible, liquid chemical wastes has been undertaken for several years, primarily in Europe, aboard various incinerator ships. The experience of these vessels has been very encouraging and has provided significant information which is used here.5/

In furtherance of the Secretary's goals and responsibilities under the Act, MarAd is considering federal support for the development of a U.S. capability to incinerate toxic chemical wastes at sea. No single mode of support, to the exclusion of others, is contemplated at this time. Although MarAd support could come in many forms, three specific forms are most likely:

5/ See Volume 2 of the EIS for particularly detailed discussions of research burns aboard these vessels.

1. The National Defense Reserve Fleet (NDRF) is maintained by MarAd and comprises several hundred merchant ships available for use during national emergencies.6/ From time-to-time, some of these vessels become obsolete due to their age, advances in technology and changes in U.S. emergency needs. It is possible that such obsolete vessels, upon conversion, would be capable of chemical waste incineration at sea. In the past, many such obsolete vessels have been successfully utilized as platforms for various non-shipping functions.

2. The Merchant Marine Act, 1936, as amended, provides for a loan Guarantee Program whereby the full faith and credit of the United States is pledged to the repayment of principal and interest on qualified shipbuilding loans.7/ These so-called Title XI guarantees could be granted in connection with the consideration of chemical waste incinerator

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6/ Merchant Ship Sales Act of 1946, 60 Stat. 41, U.S.C. App. 1735 et seq.

7/ 46 U.S.C. 1271 et seq.

ships and would greatly facilitate the construction financing of such vessels.

3. The advantages of both NDRF and Title XI mortgage loan guarantees could be combined to provide the government Title XI mortgage loan guarantees to secure financing for conversion of vessels from the NDRF to chemical waste incinerator ships.

III. ENVIRONMENTAL IMPLICATIONS OF THE PROJECT

As noted earlier, NEPA requires that the environmental implications of proposed major federal programs be considered prior to taking action. These implications are set forth in detail in the final EIS for the project,[8/] and are summarized herein:

A. ENVIRONMENTAL IMPACT OF THE PROJECT

The final EIS properly indicates that the environmental considerations incident to the Chemical Waste Incinerator Ship Project arise in three principal areas:

[8/] Final EIS, Volume 1, §III.

accidental discharge or spillage; incineration discharge effects; and ship construction, conversion, repair and scrapping. In addition, the final EIS indicates certain minimal adverse environmental effects of the project which cannot be avoided.

1. ACCIDENTAL SPILLAGE OF THE CHEMICAL WASTE CARGO

The most serious potential environmental consequence of the project is the potential adverse environmental effects of accidental spillage of chemical waste due to a vessel casualty or during the loading of the ship. In the event of such a chemical spill, the environmental impact will depend on a number of factors including: (1) the environmental conditions where the spill occurs in terms of the water's temperature, turbulence, and existing pollution load; (2) the spill site's marine life population; (3) the spill rate; and (4) the nature of the chemical involved.

From the foregoing factors it is apparent that an accidental chemical spill would have a substantial adverse effect on marine life in the spill site area and could pose a threat to human health in recreational water areas. It is, therefore, the opinion of the Board that prevention of accidental discharges of hazardous chemical wastes is a primary goal, although not the only goal, of the MarAd Chemical Waste Incinerator Ship Project. As such, we later discuss various safety and control measures which will be required in connection with the Chemical Waste Incinerator Ship Project. These precautions will minimize the potential for accidental discharge of chemical wastes at sea and in port.

2. INCINERATION DISCHARGE EFFECTS

The safe and relatively non-polluting incineration at sea of hazardous chemical wastes is an additional goal of the Maritime Administration's Chemical Waste Incinerator Ship Project. Incineration necessarily produces combustion by-products, primarily the emission of gaseous materials. These products can themselves result in air pollution and also water pollution when they contact the ocean surface and become mixed with the ocean water. The effect of these products can best be judged by observing the actual experience of incineration aboard the foreign flag vessel VULCANUS in both Europe and the United States. This history has revealed that a high combustion efficiency well in excess of 99.9% is regularly achieved, and that such combustion efficiency contributes to minimizing the adverse environmental effects created by the incineration emissions.

3. SHIP CONSTRUCTION, CONVERSION, REPAIR AND SCRAPPING

As noted earlier, MarAd's Chemical Waste Incinerator Ship Project may include support for the conversion and repair of existing vessels or the construction of new vessels to incinerate chemical waste at sea. The construction or conversion process itself may have an environmental impact.

Principally three aspects of the ship construction industry have an effect on the environment: expansion of shipbuilding capacity; actual ship construction, alteration, conversion or repair; and the use of various raw materials. The Board has had occasion in the past to consider the environmental impact of the ship construction industry generally in its decisions in Docket No. A-75 — MarAd

Tanker Construction Program [9] and in Docket No. A-93 — The MarAd Bulk Chemical Carrier Construction Program. [10] The Board finds that the environmental impact created by the ship construction industry in connection with the MarAd Chemical Waste Incinerator Ship Project will be substantially the same as that considered by the Board in the foregoing decisions. The Board notes that the Chemical Waste Incinerator Ship Project is of small proportion compared to the general ship construction industry activity and will have minimal effect on the environment. Additionally, the building of these few new ships will not require the expansion of any existing shipbuilding facilities. Thus, the small scale of the MarAd Chemical Waste Incinerator Ship Project and the minimal use of shipyard facilities combine to lessen any potential environmental impact which might flow from the shipbuilding aspects of the execution of the project.

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[9] 13 SRR 1117 (MSB 1975).

[10] Final Opinion and Order of the Maritime Subsidy Board served December 13, 1974 (unreported).

4. UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

Some unavoidable adverse environmental impact will most likely occur under the MarAd Chemical Waste Incinerator Ship Project in the mining and processing of raw materials associated with ship construction, conversion and repair. As noted earlier, the potential for accidental polluting spills also exists notwithstanding the strict observance of precautionary safety measures. Additionally, the incineration exhaust will be deposited on the ocean surface and mixed with the ocean waters. However, the high incineration flame temperature, the residence time for the atomized waste in the incinerator, and the burn efficiency rate in excess of 99.9% combine to minimze adverse effects from incineration. Finally, small amounts of air, water, noise and solid waste pollution will undoubtedly result from the construction, operation and utilization of the project vessels. It is noted that these sources of pollution are minimal in their impact and will be kept within the limits of local, state, national and international standards for such forms of pollution.11/

11/ Final EIS, Volume 1, §VI.

B. RELATIONSHIP BETWEEN LOCAL SHORT TERM USE OF THE ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG TERM PRODUCTIVITY AND THE IRREVERSIBLE AND IRRETREIVABLE COMMITMENT OF RESOURCES

The Chemical Waste Incinerator Ship Project will have a beneficial effect upon the long term productivity of the oceans since incineration at sea is a viable alternative to the direct ocean dumping of hazardous chemical wastes. The adverse environmental impacts of ocean dumping are obvious. The implementation of the Chemical Waste Incinerator Ship Project will greatly lessen these adverse environmental impacts. The vessels built or converted under this project are to be designed, constructed and operated in accordance with the most stringent national and international standards. The Board concludes that the useful function to be performed by the vessels coupled with the minimal adverse environmental impact of the vessels' construction and operation combine to produce an overall beneficial environmental effect which will enhance the long term productivity of the ocean.12/

12/ Final EIS, Volume 1, §VII.

In carrying out this project, it is expected that certain irreversible and irretrievable commitment of resources will be experienced. Such experience, however, will be minimal.13/

IV. ALTERNATIVES TO THE PROJECT AND ENVIRONMENTAL IMPLICATIONS

NEPA declares as national environmental policy not only commonly understood conservation oriented goals, but also fulfillment of social, economic and other requirements of our nation and its people. To carry out this policy NEPA requires federal agencies to use "all practical means, consistent with other essential considerations of national policy," to protect and enhance the environment.14/ The emphasis upon federal decisions that weigh both environmental considerations and other national policy considerations is essential to NEPA. The statute expressly provides that, "the policy and goals set forth in this chapter [NEPA] are supplemental to those set forth in existing authorizations of federal agencies."15/ Only two alternatives to the project

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13/ Final EIS, Volume 1, §VIII.

14/ 42 U.S.C. 4331(b).

15/ *Id*. at §4335.

are available: discontinuing the project or disposition of chemical wastes on land or at sea.

A. DISCONTINUING THE PROJECT

An alternative to the Chemical Waste Incinerator Ship Project is for the Board to provide no federal assistance at all with respect to chemical waste disposal. We believe that such action would be counter to the spirit of the Act and would not serve to lessen existing pollution problems of chemical waste disposal. It is clear to the Board that the benefits to be derived from this project, a project designed to reduce pollution, will vastly outweigh the relatively negligible adverse environmental impact which flows from the implementation of the project. Thus, discontinuance of the project would not be in the national interest.

B. OTHER TYPES OF CHEMICAL WASTE DISPOSITION

The EIS addresses various forms of chemical waste disposal, including disposal processes on land, dumping at sea and incineration aboard foreign flag ships.[16] Land based disposal could consist of physical treatment, chemical

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[16] Final EIS, Volume 1, §V.

treatment, thermal treatment, or biological treatment. Each of these methods provides an environmental impact of its own which, in certain circumstances, can be substantial, and in many instances is believed greater than for incineration at sea with U.S.-flag vessels. It is the Board's view that disposition of certain types of chemical wastes by incineration at sea provides a highly desirable alternative to many existing methods of disposal. Thus, it is anticipated that incineration at sea will add another viable method to safe disposal of hazardous chemical wastes.

V. DECISION ON PROJECT

It is decided to pursue the MarAd Chemical Waste Incinerator Ship Project since it is found that the project will further the purposes of NEPA. Such approval will be conditional on safeguards to protect the environment.

As noted earlier in this opinion, the chief environmental impact of the project would result from the accidental spillage of hazardous chemical wastes. Various local, state, federal and international regulations and programs presently exist which bear on the avoidance of such accidental discharges.17/ In addition, extensive safety and pollution abatement regulations exist which are administered by the U.S. Coast Guard, the U.S. Environmental Protection Agency, the American Bureau of Shipping, and the Intergovernmental Maritime Consultive Organization. These regulations are discussed below. The incinerator type ships proposed in this project will be required to comply with such regulations and various other regulations and standards established to protect the environment. Also discussed below are further specific actions to be taken by MarAd to protect the environment

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17/ The federal regulations and standards were promulgated pursuant to national laws including: (i) NEPA, (ii) Oil Pollution Act of 1961 (P.L. 87-167), (iii) Oil Pollution Act Amendments of 1973 (P.L. 93-119), (iv) Marine Protection, Research and Sanctuaries Act of 1972, (v) Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500), (vi) Clean Water Act of 1977 (P.L. 95-217), (vii) Ports and Water Safety Act of 1972 (P.L. 92-340), (viii) The Port & Tanker Safety Act of 1978 (P.L. 95-474), (ix) Coastal Zone Management Act of 1972 (P.L. 92-583), (xi) Resource Conservation & Recovery Act of 1976 (RCRA) (P.L. 94-580). The last statute, RCRA, does not extend to incineration at sea. It requires the EPA to promulgate regulations establishing performance standards for storage, transportation, treatment and land disposal of hazardous wastes. As a practical matter, it has been a major catalyst for incineration at sea because of the stringent regulation thereunder of land-based alternatives.

with respect to the project in the form of standard specifications for ship construction, incinerator ship system safety analyses, and training support.

A. U.S. COAST GUARD DESIGN, CONSTRUCTION AND OPERATION REQUIREMENTS

The federal agency principally responsible for maritime law enforcement, safety at sea and pollution avoidance from ships is the U.S. Coast Guard. Among its regulatory duties, the Coast Guard is responsible for the safe transportation of hazardous materials in the marine mode. The transportation of chemical waste by the vessels of this project falls within the purview of Coast Guard regulation.

The Coast Guard would become involved in ship construction of vessels for this project once initial plans and specifications are submitted for approval by the agency.18/ During construction, each ship would be visually inspected by Coast Guard personnel to insure that the approved plans were followed. Additionally, throughout a vessel's operating life the vessel would be inspected periodically. The Coast Guard's regulations are designed to insure that pollution

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18/ Final EIS, Volume 1, §IV A.

from chemical carriers is minimized or eliminated to the highest degree practicable through the enforcement of standards, regulations and procedures for design and construction, cargo containment, fire protection, navigation, cargo transfer and spill notification.

The Coast Guard requires that vessels be designed to minimize collision effects in a manner appropriate to the cargo for which the vessel is constructed so that even if a vessel sustains damage at sea, it will remain afloat with minimum or no loss of its hazardous cargo. Requirements include double hull construction; a two-compartment standard of subdivision and damage stability; collision protection for cargo tanks, piping and equipment; and special allowances for localized loading and longitudinal bending. Additionally, the cargo tanks utilized in these vessels will be designed specially to accommodate the particular type of cargo which they will carry. Certain kinds of auxiliary equipment will be required aboard these vessels to control heating, cooling, pressurization, pumping and venting along with fire protection. These auxiliary equipment systems will aid in the prevention of leakage, the ability to combat fire and explosion, the prevention of chemical reaction, and the minimizing of toxic exposure.

B. U.S. ENVIRONMENTAL PROTECTION AGENCY INCINERATOR REQUIREMENTS

The Environmental Protection Agency (EPA) has jurisdiction under the Act over the design and operation of the at-sea incineration system and related matters. EPA requirements are based upon international regulations and technical guidelines on the control of incineration of wastes at sea. These regulations and guidelines are part of the International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972. The regulations and guidelines address a variety of matters including the following: (1) construction of the marine incinerator system; (2) approval of the incineration system; (3) wastes requiring special studies; (4) operational requirements for the incineration ship; (5) control over the nature of wastes incinerated; (6) incineration site selection; (7) notification procedures; (8) incinerator operations; and (9) general controls on the incinerator ship and its operation.

EPA considers ocean incineration as an emerging viable technological alternative, under carefully controlled conditions, to the direct ocean dumping of various types of chemical wastes. No significant degradation of air and water quality has been noted during careful and extensive EPA monitoring of research burns of organochlorine wastes in the Gulf of Mexico and the Pacific Ocean.

C. THE AMERICAN BUREAU OF SHIPPING RULES

The American Bureau of Shipping (ABS) prescribes standards for the design and construction of the hull structure, main propulsion machinery and vital auxiliary equipment for all types of merchant vessels. Both the U.S. Coast Guard and MarAd along with various private corporations and foundations, participate in the formulation of the ABS rules.

D. INTERGOVERNMENTAL MARITIME CONSULTATIVE ORGANIZATION

Over the last decades several agreements have been reached among nations designed to arrest the growing amount of pollution from ships. Chief among these conventions are those adopted by the Intergovermental Maritime Consultative

Organization (IMCO). The IMCO Marine Environment Protection Committee and Maritime Safety Committee are principally concerned with the abatement of marine pollution and with marine safety. Various IMCO documents bear on this program and include:

1. IMCO Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk;
2. 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter;
3. 1973 International Convention for the Prevention of Pollution from Ships;
4. 1974 International Convention on Safety of Life at Sea;
5. 1978 Protocol relating to the International Convention for the Prevention of Pollution from Ships;
6. 1978 Protocol relating to the International Convention on Safety of Life at Sea;
7. 1978 International Convention on Training & Watchkeeping of Seafarers.

It is the Board's opinion that the execution of the MarAd Chemical Waste Incinerator Ship Project will be in compliance with IMCO regulations and standards and in furtheranc of IMCO pollution abatement and safety goals.

E. MARITIME ADMINISTRATION STANDARD SPECIFICATIONS FOR MERCHANT SHIP CONSTRUCTION

Over the years MarAd has developed standard specifications to provide guidance to naval architects, ship owners and shipyards in the construction of various kinds of merchant vessels. On a continuing basis, MarAd has incorporated sections into the standards relating to pollution abatement and ship safety which are relevant to this project. These standard specifications include sections for: (1) invoking compliance with regulatory body requirements; (2) contributing to the overall physical safety potential of the vessel; (3) enhancing the safe navigation and/or operation of the vessel; and (4) mitigating water and air pollution. Additionally the MarAd specifications provide for collision avoidance radar.

F. INCINERATOR SHIP SYSTEM SAFETY ANALYSIS

MarAd considers that the performance of a comprehensive System Safety Analysis would enhance the safety of operating an incineration ship. This System Safety Analysis should address: (1) the design, construction, equipment, maintenance, and operation of the incineration ship; (2) measures to protect the health of the operating personnel and the public; and (3) methods to preserve the environment. The Analysis would be submitted by the applicant with the initial plans to MarAd for co-ordination with the Coast Guard and the EPA. It would assist in assuring that all safety and pollution control requirements have been met.

G. TRAINING

Recent statistical studies have shown that personnel errors are responsible for a significant percent of marine casualties. Thus, effective and comprehensive training of personnel is a necessity for the safe execution of the project. Various procedures are already extant which combine to provide effective and thorough training of personnel aboard vessels such as those proposed to be used in this project. Such training will contribute to reduction of potential accidental spillage. IMCO standards, U.S. Coast Guard regulations and MarAd training support should contribute to minimize adverse environmental effects resulting from personnel deficiencies.

VI. CONCLUSION

In summary, upon careful review and consideration of the Final Environmental Impact Statement - Maritime Administration Chemical Waste Incinerator Ship Project, issued on July 2, 1976, as NTIS Report No. MA-EIS-7302-76-041F, and alternatives thereto, and for the reasons set forth in this decision, the Maritime Subsidy Board and the Assistant Secretary for Maritime Affairs take the following actions regarding the MarAd Chemical Waste Incinerator Ship Project pursuant to the National Environmental Policy Act of 1969, The Marine Protection, Research, and Sanctuaries Act of 1972 and the Merchant Marine Act, 1936, as amended, including the Merchant Marine Act of 1970:

1. Find and conclude that the aforesaid Final Environmental Impact Statement presents adequate information in accordance with the National Environmental Policy Act of 1969, on the environmental implications of the MarAd Chemical Waste Incinerator Ship Project and the alternatives thereto;

2. Find and conclude that contracts of sale of obsolete National Defense Reserve Fleet vessels and Title XI

loan guarantees in connection with construction or conversion of vessels to incinerator ships will require shipyard compliance with government (local, state and federal) environmental standards for actual ship construction under contract and any expansion of yard facilities necessary to perform such work;

3. Find and conclude that the MarAd Chemical Waste Incinerator Ship Project will be pursued;

4. Find and conclude that contracts of sale for obsolete National Defense Reserve Fleet vessels to be converted to incinerator ships and granting of Title XI loan guarantees will require compliance with the applicable national and international requirements for safety and pollution control, including those of the Maritime Administration Standard Specifications for Merchant Ship Construction and the provisions of said Specifications pertaining to collision avoidance radar;

5. Find and conclude that the Board will continue to work cooperatively with the U.S. Coast Guard and the U.S. Environmental Protection Agency in ongoing efforts to minimize or end ocean dumping of chemical wastes.

6. Find and conclude that a System Safety Analysis, as described herein, should be submitted by each applicant for participation in the MarAd Chemical Waste Incinerator Ship Project with the initial plans to MarAd for coordination with the U.S. Coast Guard and the U.S. Environmental Protection Agency.

SO ORDERED BY THE
MARITIME SUBSIDY BOARD and
MARITIME ADMINISTRATION

Dated: February 16, 1979

Robert J Patton Jr
ROBERT J. PATTON, JR.
Assistant Secretary
Maritime Subsidy Board
Maritime Administration

APPENDIX B

to

REPORT OF THE INTERAGENCY AD HOC WORK GROUP FOR THE CHEMICAL WASTE INCINERATOR SHIP PROGRAM

DESIGN RECOMMENDATIONS FOR A SHIPBOARD AT-SEA HAZARDOUS WASTE INCINERATION SYSTEM

FINAL REPORT

by

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ABSTRACT

This report summarizes the results of an engineering study assessing the key aspects of at-sea incineration, including the total shipboard incineration system, in several alternative forms, and all phases of waste disposal from waste selection to final disposition of any effluent, ash, or residues produced. Evaluation of basic incinerator devices potentially applicable to shipboard operation resulted in the selection of liquid injection incinerators for routine destruction of pumpable wastes. A rotary kiln is recommended for shipboard experimental evaluation of solid waste incineration. Fluidized bed, molten salt, multiple hearth, multiple chamber, and starved air incinerators are all limited in operating temperatures and waste type handling capacity compared to the rotary kiln.

Emission control devices, although commonly used with land based incinerators, have many limitations for at-sea operation. A high energy venturi scrubber utilizing sea water should be considered for shipboard evaluation. The molten salt bath should be considered for experimental evaluation as a scrubber for trace metal emissions.

Estimated cost of a rotary kiln incinerator designed for shipboard application is \$900,000 or \$1,119,000 installed. Cost of each liquid injection incinerator is estimated to be \$2,500,000 or \$3,812,000 installed. One rotary kiln and three liquid injection incinerators are recommended for the ship of approximately 8,000 metric tons waste capacity under consideration. Required sampling, monitoring, and analysis equipment is estimated to cost approximately \$261,000.

This report was submitted in partial fulfillment of Contract No. 68-03-2560, Work Directive No. T5017, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from March 26, 1980 to September 18, 1980.

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) has estimated that in 1980 at least 57 million metric tons of industrial hazardous wastes will be produced nationally. Many of these wastes, particularly organic chemical wastes, are incinerable; however, there are only a limited number of commercially available land based hazardous waste incinerators in the United States. Thermal destruction of liquid chemical wastes at sea has been shown to be an environmentally acceptable means of disposal. The EPA, Office of Research and Development, is considering a demonstration project for at-sea incineration of hazardous wastes in cooperation with the U.S. Department of Commerce, Maritime Administration, which will provide the required vessel. EPA has recommended that a U.S. incinerator ship be built to extend the capabilities of at-sea incineration to destruction of solid and semi-solid materials, as well as to perform operational destruction of liquid wastes.

This engineering study was undertaken to assess the key aspects of a total shipboard incineration system. Major characteristics of incinerator types evaluated for at-sea application are compared in Table A. Liquid injection incinerators, which have been proven for shipboard destruction of pumpable wastes, are recommended for the proposed vessel. A rotary kiln is recommended for solid waste incineration because of its versatility in incinerating all waste types and its high temperature capability. Modifications to the standard kiln mounting and seals are required for shipboard operation. The molten salt reactor, because of its potential for retaining particulate and contaminants in the melt, should be considered for further evaluation and development testing on land, but is not sufficiently proven commercially to be selected as a solids incinerator for shipboard application. Also, the risk of molten salts spills onboard ship must be assessed.

Emission control devices commonly used with land based incinerators have many limitations for shipboard operation including size, weight, and

TABLE A. COMPARISON OF CANDIDATE INCINERATOR TYPES FOR SHIPBOARD AT-SEA APPLICATION

	Liquid Injection	Rotary Kiln	Fluidized Bed	Molten Salt	Multiple Hearth	Multiple Chamber	Starved Air
Waste Types							
Pumpable liquids	X	X	X	X	X	X	X
Slurries, sludges		X	X	X	X		X
Tars		X		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	low[a]	med[a][b]	med[a][c]	med[a][d]	high[e]	med[e]	high[e]
Commercial Applications	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	limited use, 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.

fresh water requirements. A high energy venturi scrubber utilizing sea water is recommended for initial shipboard evaluation. Marine environmental effects of a single-pass sea water scrubber will require evaluation.

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. Gas blanketed storage tanks with corrosion-resistant linings and waste feed flowmeters are recommended for liquid wastes. Solids should be loaded into sealed containers on land: either smaller fiber containers to be fed directly into the incinerator or larger standard bulk material containers to be discharged directly into a sealed hopper. Handling of 55 gallon drums, particularly potential leakers, and shredding operations involve too much risk onboard ship.

Environmental monitoring during at-sea incineration should be conducted to ensure personnel safety and protection of the environment. All requirements of the Marine Protection, Research, and Sanctuaries Act (MPRSA) and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) will be met. A shipboard laboratory should be provided for analysis and identification of effluent waste samples and verification of destruction efficiency.

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

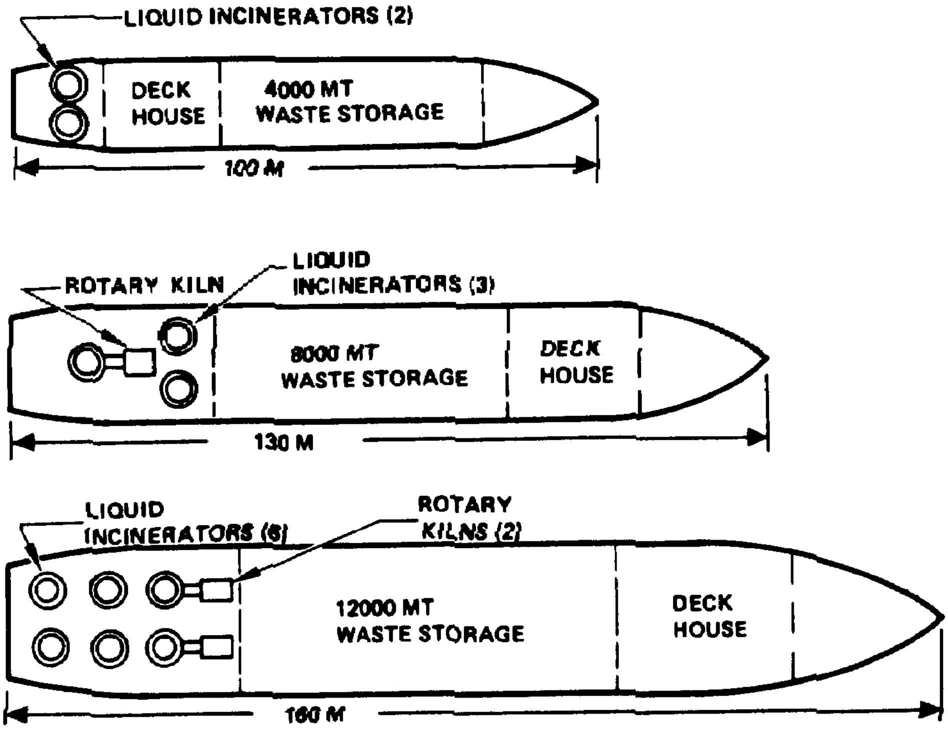

Figure A. Incineration System/Ship Integration.

A U.S. incineration 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; second, it would provide a safe site to continue EPA's research and development efforts in hazardous waste incineration. An incineration vessel would expand the 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 need to be further investigated, including many types of wastes not yet tested. In addition to performing operational destruction of hazardous wastes, the proposed incineration vessel could be effectively utilized for development testing of incinerator designs, emission control concepts, and improved sampling/monitoring equipment and methodology.

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ILLUSTRATIONS

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1. INTRODUCTION

1.1 BACKGROUND

The U.S. Environmental Protection Agency (EPA), Office of Research and Development, is considering a research and demonstration project for at-sea incineration of hazardous wastes. This project is a joint venture with the U.S. Department of Commerce, Maritime Administration (MarAd), which will provide the required vessel. EPA will undertake the design and installation of the incineration system, and operate the ship for one year intermittently over more than one calendar year period. The intent is then to turn the ship over to a commercial operator.

Thermal destruction of chemical wastes at sea has been shown to be an environmentally acceptable means of disposal.(1,2) However, all currently operating incinerator ships are limited to destruction of homogeneous pumpable liquid wastes only. EPA has recommended that a U.S. Flag incinerator ship be designed and constructed to not only dispose of the accumulation of hazardous materials by present state-of-the-art technology, but also to extend the capabilities of at-sea incineration to include destruction of solid materials, slurries, metal-containing wastes, and low energy content wastes. Research and development tests, as well as operational destruction of wastes to show proof of concept, are intended as part of the demonstration project.

1.2 *OBJECTIVES*

The objectives of this task are to conduct an engineering study assessing the key aspects of at-sea incineration, and to prepare a study report on these findings. An engineering evaluation was performed of the total shipboard incineration system, in several alternative forms, including all phases of waste disposal from waste selection to final disposition of any effluent, ash, or residues produced. Areas of consideration were limited to handling and processing of wastes on the ship itself, and did not include land-based activities such as waste collection, transportation and storage, or loading of wastes onboard the ship.

This report presents the results of a conceptual design study, including:

- Assessment of basic incinerator devices potentially applicable to shipboard incineration of liquids, slurries, solids
- Selection of wastes suitable for incineration at sea
- Discussion of destruction efficiency requirements and combustion characteristics of different waste types
- Description of alternative waste feed systems for liquids, slurries, and solids onboard ship
- Evaluation of candidate emission control devices
- Requirements for shipboard laboratory support
- Integration of incineration systems onboard ships of various sizes and waste capacities
- Projected costs and delivery times for incineration and feed system components; and for sampling, monitoring and analysis equipment
- Requirements for environmental monitoring
- Opportunities for shipboard R & D evaluations of waste destruction efficiency and incineration system components.

2. FINDINGS, CONCLUSIONS, RECOMMENDATIONS, AND COSTS

The following findings, conclusions, and recommendations have been developed from this engineering study of the key aspects of at-sea incineration.

2.1 FINDINGS AND CONCLUSIONS

1) Liquid injection incineration represents the only technology well proven at sea for destruction of hazardous wastes.

2) Rotary kilns are the most universal incinerators available, capable of destroying liquids, slurries, tars and solids, separately or combined.

3) Although widely utilized on land, rotary kilns have not been used on ships, and would require modifications for shipboard operation.

4) The rotary kiln in conjunction with a liquid injection incinerator is the most versatile combination for thermal destruction of a wide variety of hazardous wastes.

5) Fluidized bed and molten salt reactors are both susceptible to bed material shifting due to ship motion; spills of molten salt would be dangerous onboard ship.

6) Fluidized bed, molten salt, multiple hearth, multiple chamber, and starved air incinerators are all limited in operating temperatures and waste type handling capability compared to the rotary kiln.

7) Emission control devices which may be necessary for incineration of certain wastes, although commonly used with land based incinerators, have many limitations for shipboard operation.

8) A dedicated shipboard laboratory is required to provide operational safety through analysis to detect waste constituents in the shipboard environment, and for verification of waste destruction efficiency.

9) Environmental monitoring during at-sea incineration is required to ensure personnel safety and to protect the environment.

10) A U.S. incineration ship offers many opportunities for research and development in hazardous waste incineration.

2.2 RECOMMENDATIONS

1) The recommended system for incineration of both solid and liquid hazardous wastes at sea is a rotary kiln coupled to a liquid injection incinerator.

2) Two or more identical liquid injection incinerators, depending upon the size of the ship selected, should be utilized for destruction of liquid wastes.

3) A single rotary kiln should be installed in combination with one of the liquid injection incinerators for R&D evaluation before additional kilns are added.

4) Liquid wastes should be stored in gas blanketed, lined tanks. Flowmeters are recommended for monitoring liquid waste feed rate to each incinerator burner.

5) 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 onboard ship. Use of 55 gallon drums and shredding operations onboard ship are not recommended.

6) The molten salt bath should be considered for R & D evaluation either as a scrubber or combination incinerator/scrubber because it requires no pre-quenching, while removing high levels of particulate and gaseous emissions, including trace metals. Risks associated with spills of molten salt onboard ship must be evaluated.

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

8) A shipboard laboratory should be provided for analysis of organics. Equipment should include a gas chromatograph with flame ionization and electron capture detectors.

9) Space should be provided on the ship for research and development of additional incinerators and emission control devices.

2.3 ESTIMATED COSTS

1) Estimated cost of a rotary kiln incinerator specially designed to withstand the pitch and roll of shipboard operation is $900,000 or $1,119,000 installed. Design and fabrication would require 12 to 18 months.

2) Estimated cost of each liquid injection incinerator designed for shipboard application is $2,500,000 or $3,812,000 installed. Design and fabrication would require 18 to 24 months.

3) Waste feed system costs include $300 for each liquid waste pump, $5,500 for each liquid waste ultrasonic flowmeter system, $1000 for each bulk material container for solid wastes, and $18,000 for a remote operated container lifting and discharge fixture with vibrator. All of these components could be delivered in less than 6 months.

4) Estimated installed costs of emission control devices applicable to hazardous waste incineration aboard ship are $600,000 for a dry electrostatic precipitator and $1,050,000 for a fabric filter. Delivery times would be 12 to 18 months.

5) Estimated installed costs for other emission control devices include over $1,000,000 for a molten salt scrubber and from $83,000 to $441,000 for various types of wet scrubbers. Wet scrubbers could be delivered in 6 to 12 months. An experimental molten salt scrubber would require 12 to 18 months delivery time.

6) Sampling equipment (traps, probes) is estimated to cost $78,000 and require 8 to 12 weeks for delivery.

7) Monitoring equipment (analyzers, regulators, recorders) will cost $108,280 and require an average of 6 to 8 weeks for delivery.

8) Analysis equipment (chromatographs, benches, hoods, glassware) is estimated at $75,027 with 6 to 8 weeks for delivery.

3. CONCEPTUAL DESIGNS

3.1 FUNDAMENTALS OF WASTE INCINERATION

Incineration is a deliberate, controlled combustion process in which organic wastes (including inorganic constituents) are reacted with oxygen at high temperature to produce water, carbon dioxide, and other partial and ultimate oxidation products. Incineration is applicable to virtually all organic compounds if sufficiently high temperature, oxygen concentration, mixing, and residence time are provided and maintained. Under proper operating conditions, organic wastes can be totally converted to oxidized gases, and inorganic substances are converted to ash. In any real incinerator system, trace quantities of products of incomplete combustion (PICs) will be formed. If proper operating conditions are not maintained, the combustion gases will contain excessive amounts of PICs such as smoke, carbon monoxide, gaseous hydrocarbons, tars, and other compounds. Further, the ash will also contain unburned and partially converted organic compounds.

It is the unavoidable presence of PICs (or daughter products) and unburned waste constituents in incinerator process effluent streams that necessitates monitoring of these streams. Monitoring is described in Section 6.

Two generally used performance measures for incineration are destruction efficiency (an equivalent term gaining in use is destruction and removal efficiency, DARE) and combustion efficiency.

- Destruction efficiency has conventionally been defined (1,2) as:

$$DE = 100 \left[\frac{(\text{Fed}) - (\text{Emitted})}{(\text{Fed})}\right] \qquad (1)$$

where: DE = destruction efficiency in percent.

(Emitted) = Emission rate (e.g., mg/sec) of a waste species near the exit plane of the stack and in other process effluent streams, e.g., scrubber water and solid residue stream.

(Fed) = Feed rate of a waste species expressed as a rate (e.g., mg/sec).

- Combustion efficiency is defined (3) as:

$$CE = 100 \left[\frac{(CO_2)}{(CO_2) + (CO)}\right] \qquad (2)$$

where: (CO_2) = Concentration of CO_2 in the stack gas near the exit plane of the stack.

(CO) = Concentration of CO in the stack gas near the exit plane of the stack.

Gaseous, liquid, and solid wastes can all be disposed of by incineration if the system is properly designed for these waste forms. This section, however, covers only incineration of liquid and solid wastes. Mechanisms involved in combusting these waste forms and how they relate to achieving adequate destruction and combustion efficiency are described in the following subsections.

3.1.1 Combustion of Liquids and Solids

Combustion, the high temperature reaction of organic materials with oxygen, occurs only in the vapor phase. Therefore, before combustion can occur, the waste constituents must be vaporized. Conceptual models of combustion of liquids and solids are described below.

3.1.1.1 Combustion of Liquids

When liquid waste is introduced into the combustion chamber, constituents are vaporized by radiative heat transfer from hot combustion gases. The rate of vaporization depends on the diffusion rate of a constituent from the bulk liquid to the surface and from the surface to the combustion chamber environment where the oxidation reaction process of the constituent can be completed. The diffusion rates are dependent on temperature, which is a function of the heat transfer rate, and the surface area of the liquid. Surface area is typically maximized by atomizing the waste into droplets. The smaller the droplet size, the greater the surface area. Smaller droplet diameters also increase heat transfer and vaporization rates, thus reducing the required combustion chamber volume for a given waste feed rate.

In the gaseous state, waste constituent molecules mix with oxygen in the air supplied to the process and continue to gain in temperature by exposure to hot combustion gases. When the waste molecules reach ignition temperature, chemical bonds break, and reaction with oxygen begins. In fundamental terms, ignition occurs when the necessary activation energy (that energy necessary to initiate bond breaking) has been supplied.

The entire combustion process occurs because the energy of the combustion products is lower than the energy of the reactants. Thus, heat is released during combustion (i.e., reactions are exothermic). The amount of heat released by the combustion reactions must exceed the heat required for vaporizing the waste and the heat required for activation energy, or the process will not be self-sustaining. If the combustion reactions are not sufficiently exothermic, auxiliary fuel must be fired with the waste to supply the additional needs. These energetic relationships are illustrated in Figure 1 for the simple reaction

$$A \rightleftarrows X' \rightleftarrows B \qquad (3)$$

where A is a waste molecule

X' is the activated complex in which bonds are breaking

B is the product

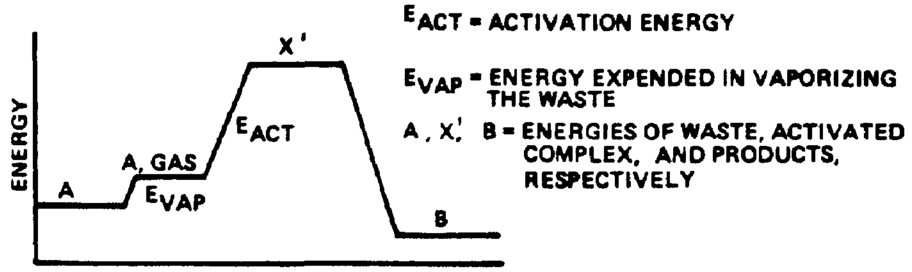

Figure 1. Schematic of energetic relationships between waste and product molecules in combustion

3.1.1.2 Combustion of Solids

The processes involved in combustion of solids are more complex and harder to model than these involved in liquid waste combustion. Again, combustion occurs only in the vapor phase. Thus, waste constituents must diffuse to the surface of the solid and then diffuse out into the combustion chamber environment for combustion to occur. Conceptually, combustion of solids involves a series of repetitive stages(4,5) : 1) diffusion and burnout of volatiles near the surface, and 2) burnout of residual surface and exposure of fresh surface. The larger the solid particles, the greater the number of times this sequence is repeated, and the longer the residence time required to complete the combustion process. Figure 2 (adapted from Figure 68 of Reference 5) is a schematic illustration of the combustion of a solid.

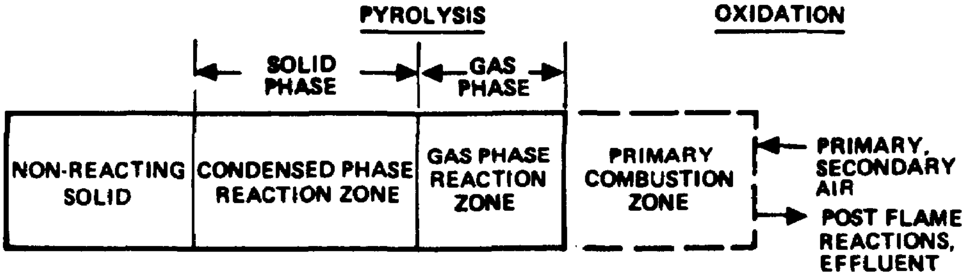

Figure 2. Schematic of combustion of solids

When exposed to high temperatures in an incinerator, organic solids are converted to gases by a variety of processes, including cracking, destructive distillation, pyrolysis, and partial oxidation. Volatile species, either originally present in the solid or formed by the above processes, volatilize from the solid and then burn in the vapor phase. The rates at which these processes occur depend on the temperature and heat release in the incinerator, the composition of the solid waste, the heat transfer to the solid, the diffusion rates, and the exposed surface area. Mechanical agitation is usually supplied to a solids incinerator to provide continuously fresh unreacted surface.

Retention time must be sufficiently long that the solids reach ignition temperature. Residence time in the gas phase is also important, so that volatilized species can be completely combusted.

3.1.2 Waste Properties Affecting Combustion

Physical, chemical, and thermal properties of a waste affect combustion. These properties are discussed in this section.

3.1.2.1 Composition

Chemical properties which should be determined in order to incinerate a waste include:

- Elemental composition - C, H, N, O, S, Cl, and P.
- Ash content and fusion temperature.
- Moisture content.

The elemental composition (i.e., C, H, N, O, S, Cl, and P) should be determined in order to calculate stoichiometric combustion air requirements and to predict combustion gas flow rate and composition. Determination of sulfur, halogen, and phosphorous contents is important in evaluating air pollution and environmental impacts. If the waste contains insufficient hydrogen to form water and hydrogen halides, auxiliary fuel or steam injection is needed to supply the necessary hydrogen.

The ash content of the waste must be known in order to determine if the ash handling capability of the system is sufficient and to assess particulate removal requirements of an air pollution control system. Some generic types of incinerator systems cannot handle high ash content wastes (e.g., liquid incinerators). Also, some types of incinerator designs cannot handle fusible ash (e.g., fluidized bed types).

The moisture content of the waste affects the heat balance in the combustion chamber. When halogens are present, water serves as a hydrogen source; otherwise, water is inert. Energy is consumed in heating and vaporizing moisture in the waste, and moisture contributes to gas handling requirements on the system. High aqueous content wastes will not normally sustain combustion without cofiring auxiliary fuel or high heat content waste. Existing incinerator ships have multiple liquid burners and can evaporate water through one burner while burning wastes through the other burners.

Other chemical characteristics of the waste also affect the design and/or operation of an incinerator. These include metals content and the presence of toxic organic compounds. Metals are not usually present in organic wastes at concentrations high enough to affect stoichiometric air requirements. Metals do contribute to particulate formulation, and many metals, including some toxic heavy metals, are concentrated in smaller particulates. EPA's Ocean Dumping regulations (40 CFR 227.6 (a)) prohibit ocean dumping (or transportation for dumping) of wastes containing organohalogen compounds, mercury and mercury compounds, and cadmium and cadmium compounds in quantities above trace levels. Trace levels are defined as levels which will not cause significant undesirable effects. Alkali metals (e.g., sodium, potassium) can cause degradation of refractory linings. (The M/T Vulcanus will not evaporate large quantities of sea water because this causes a glazing of the refractory linings of her incinerators.)

3.1.2.2 Heat Content

The heat content, or heating value, of a waste is the quantity of heat released when the waste is burned and is expressed as kcal/kg or Btu/lb. All organic compounds have a finite heat content. Knowledge of the heat content of the wastes to be burned is important in designing and operating an incineration system and in determining the need for auxiliary fuel.

Normally, a minimum heating value of 4400 to 5540 kcal/kg (8,000 to 10,000 Btu/lb) is necessary to sustain combustion. However, this is only a rule of thumb. Some materials with heat contents of 5540 to 6090 kcal/kg (10,000 to 11,000 Btu/lb) will not support combustion without supplemental firing, while materials with heat contents as low as 2490 to 2990 kcal/kg (4,500 to 5,400 Btu/lb) have been burned in high performance boilers. Below about 4,400 kcal/kg, auxiliary fuel firing is normally required.

The moisture content of a waste, as described earlier, reduces the heat content. Also, the heat content of a waste decreases as the chlorine (or other halogen) content increases. Wastes with chlorine contents greater than about 70 percent normally require auxiliary fuel. 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 (1).

The heat contents of various wastes vary tremendously. In order to reduce the adverse effects (e.g., flame flickering, flame outs) of varying heat content, it is customary practice to provide some minumum value. For example, the heat content is determined for wastes going into each of the 15 covered tanks onboard the M/T Vulcanus. Feed rates from the tanks are metered and adjusted in proportion to heat content to achieve stable incinerator operation.

3.1.2.3 Physical Properties

In addition to the chemical composition and heat content of a waste, information about its physical form and properties is necessary to determine if it is compatible with a particular incinerator design. As discussed in Section 3.3, each generic incinerator type is limited in terms of the physical form of waste it can handle or tolerate. Feed systems and materials handling are discussed in Section 3.4.

Both the size and form of solids must be considered. For example, feed system, retention time, incinerator type, and ash disposal requirements differ for powdered, granular, pelletized, bulk, or containerized wastes. For a shipboard incineration system, it would be desirable to have wastes of minimal ash content. The system should be designed so that high ash solids do not pass into the liquid incineration or afterburner sections of the system. If ash is not collected before the liquid injection or afterburner sections, these sections would have to be sized accordingly. Further, the ash would have to be nonfusible at the higher temperatures of these parts of the system. If ash is collected before the liquid injection system, the temperature and retention time would have to be sufficient to render the ash devoid of organic compounds.

If the waste is a slurry, sludge, or semi-solid, it is necessary to decide whether it should be handled as a liquid or a solid. Treating the waste as a liquid would involve determining whether its viscosity would allow it to be pumped and whether solids could be kept in suspension. The particle size, abrasiveness, and viscosity are considerations if the waste is to be injected through an atomization burner.

Kinematic viscosity is the chief physical property to be considered in the incineration of liquids. Kinematic viscosities of less than about

750 Saybolt Seconds Universal (SSU) are required for proper atomization although liquids with kinematic viscosities as high as 10,000 SSU can be pumped. Viscosity is strongly dependent on temperature, and it should be determined at the expected injection temperature. The levels of solids in a liquid must be determined because they can cause plugging and erosion of injection nozzles, as well as ash buildup and incomplete burnout in the combustion chamber.

Other characteristics such as extreme toxicity, corrosiveness, odor, thermal stability, chemical stability, pyrophoric properties, shock sensitivity, etc., need to be considered. However, because these properties are highly waste-specific, they can only be treated here in the most general way. Wastes that are pyrophoric, shock sensitive, or chemically or thermally unstable should probably not be considered for at-sea incineration because of the potential hazards of the extra handling and harsh shipboard environment involved. Materials of construction of the ship (i.e., tanks and pipes) need to be evaluated for their ability to withstand corrosive wastes. Extremely toxic or odorous wastes can be burned at sea if adequate attention is given to handling, personnel protection, etc.

3.1.3 Combustion Air

The most basic requirement of any combustion system is sufficient air to oxidize the feed material completely. The stoichiometric or theoretical air requirement is calculated from the chemical composition of the feed material. Carbon dioxide, water, and HCl are the major products formed from the combustion of organochlorine wastes. Nitrogen (which is nonreactive) is the major component of the combustion effluent. In any actual system, however, trace quantities of carbon monoxide, free chlorine (Cl_2), nitrogen oxides, and other PICs will also be formed. Because these species are formed only at trace levels, it is not necessary to consider them in calculating combustion air requirements and gas flow rates. If the waste contains significant concentrations (e.g., 5% or higher) of sulfur or phosphorous, it is necessary to consider these elements.

All incineration systems need to be operated with some excess air (air in excess of stoichiometric requirements) because in actual system operation air and waste are not perfectly mixed and are not instantaneously burned. The mandatory regulations of the London Dumping Convention (11) require a minimum excess oxygen level of 3%. Required levels of excess air depend on the type of incinerator (Section 3.3) and on the type of waste being burned. In practice, excess air levels vary from 20 to 300%, and levels of 50 to 100% are most common.

The amount of excess air required depends on the degree of air/waste mixing achieved in the combustion zone (a function of incinerator type and design), secondary combustion requirements, and the desired degree of combustion gas cooling. In general, excess air requirements vary inversely with the degree of mixing achieved in the incinerator and the surface-volume ratio of the waste particles or droplets. If there is a secondary combustion zone (e.g., in a rotary kiln - liquid injection system), excess air requirements are higher. Because excess air is chiefly a diluent, it absorbs heat and reduces the temperature in the incinerator. Temperature reduction may be desirable when high heat content, readily combustible wastes are incinerated in order to reduce degradation of refractory linings. Conversely, when a lower heat content waste is burned, reduced excess air levels should be used in order to help increase the incinerator temperatures. In general, it is desirable to minimize excess air feed rates (consistent with adequate combustion and destruction efficiency) in order to minimize gas handling requirements of downstream equipment and minimize fan size and power requirements.

Combustion air requirements are used in incinerator system design to size the induced draft fans that are the prime gas movers in the system.

3.1.4 Temperature, Residence Time, and Mixing

Temperature (a function of heat release), residence time, and mixing are three of the four primary variables affecting incineration efficiency. They are described in this section. The fourth primary variable, oxygen, was described in Section 3.1.3.

3.1.4.1 Temperature

In designing, evaluating, or operating an incineration system, there are four aspects or questions about temperatures that should be considered:

- Is the temperature high enough to raise all waste components above their ignition temperatures?

- Is the temperature high enough for complete destruction to occur at the residence time of the system? (For a fixed volume system, temperature and residence time are inversely proportional.)
- Is the required temperature within normal limits for the type of incineration system?
- At what locations in the system is the temperature to be measured?

As discussed in Section 3.1.2, waste combustion requires a temperature (and a heat release rate) sufficiently high to raise waste component temperatures above their ignition level. It was also described in Section 3.1.2 that heat transfer, mass transfer to the vapor phase by diffusion, and mixing all required finite time. Thus, temperature requirements must be evaluated with respect to the residence in the incinerator. Heat transfer, mass transfer, and mixing rates all increase with increasing temperature, thereby lowering the required residence time. If the residence time of the incinerator type is extremely short, temperatures well in excess of those required for ignition may be required. In general, incinerator types used for hazardous waste operate well in excess of waste ignition temperatures.

The current state-of-the-art combustion theory does not allow a theoretical calculation of temperature-residence time requirements for complete waste destruction. However, there are certain laboratory experiments which can produce accurate measurements of temperature-residence time requirements. Duvall and Ruby (12) used a quartz tube reactor in which both temperature and residence time could be controlled and varied to study destruction requirements for PCBs. This system has been further refined under EPA sponsorship into the Thermal Destruction Analysis System (TDAS). The most practical means of assessing adequate temperature-residence time requirements is an examination of these parameters found to be satisfactory in the destruction of the same or similar waste on the same or similar type and size of incinerator. Although the TDAS provides guidelines, trial burns will be necessary for some wastes, including many solids.

After determining temperature requirements, it is necessary to determine whether or not they are within normal limits for the incinerator type and whether or not they can be attained with possible firing conditions. In general, incinerator temperatures range from about 800°C (combustion stage of multiple hearth incinerator or a fluidized bed) to about 1650°C (certain special liquid injector incinerators).

After determining that the incinerator system can withstand the required temperatures, it is necessary to specify the location(s) at which temperatures will be measured. Specifying the temperature measurement location(s) directly affects the residence time because residence time is specified at a particular temperature (see Section 3.1.4.2 for further discussion). There is great variation in temperature in an incineration system. It is highest in the flame zone, lower at the walls of combustion chambers, and decreases toward the gas exit after the combustion chamber(s). Ideally, temperature would be measured in the bulk gas flow at a point after which the gases have traversed the combustion chamber volume that provides the specified residence time for the incinerator. For a multiple unit system (e.g., rotary kiln coupled with a liquid injection burner), temperature in both units should be measured. In practice, most operators establish a correlation between flame temperature (optical pyrometer) and a wall temperature (thermocouple) and thereafter monitor wall temperatures.

3.1.4.2 Residence Time

Residence time (dwell time or retention time) is defined as the length of time the waste and combusting gases are exposed to and maintained at the high or specified temperature necessary for complete destruction.

The usual method of calculating residence time is to specify the combustion gas flow rate, e.g., m^3/sec, at the desired operating temperature (measured at the combustion chamber outlet) and to divide by the combustion chamber volume, V,m^3. Residence time can be calculated from:

$$t\ (\text{sec}) = \frac{V\ (m^3)}{Q\ (m^3/\text{sec})} \qquad (4)$$

Where V = Volume traversed by combustion gases
at the required temperature, and

$$Q = \frac{(0.79)}{X_{N_2}} \times \frac{(\ T\ )}{273} \times \begin{matrix}\text{(Stoichiometric Air)} \\ \text{Flow at 0°C}\end{matrix} \times (1 + \% \frac{\text{Excess Air)}}{100} \qquad (5)$$

In actuality, the volume through which the combustion gases flow (V) after they have been heated to the required temperature is smaller than the total combustion chamber volume (V_T). Thus, the chamber volume used in the residence time calculation above is smaller than the total chamber volume. However, it is difficult to determine the proper volume, and this is why thermocouple location is important as discussed in Section 3.1.4.1. The combustion gas flow rate is the sum of flow rates of combustion products (calculated from waste stoichiometry) and excess air. An upper bound on residence time can be calculated using the total combustion chamber volume (V_T) and the combustion gas flow rate, Q:

$$t\ (\text{sec}) = \frac{V_T\ (m^3)}{Q\ (m^3/\text{sec})} \qquad (6)$$

Residence times calculated from equations 4 or 6 will not be rigorous and should be used only for comparison purposes.

In solid waste incineration, the retention time of the solids as well as the gases, must be considered in order that residual hazardous compounds in the solids be destroyed as completely as possible.

3.1.4.3 Mixing

Temperature, oxygen, and residence time requirements discussed in preceding sections all depend to some extent on the degree of waste-air mixing achieved in the combustion chamber. The degree of mixing is difficult to express in absolute terms because of limitations in state-of-the-art combustion theory.

In liquid waste incinerators, the degree of mixing is fixed largely by: 1) the specified burner design which determines how the waste and primary combustion air are mixed, 2) the gas flow patterns in the combustion chamber, and 3) turbulence. In general, liquid injection burners are designed to produce droplets as small as possible. This increases the surface-to-volume ratio which enhances the rate of heat transfer to the waste, the rate of volatilization of the waste, and the mixing of waste vapor and air. Mixing in the combustion chamber is enhanced by making the gas change directions and by designs which promote turbulence.

3.2 WASTE TYPES

3.2.1 Sources and Characteristics

The sources of chemical wastes are extremely widespread and the volume of industrial hazardous waste expected to be produced in 1980 has been estimated to be at least 57 million metric tons, of which 60% is estimated to result from the chemical industry.[†] Much of the chemical industry waste can be assumed to be incinerable. Thus the volume of waste produced annually, along with waste currently stockpiled or from clean-up of old dump sites, appears to be more than adequate to support the operation of an incineration ship. Chemical wastes may originate from the routine operations of manufacturing processes, intermediate manufacturers and end product users, as well as nonroutine events such as spills and accidents.

Chemical wastes which are most likely to be destroyed by incineration are organic chemicals. The manufacturing sources of these wastes will largely follow the location pattern of the chemical industry. Thus it is expected that the major concentration of primary sources will be along the Gulf Coast and the eastern seaboard. Sources of wastes involving specialty chemicals and pesticides manufacture can also be readily pinpointed because of the relatively small number of manufacturers. Wastes from intermediate or secondary sources will be much more widely dispersed but will still tend to follow the location pattern typical of the chemical and petrochemical industry. Source of wastes from end product users (e.g., PCB-containing electrical capacitors) can also be expected to be widely dispersed.

In classifying chemical wastes for thermal destruction, it has been found useful to categorize them on the basis of their elemental chemical composition (6). Within each class of compounds with the same elemental composition, subclasses may be developed based on properties (e.g., physical form, chemical composition, heat content, viscosity, etc.) which are related to specific burning characteristics. Examination of

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[†] "Everybody's Problem: Hazardous Waste," EPA/SW-826, 1980, pp 1,14,15.

chemical waste streams shows that those suitable for thermal destruction fall into one of the following four classes:

1) C-H and C-H-O compounds, yielding CO_2 and H_2O on complete combustion
2) C-H-N and C-H-O-N compounds, yielding CO_2, H_2O and nitrogen oxides
3) C-H-Cl and C-H-O-Cl compounds, yielding CO_2, H_2O and HCl (gas)
4) Other wastes including organic wastes containing both nitrogen and chlorine, organic wastes containing sulfur, organic wastes containing bromine, organic wastes containing fluorine, organic wastes containing phosphorus, organic wastes containing silicon, and varied wastes not included in the first three major classes

Typical waste streams in each of these four waste classes are listed in Table 1. The heating value for each waste stream has been denoted either low (less than 2800 kcal/kg), medium (2800 to 5600 kcal/kg), or high (greater than 5600 kcal/kg), as the precise heat content of most waste streams is not well-defined or consistent. It is important to recognize that waste stream descriptions obtained from the literature, or supplied by a plant, cannot be considered reliable until an actual sample of the waste stream which is to be delivered has been obtained and analyzed. For example, still bottoms (i.e., residues from distillation towers used in chemical manufacturing) may be liquids or tars, depending upon the stage at which distillation is stopped. This, in turn, may be entirely at the discretion of the operator.

3.2.2 *Suitability for Incineration*

Assuming that the wastes listed in Table 1 might be destructed in any of four candidate destruction processes (i.e., liquid injection, rotary kiln, molten salt, or fluidized bed), the processes and wastes were matched according to the following criteria:

- Physical form of waste: gas, liquid, slurry, sludge or solid
- Temperature range required for destruction: above $1090^{\circ}C$ ($2000^{\circ}F$), 1090° to $760^{\circ}C$ (2000° to $1400^{\circ}F$), 760° to $370^{\circ}C$ (1400 to 700°F), or below 370°C (700°F)

- Ash: nonfusible, fusible, and/or metallic
- Waste heating value: Less than 2800 kcal/kg (5000 Btu/lb), 2800 to 5600 kcal/kg (5000 to 10,000 Btu/lb), or above 5600 kcal/kg (10,000 Btu/lb).

No attempt was made in this waste suitability matching to consider the appropriateness of the candidate processes for the at-sea application. This consideration is discussed elsewhere in this report (see Section 3.3.6). A comparison of the characteristics of each waste with the candidate destruction processes was performed previously (6) using detailed forms as illustrated by the example given in Table 2. The results of this comparison are summarized, along with the waste descriptions, in Table 1. The degree of suitability is indicated on a scale of 0 to 2 with "0" being totally unsuitable, "1" being slightly suitable (i.e., suitable only if waste is mixed, diluted, heated, etc.), and "2" being totally suitable.

Table 1. WASTE CHARACTERISTICS AND APPROPRIATE THERMAL DESTRUCTION PROCESSES

Waste Class	Hazardous Waste Stream	Waste Stream Characteristics			Potentially Applicable Candidate Destruction Processes			
		Constituents	Physical Form	Heating Value	Liquid Injection	Rotary Kiln	Fluidized Bed	Molten Salt
1	Ethylene glycol manufacturing wastes	Mixture of water and glycols	Liquid	Low	2	2	2	2
	Off-specification isoprene	Unstable oxidizable liquid containing isoprene	Liquid	High	2	2	2	2
	Off-specification phenol	90 to 92% or 82 to 84% phenol containing some cresols and water	Liquid	High	2	2	2	2
	Evaporator residue from the cumene process for phenol manufacture	Polymeric matter containing acetophenone (1.68 wt %), phenol (0.66 wt %), and cumylphenol (0.75 wt %)	Tar	Medium	0	2	0	1
	Ethylene manufacturing wastes	Water separable oil containing heavy polymeric oils with traces of aromatics	Liquid	High	2	2	2	2
	Organic peroxide manufacturing wastes (from dicumyl peroxide manufacture)	Organic waste stream containing dicumyl peroxide and other aromatic diacyl peroxides in a mixture of alcohols, phenols, cumene alcohol derivatives and other unknown reaction by-products. High sodium content.	Liquid	High	1	1	2	2
	Still bottom from acetaldehyde production and by-product recovery operation	Liquids containing various aldehydes	Liquid	High	2	2	2	2
2	Steam still bottoms from aniline and alkylated phenol production	Mixture of phenolic compounds and aniline derivatives	Tar	Medium	0	2	0	1
	Catch basin grease, nitrile pitch from production of surface active agents	Fatty alkyl acids, nitriles, and amines (C-8 to C-18 chain length), water (20%)	Solid	Medium	0	2	0	1
	Carbamate pesticides (carbaryl)	Naphthol residues containing approximately 1% b-naphthol	Liquid	High	2	2	2	2
	Reactor tar bottoms from adiponitrile manufacture	Tars containing phosphoric acid (4.8 wt %) and adiponitrile	Tar	Medium	0	2	0	1

Rating Scale: 0 - Totally Unsuitable
1 - Slightly Suitable (i.e., with dilution, heating, etc.)
2 - Totally Suitable

Table 1. (Continued)

Waste Class	Hazardous Waste Stream	Waste Stream Characteristics			Potentially Applicable Candidate Destruction Processes			
		Constituents	Physical Form	Heating Value	Liquid Injection	Rotary Kiln	Fluidized Bed	Molten Salt
2	Acrylonitrile manufacturing wastes	Heavy ends containing acrylonitrile (CH_2 = CHCN), acetonitrile (CH_3CN), HCN and probably polymeric material	Tar	Medium	0	2	0	1
	TDI manufacture reactor tar bottoms	Wastes in tar are cyclic biureates and a complex mixture of heavy organics; no analysis available. However, effluent gas from incinerator has the following composition: CO_2, 33.3%; H_2O, 26%; N_2, 38.8% O_2, 5%; HCl, small amounts	Tar	Medium	0	2	0	1
	Diphenylamine (DPA) manufacture	Tars containing cyclic biureates (50%) and heavy organics (50%)	Tar	Medium	0	2	0	1
	Waste from toluenediamine (TDA) production from dinitrotoluene (DNT)	Refining still residue containing TDA and other isomers of TDA	Thick Liquid	Medium	0	2	2	2
	DNT/MNT mix from DNT production	Sludge containing MNT (mononitrotoluene), DNT and other organic solids	Sludge	Medium	0	1	1	2
	Phenylamine tar wastes	Tars containing aniline (30%), nitrobenzene (5%), cyclic biureates (33%) and heavy organics (32%)	Tar	Medium	0	2	0	1
	Wastes from polymer polyol production from polymerization of styrene with acrylonitrile	Liquid containing unreacted styrene and acrylonitrile	Liquid	High	2	2	2	2
3	Organic chemical capacitor, transformer production wastes containing PC9's and alpha methylstyrene	Waste containing PCB's and alpha methylstyrene, in capacitors	Solid	Low	0	2	0	1
	Epichlorohydrin manufacturing wastes	Heavy ends from fractionation column containing dichlorohydrin, epichlorohydrin, allyl chloride, and polymeric material	Tar	Medium	0	2	0	1

Rating Scale: 0 - Totally Unsuitable
1 - Slightly Suitable (i.e., with dilution, heating, etc.)
2 - Totally Suitable

Table 1. (Continued)

Waste Class	Hazardous Waste Stream	Waste Stream Characteristics			Potentially Applicable Candidate Destruction Processes			
		Constituents	Physical Form	Heating Value	Liquid Injection	Rotary Kiln	Fluidized Bed	Molten Salt
3	Wastes from perchloroethylene production	Still bottoms containing perchloroethylene, carbon tetrachloride, hydrocarbons and other chlorinated hydrocarbons	Liquid	Medium	2	2	2	2
	Hexachlorocyclopentadiene manufacturing wastes	Mixture of chlorinated toluenes, pentanes, and benzenes	Liquid	Medium	2	2	2	2
	Phenolic tar from 2,4-D manufacture	Typical composition: 2,4-dichlorophenol (8%), 2,6-dichlorophenol (2%), 2,4,6-trichlorophenol (35%), phenolic resins (55%)	Tar	Medium	0	2	0	1
	Organic pharamaceutical wastes	Liquid wastes containing mixture of organics such as phosgene, chlorobenzene, toluene, methanol methylene dichloride, tetrachloroethane	Liquid	Medium	2	2	2	2
	Chlorotoluene production wastes	Tars containing benzoyl chloride residues	Tar	Medium	0	2	0	1
	Phenolic tar from MCPA manufacture	Typical composition: 4-MCPA (20%); 6-MCPA (20%), phenolic resins (60%)	Tar	Medium	0	2	0	1
4	Nitrochlorobenzene manufacturing wastes	Heavy ends and tars from orthochloronitrobenzene vacuum distillation	Tar	Medium	0	2	0	1
	Amiben manufacturing wastes	Mixture of 90% water, 5% isomer, and 5% NaCl and Na_2SO_4	Liquid	Low	0	1	2	2
	Dichloroaniline still bottoms	Mixture of isomers; containing 25% chlorine	Solid	Medium	0	2	2	2
	Alkyl and aryl sulfonic acid manufacturing wastes	Emulsified oil and sulfones	Liquid	Medium	2	2	2	2
	Mercaptobenzothiazole (MBT) manufacturing	Tarry mixture of 75% organic sulfur containing heterocyclics, 15% sulfur and 10% water	Tar	Medium	0	2	0	1

Rating Scale: 0 - Totally Unsuitable
1 - Slightly Suitable (i.e., with dilution, heating, etc.)
2 - Totally Suitable

Table 1. (Continued)

Waste Class	Hazardous Waste Stream	Waste Stream Characteristics			Potentially Applicable Candidate Destruction Processes			
		Constituents	Physical Form	Heating Value	Liquid Injection	Rotary Kiln	Fluidized Bed	Molten Salt
4	Dodecyl mercaptan manufacturing wastes	High viscosity liquid	Liquid	High	2	2	2	2
	Fluorinated herbicide wastes	Liquid containing aromatic fluorides	Liquid	Medium	2	2	2	2
	Halogenated aliphatic fumigants (ethylene bromide)	Mixture of brominated organic liquids containing 10-20% dibromopropanol from ethylene bromide manufacture	Liquid	Medium	2	2	2	2
	Urethane manufacturing wastes	Mixture of polyols and phosphate esters	Liquid	Low	2	2	2	2
	Organophosphorus pesticides (Malathion)	Off-specification technical grade malathion	Liquid	High	2	2	2	2
	Tetraethyl orthosilicate wastes	Tetraethylorthosilicate liquid with traces of iodine, alcohol, "genesolu" D	Liquid	Medium	2	2	2	2
	Organometallic Wastes	Complexes of various heavy metals in organic matrices	Liquid	Medium	2	2	2	2
	Contaminated soils from spill and old dump site clean-up	Water and mineral matter mixed with various hazardous organic compounds	Solid	Low	0	2	0	2

Rating Scale: 0 - Totally Unsuitable
1 - Slightly Suitable (i.e., with dilution, heating, etc.)
2 - Totally Suitable

TABLE 2. MATRIX FOR MATCHING WASTES AND INCINERATORS †

WASTE STREAM

CLASSIFICATION: H-C and H-C-0

DESCRIPTION: Evaporator residue from the cumene process for phenol manufacture

HEATING VALUE (CIRCLE ONE)
Above 10,000 Btu/#,
[✓ 5000-10000 Btu/#,]
Below 5000 Btu/#

		FACILITY TYPE								
		WASTE CHARACTERISTIC	LIQUID INJECTION	MULTIPLE HEARTH	ROTARY KILN	CATALYTIC AND THERMAL	MOLTEN SALT	PYROLYSIS	FLUIDIZED BED	WET AIR OXIDATION
GAS				▨				▨		▨
LIQUID	Low Viscosity (Below 500 SSU)			▨				▨		
	High Viscosity (Above 500 SSU)		▨	▨		▨		▨		
SLURRY	Low Viscosity (Below 500 SSU)			▨		▨		▨		
	High Viscosity (Above 500 SSU		▨	▨		▨		▨		
SLUDGE			▨			▨				▨
SOLID	Friable Powder		▨			▨				▨
	Tarry	/	▨	▨	/	▨	/	/	▨	▨
TEMP. RANGE FOR DESTRUCT.	Above 2000°F	/	/	▨	/	▨	▨	/	▨	▨
	1400-2000°F	/		/		▨	/		/	▨
	700-1400°F		▨	▨	▨			▨	▨	▨
	Below 700°F		▨	▨	▨	▨	▨	▨	▨	
OFF GASES	Essentially Oxides of C, H, N	/	/	/	/	/	/	/	/	/
	Contain Halogen, Sulfur, Phosphorus, or Volatile Metals							▨		
ASH	Non Fusible					▨				
	Fusible			▨		▨			▨	
	Metallic					▨				
TOTALS		3	2	2	③	1	3	3	2	1

ADDITIONAL CRITERIA AND REMARKS:

Phenol waste may be too hazardous to be handled at a pyrolysis facility.

Molten salt is not too suitable for handling tarry wastes.

Rotary kiln is selected.

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† Taken from Reference 6.

3.3 INCINERATOR TYPES

Assessments and preliminary sizing and design selections were made of the basic incineration devices potentially applicable to shipboard at-sea incineration of liquids, slurries, and solids. Incinerators commonly used for land-based destruction of hazardous waste - liquid injection, rotary kiln, and fluidized bed - were evaluated first, along with molten salt, a developing technology with potential advantages for shipboard at-sea incineration. All of these incinerators are continuous feed units, rather than batch feed, which provides maximum waste throughput for the size and weight of the unit. Other continuous feed incinerators considered were multiple hearth, multiple chamber, and starved air. Each of these incinerator types are described in the following subsections, and their advantages and limitations for shipboard operation are discussed.

3.3.1 Liquid Injection(1,2,7,8,9,10)

Liquid injection waste incinerators are furnaces fired with liquid fuels which can be the waste itself or an auxiliary fuel, or a combination of both, depending on the heat content and combustion characteristics of the waste. A variety of liquid injection incinerators are commercially available and used widely throughout the manufacturing and processing industries. The units are generally classified as being either horizontal or vertical. The vertical chamber has an advantage in that the incinerator acts as its own stack. Horizontal incinerators can be easily connected to tall stacks. A typical land-based industrial liquid injection horizontal incinerator system operated by General Electric in Pittsfield, Massachusettes is shown in Figure 3. This incinerator is used to destroy polychlorinated biphenyls (transformer oil waste) and chlorinated hydrocarbons from various G.E. plants where they cannot be burned in on-site steam boilers. Figure 4 is a sketch of a vertical liquid injection incinerator, one of two units onboard the M/T Vulcanus,(1,2,7) an incineration vessel chartered by Ocean Combustion Services, B.V., Rotterdam, the Netherlands. This ship has been incinerating European waste in the North Sea since 1972. The Vulcanus has also been successfully used under permit from EPA to

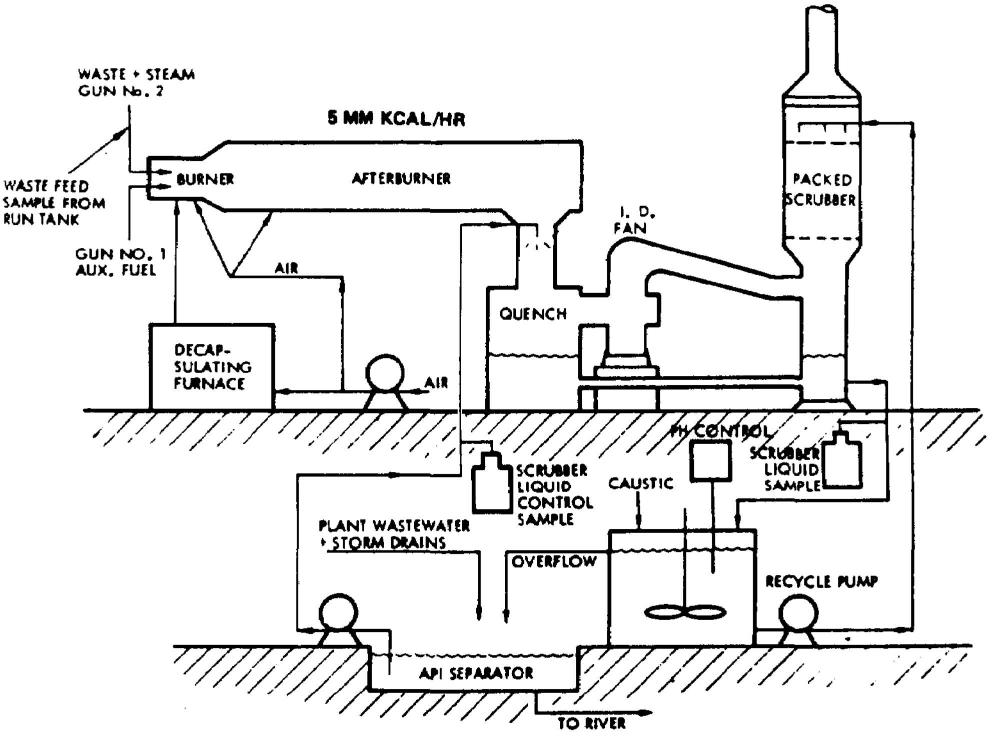


Figure 3. General Electric Liquid Injection Incinerator
(Manufactured by John Zink Co.)

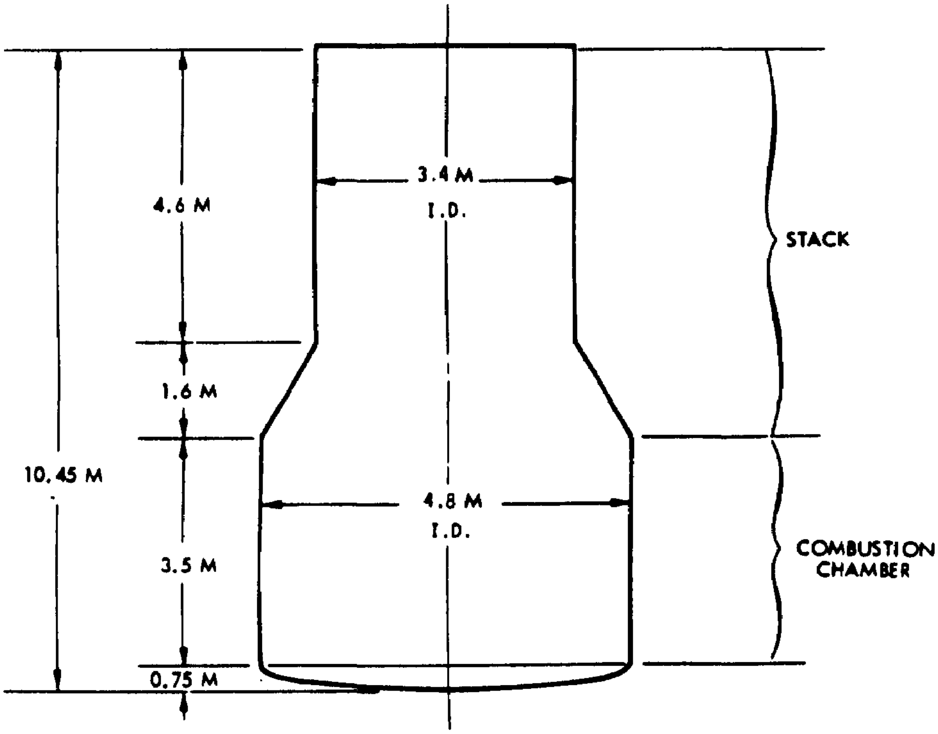


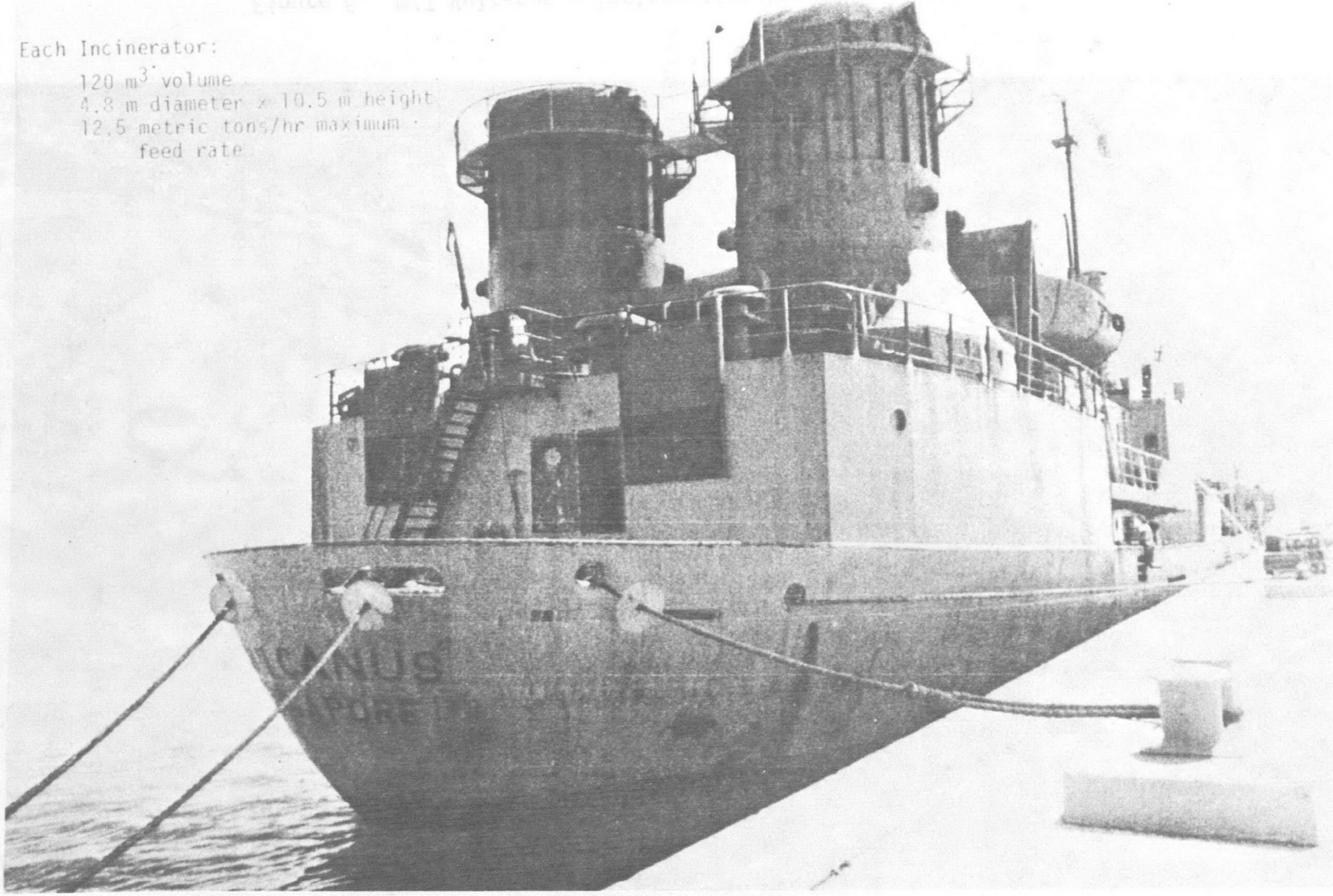
Figure 4. Dimensional Sketch of Vulcanus Incinerator

destroy organochlorine wastes in the Gulf of Mexico and Herbicide Orange in a remote area of the Pacific Ocean. Each incinerator has a capacity of 40 MM kcal/hr. Location of the incinerators onboard the ship is shown in Figures 5 and 6

Liquid injection incinerators are flexible units which can be used to dispose of virtually any combustible liquid waste with a viscosity less than 10,000 Saybolt Seconds Universal (SSU), the maximum practical for pumping. Viscosity can be controlled by solubilizing the waste in a lower-viscosity liquid on shore before transferring the waste to the ship, or by heating the waste feed with in-line heaters on-board ship. However, 200-260°C (400-500°F) is normally the limit for heating to reduce viscosity due to pump limitations. Heating of hazardous materials to higher temperatures may also increase risk onboard ship.

Before a liquid waste can be combusted, it must be converted to the gaseous state. This change from a liquid to a gas occurs inside the combustion chamber and requires heat transfer from the hot combustion product gases to the injected liquid. The heart of any good liquid incinerator is the atmomization device or nozzle (burner). Efficient and complete combustion is obtained only if the waste is adequately divided or atomized and mixed with the oxygen source. To achieve fine enough atomization, the wastes should have a viscosity of 750 SSU or less. Atomization is usually achieved mechanically using rotary cup or pressure atomization systems. Since rotary cup burners can usually accommodate more viscous wastes and some solid material in suspension in the liquid waste, they are used on the Vulcanus. Each incinerator on the Vulcanus has three vortex type rotary cup burners, located as shown in Figure 7. Steam or air pressure can also be used for atomization; however, separate systems to supply pressurized air or steam would have to be provided onboard ship.

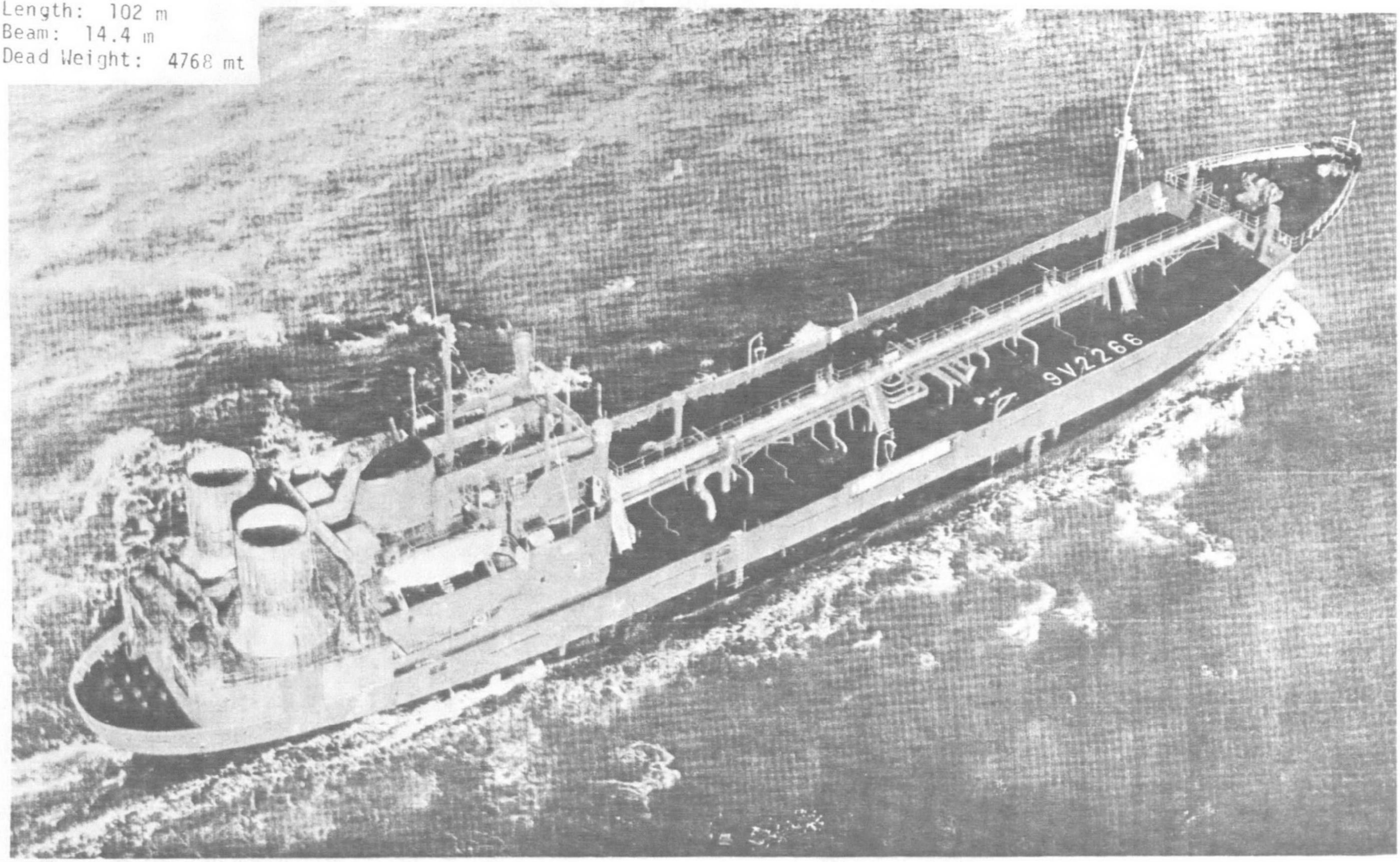
The major components of an incineration system include one or more liquid and/or auxiliary fuel burners, a primary air blower, one or more secondary air blowers, and an emergency relief stack, in addition to the refractory lined combustion chamber itself. Liquid waste incinerators



Each Incinerator:

120 m^3 volume
4.8 m diameter x 10.5 m height
12.5 metric tons/hr maximum
feed rate

Figure 5. M/T Vulcanus Incinerators



Length: 102 m
Beam: 14.4 m
Dead Weight: 4768 mt

Figure 6. M/T Vulcanus - Incineration Vessel

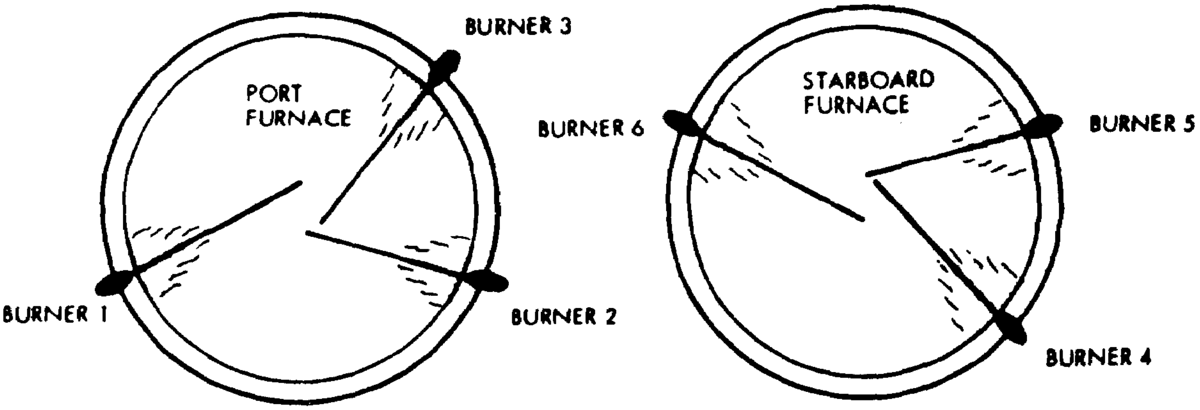


Figure 7. Incineration System — Burner Locations

operate at temperatures ranging between 820 and 1,600°C (1,500 and 3,000°F), depending on the requirements of the process. Residence times normally range from 0.5 to 2 seconds.

Advantages and limitations associated with liquid injection incineration are:

Advantages

- Incinerates wide variety of liquid wastes
- Presently utilized for shipboard incineration; well developed technology and equipment for both land-based and shipboard incineration
- Ability to operate over a wide feed range (high turndown ratio)
- Fast temperature response to changes in the waste fuel flow rate
- Operating temperature up to 1600°C
- No moving parts, except for rotating cup burners, therefore low maintenance

Limitations

- Wastes must be capable of atomization
- Burners susceptible to plugging by solids (problem minimized by use of rotary cup burners)

3.3.2 Rotary Kiln (6,8,9,10)

Rotary kiln incinerators are versatile units capable of handling liquid wastes, bulk solids, and containerized waste, separately or combined.

Rotary kilns are long, horizontal cylindrical rotating furnaces lined with firebrick or other refractory in which solids are heated by combustion of an auxiliary fuel or liquid waste. A typical commercial rotary kiln/afterburner system operated by Rollins Environmental Services in Deer Park, Texas is shown in Figure 8. This incinerator system has been used to destroy PCBs and nitrochlorobenzene production wastes; it can also handle solid wastes packed in fiber drums(6).

A rotary kiln is an efficient incinerator of solids, liquids, sludges, and tars because of its ability to attain thorough mixing of unburned waste, fuel and oxygen as it revolves. The waste feed is introduced at the upper end of the kiln and tumbled by the rotation of the kiln. The kiln is mounted at a slight angle from the horizontal. The hot products are discharged at the lower end. Fuel and air inlets are located either at the lower end, resulting in a countercurrent gas/solids flow, or at the upper end, yielding a cocurrent flow. Cocurrent flow is usually used in incinerators. Ash is discharged from the lower end of the kiln into a conveyor trough containing quench water. High temperature gas seals between fixed and rotating parts at the discharge end of the kiln are difficult to maintain. Therefore, rotary kilns operate at subatmospheric pressure to avoid combustion gas release. Adjustable and replaceable gas seals are available for special applications.

The major components of the rotary kiln incineration system include the kiln, an external mechanical drive mechanism that rotates the kiln, a ram feed mechanism for solid wastes, an ash quench tank, an afterburner equipped with an emergency relief stack, and primary/secondary air blowers for the kiln and afterburner. If only solid wastes are being burned, auxiliary fuel burners are required in the kiln and the afterburner. Complete combustion of the solids in the kiln is difficult to achieve. The tumbling action in the kiln results in fine particle entrainment in the gas stream. Therefore, an afterburner is almost always required for complete combustion. This provides increased gas mixing and additional residence time for the combustion reactions to occur. Liquid wastes can be burned concurrently with the solids in the kiln and afterburner, thus eliminating the need for auxiliary fuels in some cases.

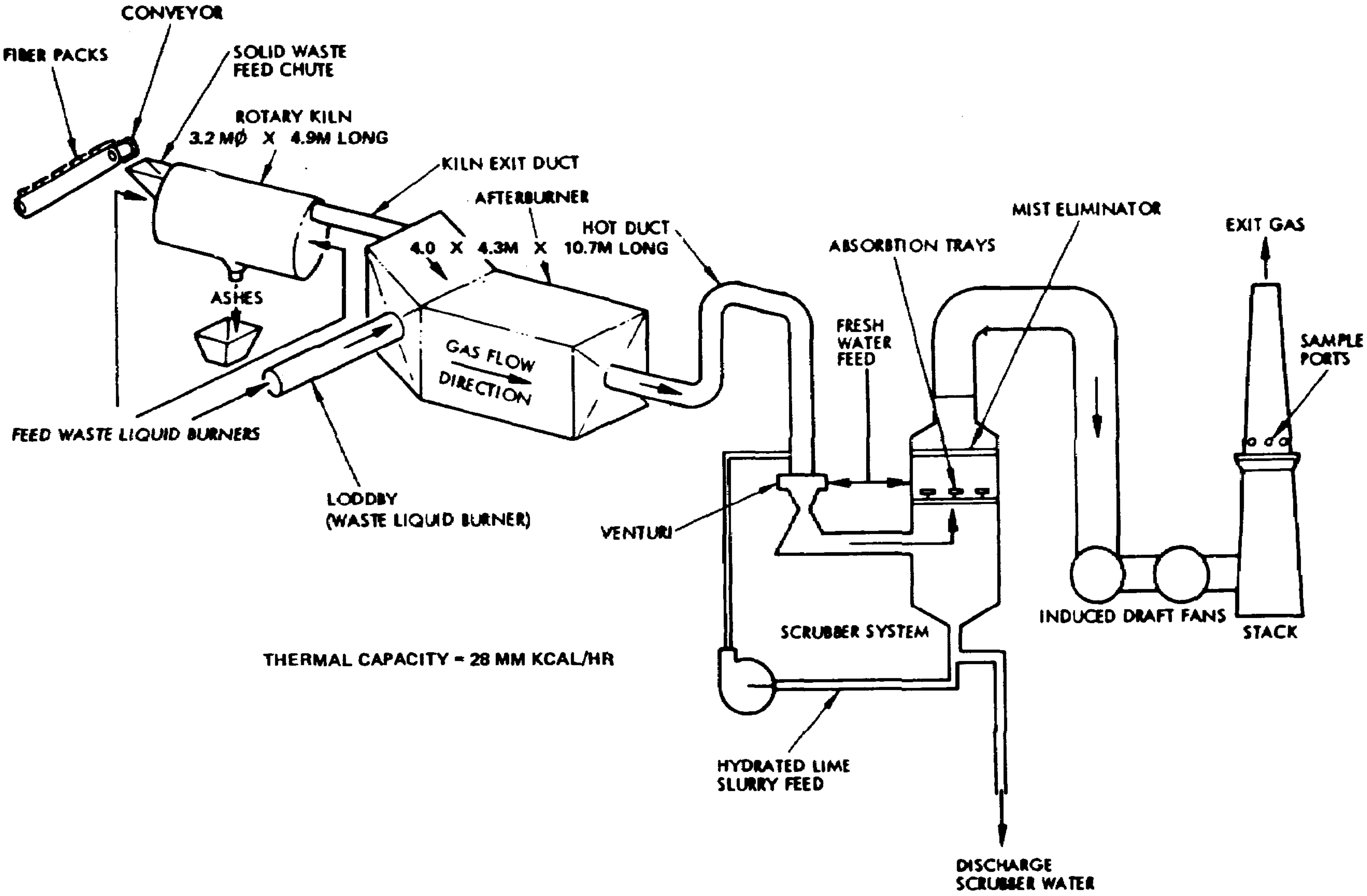


Figure 8. Schematic of Rollins Environmental Services Incinerator

Rotary kiln incinerators are used by industry to destroy both solid and liquid wastes. Rotary kilns are no longer generally used for municipal waste disposal. They have been replaced by multiple hearth or by landfill because of the cost of pollution control. Rotary kilns are also used by the military to incinerate chemical warfare agents and explosives such as obsolete munitions. Rotary kilns can be designed to handle containerized wastes, and are especially effective when the size or nature of the waste precludes the use of other types of incineration equipment. Combustion temperatures range from 870° to 1600°C (1600° to 3000°F) depending on the waste material combustion characteristics. Required residence times vary from seconds to hours (for solids) depending on the type of waste. Shipboard operation of rotary kilns would require special mounting and seals to withstand the pitch, roll, and vibration imposed by the vessel.

Advantages and limitations associated with rotary kiln incineration are:

Advantages

- Incinerates a wide variety of liquids, slurries, tars and solids, separately or combined
- Feed capability for containerized wastes
- Long residence time for slow burning solids
- Good mixing of unburned waste with air
- Operating temeprature up to 1400°-1600°C
- No moving parts within high temperature area of kiln
- Minimal waste preparation required
- Rotational speed control allows for variations in feed rate
- Continuous ash discharge
- Well-developed technology and equipment for land application

Limitations

- Higher maintenance costs associated with refractory maintenance and replacement
- Rotating parts require maintenance and may cause downtime
- Airborne particles may be carried out of kiln before complete combustion; therefore, a secondary combustion chamber is usually required
- Spherical or cylindrical items may roll through kiln before complete combustion
- Some fusible material may remain in kiln
- Leakage past end gas seals
- Not previously used for shipboard application - special mounting and gas seals required with shipboard evaluation necessary

3.3.3 Fluidized Bed (6,8,9,10)

Fluidized bed incinerators can be used to dispose of solid, liquid, and gaseous combustible wastes. The technique is a relatively new method for waste disposal and was first used commercially in the United States in 1962. Fluidized bed incinerators are refractory-lined reactors in which a bed of inert particulates (usually high silica sand) is supported by a distribution plate through which air is blown. The upward flow of air through the sand bed results in a dense turbulent mass which exhibits the characteristics of a fluid. Figure 9 is a schematic of a commercial fluidized bed incineration system built by Dorr-Oliver and operated by Black and Clawson in Franklin, Ohio(6). This incinerator is capable of receiving light or viscous liquids as well as liquids with high solids content. Liquid wastes successfully destructed in this incinerator include off-specification phenol, paint sludge and paint thinners, and oil sludges from oil reclaimers and oil processors.

Waste material to be incinerated can be injected into the bed with a pump, a screw feeder, or pneumatically. The strong agitation of the bed particles by the air promotes rapid and relatively uniform mixing of the waste material within the fluidized bed.

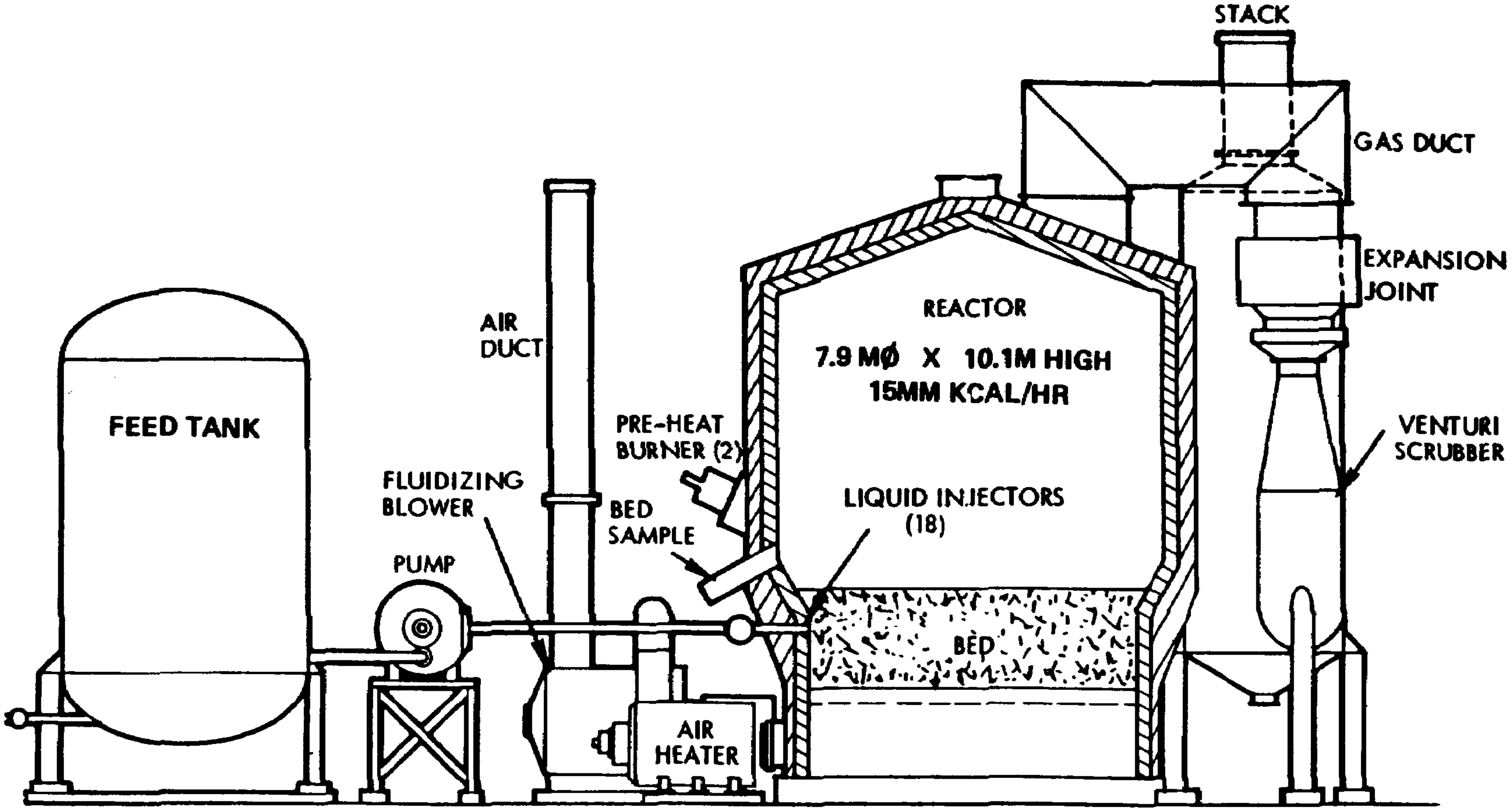


Figure 9. Fluidized Bed Facility Schematic (manufactured by Dorr-Oliver)

The mass of the fluidized bed is large in relation to the injected material. The large thermal heat sink formed minimizes temperature variations. Heat is transferred from the bed to the waste materials. Upon reaching ignition temperature (which takes place rapidly) the materials combust and transfer heat back to the bed. Continued bed agitation by the fluidizing air allows larger waste particles to remain suspended until combustion is completed or until they become small and light enough to be carried out of the bed with the flue gases as particulates. These gases are scrubbed before they are discharged to the atmosphere.

Gas velocities which are a function of particle size are typically low, from 1.5 to 2.4 m/s (5 to 8 ft/s). Bed depths range from about 40 cm to a few meters (16 inches to several feet). Variations in bed depth affect waste particle residence time and system pressure drop. Solids have a longer residence time than gases or liquids. Bed temperatures are quite uniform and are in the range of 760° to 870°C (1400° to 1600°F). Bed temperatures are restricted by the softening point of the bed material to avoid agglomeration of the bed particles. **In addition, formation of fusible ash can agglomerate the bed.**

Advantages and limitations associated with fluid bed incineration are:

Advantages

- Incinerates granular solids, slurries, liquids, and gases
- Uniform temperatures, high heat transfer rate to waste
- High volumetric heating rates
- No moving mechanical parts, low maintenance
- Relatively low excess air requirements
- Solids remain in bed until combusted
- Fluctuations in feed can be tolerated because of the large heat sink available

Limitations

- Not suited for bulky, irregular wastes or tarry solids which may plug bed
- Waste selection must avoid bed damage such as the formation of an eutetic
- Operating temperature in bed limited to 870°C to avoid agglomeration of particles (free board may be 980°C)
- Difficult to remove residuals from bed
- High power consumption for blower, high operating costs
- Additional equipment needed for removal of fine entrained particles
- Bed material replacement required due to attrition

3.3.4 Molten Salt(8,9,10)

Molten salts have long been used in the metallurgical industry to recover metals, especially aluminum, and in the heat treating of metals. Molten-salt systems (Figure 10) have only recently been developed to pilot-plant and demonstration scale for the destruction of organic waste compounds by the Atomics International Division of Rockwell International. Rockwell's test units have demonstrated that the process is capable of destroying chlorinated organics (such as PCBs), pesticides, and chemical warfare agents.

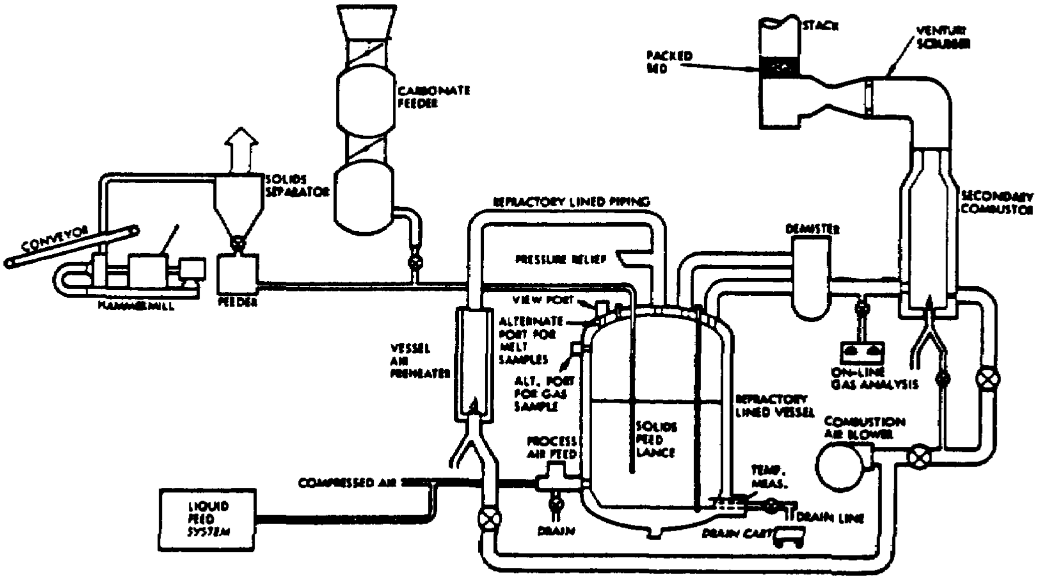


Figure 10. Atomics International Div., Molten Salt Reactor

In the basic molten salt concept for waste disposal the waste is injected below the surface of a molten salt bath. Usually the molten salt bath is composed of approximately 90 percent sodium carbonate and 10 percent sodium sulfate and is designed for operation in the range of 820° to 980°C (1,500° to 1,800°F). Substitution of other salts, such as potassium carbonate, allows for even lower incineration temperatures. The use of reactive salts, such as the eutetic mixtures NaOH-KOH and Li_2CO_3-Na_2CO_3-K_2CO_3, produces the additional benefit of entrapping potentially toxic or objectionable offgas constituents such as heavy metals (mercury, lead, cadmium, arsenic, selenium). This reduces or eliminates the need for pollution-abatement equipment.

Wastes such as free-flowing powders and shredded materials may be directly fed to molten-salt incinerators. Waste liquids may be sprayed into the combustion air and fed to the unit. The chemical reactions of the waste with salt and air depend on the waste composition. The carbon and hydrogen of the waste are converted to CO_2 and steam; halogens form their corresponding sodium halide salts; phosphorus, sulfur, arsenic, and silicon (from glass or ash in waste) form oxygenated salts; and the iron from metal containers forms iron oxide. Any char is completely consumed in the melt. The ash is trapped in the melt. The products of destruction build up in the melt and must be removed. On land, the spent salt can be regenerated or may be land disposed. However, at-sea handling of the high temperature, caustic spent salt may pose a safety problem. The advantages and limitations of molten salt incineration are:

Advantages

- Incinerates liquids, slurries, and shredded solids
- Particulates and contaminants remain in the melt
- Rapid and complete destruction of carbonaceous material
- Compactness and potential fuel efficiency predicted

Limitations

- Not commercially used - only pilot scale demonstration unit

- Operating temperature in bed limited to 820°-980°C
- Safety problem associated with accidents in handling of molten salts onboard ship

3.3.5 Other Incinerator Types (7,8,9)

Three other incinerator types, multiple hearth, multiple chamber, and starved air, were reviewed with regard to their potential for at-sea incineration of hazardous wastes. The multiple hearth incinerator (Figure 11) has been utilized to dispose of sewage, sludges, tars, solids, gases, and liquid combustible wastes. It is most commonly used for sewage plant sludge disposal. The multiple hearth furnace consists of a refractory-lined circular steel shell with refractory hearths located one above the other. Sludge and/or granulated solid combustible waste is fed through the furnace roof by a screw feeder or belt and flapgate. Liquid and gaseous combustible wastes may be injected into the unit through auxiliary burner nozzles. A rotating air-cooled central shaft with air-cooled rabble arms and teeth plows the waste material across the top hearth to drop holes. The waste falls to the next hearth and then the next until

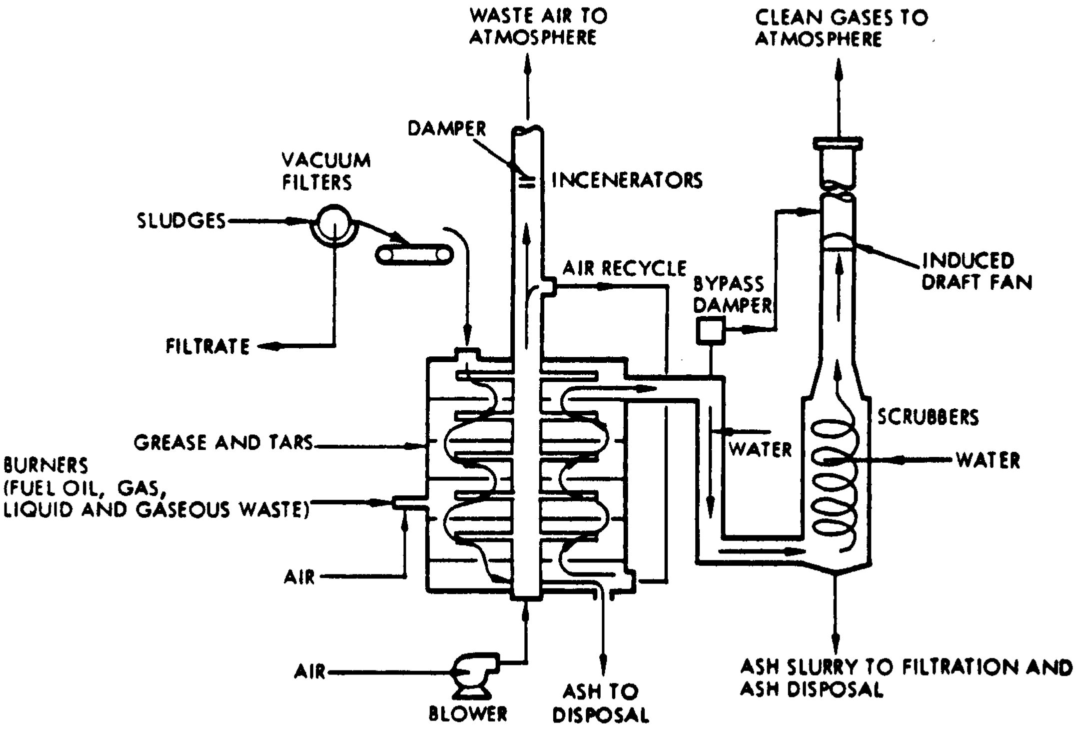


Figure 11. Multiple Hearth Incineration System

ash discharges at the bottom. The waste is agitated as it moved across the hearths to make sure maximum surface is exposed to hot gases. Air from the main blower follows a path countercurrent to the solids, flowing up from the bottom and across each hearth. Before it is injected at the bottom hearth, however, this air is passed through the central shaft and preheated while cooling the shaft.

The multiple hearth incinerator is usually operated so that the top hearth temperature is in the 315° to 540°C (600° to 1000°F) range, the combustion hearths are in the 760° to 980°C (1400° to 1800°F) range, while the ash cooling hearths are maintained in the 200° to 315°C (400° to 600°F) range. Solid retention times in multiple hearth furnaces typically range from 15 to 90 minutes. Scrubbers are required for most applications, and afterburners are used following some multiple hearth furnaces.

Advantages and limitations associated with multiple hearth incineration are:

Advantages

- Incinerates sludges and granular solids
- Long solids residence time
- Air preheated by passage through central shaft before injection into hearth
- Large quantities of water can be evaporated
- Well-developed technology and equipment for sludge disposal

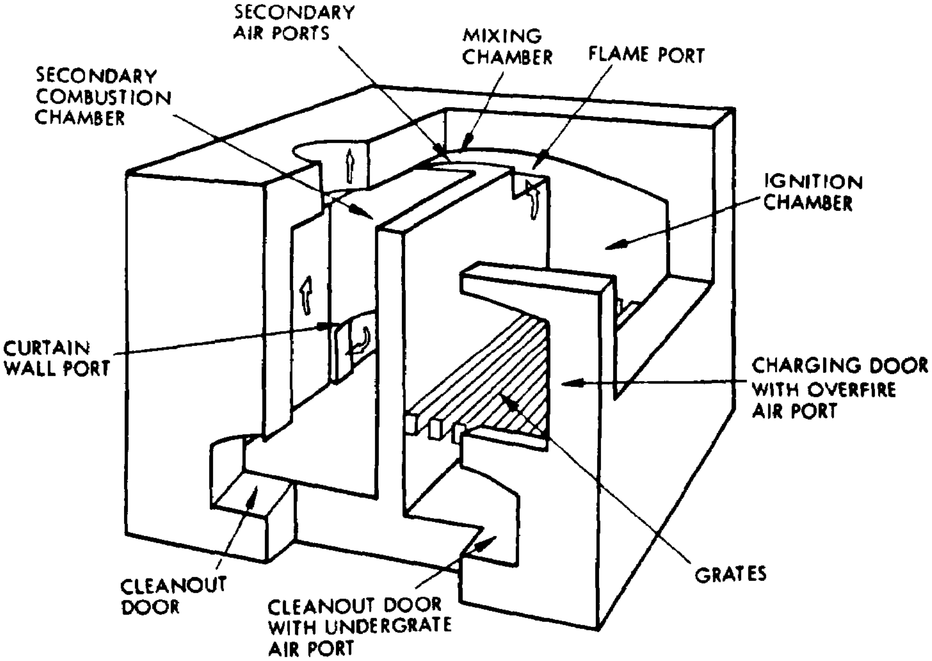
Limitations

- High maintenance cost because of moving parts in combustion zone
- Grates plugged by fusible ash
- Internal mechanical parts limit operating temperature to 1000° - 1100°C
- Less solids/air contact compared to rotary kiln and fluidized bed
- Possibility of some bypassing due to the closeness of the inlet and output ports

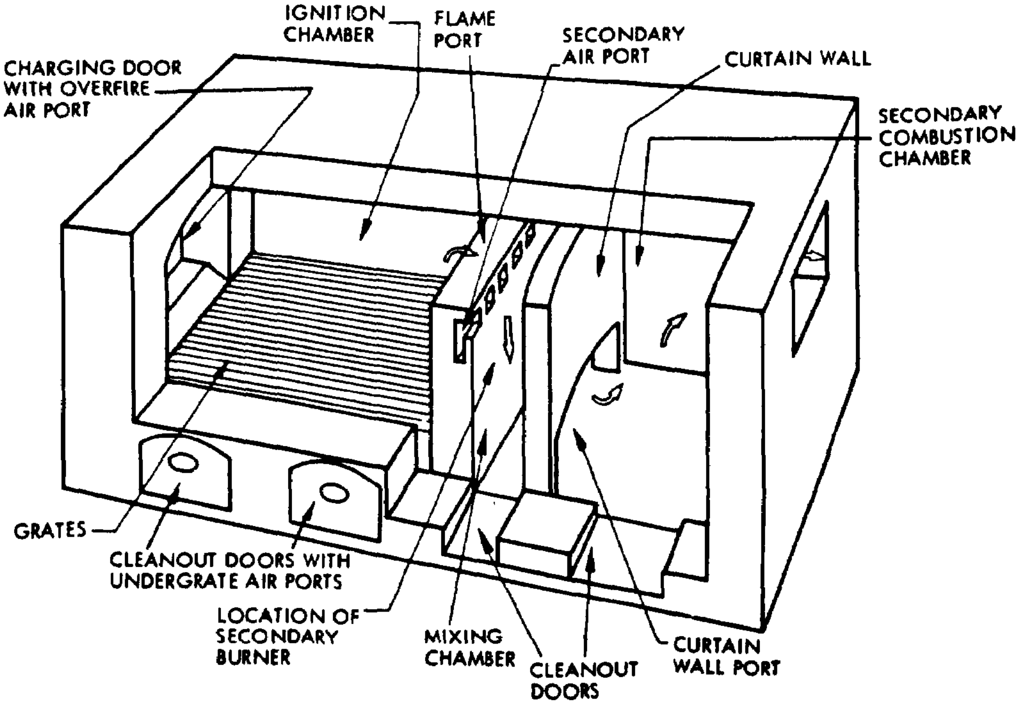
Another incinerator system reviewed with regard to at-sea incineration of hazardous wastes was the multiple chamber incinerator (Figure 12). Multiple chamber incinerators are used industrially for the disposal of bulky, solid wastes such as refuse, scrap wood, and paper, and chemical wastes such as resins and PVC plastics. They are usually not suitable for handling slurries, sludges, or flowable solids which fall through the grate without special modifications. It is also possible to burn liquid wastes by injecting the liquid with the auxiliary fuel.

Multiple chamber incineration takes place in two stages: primary or solid fuel combustion occurs in the ignition chamber, followed by secondary or gaseous-phase combustion. Solid wastes are either manually or automatically fed into the incinerator through charging doors onto grates at the bottom of the ignition chamber. Here, the wastes are dried, ignited, volatilized, and partially oxidized into gases and particulates. As more waste is charged to the system, the pile of burning waste is pushed farther along the hearth toward the ash pit. The moisture and volatile components of the fuel pass from the ignition chamber through the flame port to the mixing chamber. Here, the gases are mixed with secondary air, heated by auxiliary fuel firing (if necessary), and subjected to abrupt changes in direction to promote turbulent mixing. After expansion and contraction through a series of ducts, the gases pass into the upflow secondary combustion chamber where the oxidation reactions go to completion. Fly ash is also collected in this chamber by wall impingement and settling and is removed through ports in the chamber wall.

There are two basic types of multiple chamber incinerators, both of which are shown in Figure 12. The first is the retort type, where the arrangement of the chamber causes the combustion gases to flow through 90° turns in both lateral and vertical directions. This arrangement permits the use of a common wall between the primary and secondary combustion chambers. The retort type is used for the small capacity systems because of its simple box-like construction and reduced exterior wall length. It performs more efficiently than its in-line counterpart in the capacity



a. Retort Type



b. In-Line Type

Figure 12. Multiple Chamber Incinerator

range from 23 to 340 kg (50 to 750 lb) per hour. The other type of multiple chamber incinerator is the in-line type, where the flow of the combustion gases is straight through the incinerator with 90° turns only in the vertical direction. The in-line arrangement gives a rectangular plan to the incinerator and is readily adaptable to installations which require variation in sizes of either the mixing or the combustion or ignition chambers. All ports and chambers extend across the full width of the incinerator and are as wide as the ignition chamber. It is the more efficient multiple chamber incinerator at capacities greater than 450 kg (1000 lb) per hour.

Advantages and limitations associated with multiple chamber incineration are:

Advantages

- Incinerates a wide variety of wastes including bulky solids
- Extensive waste preparation not required
- Considerable flexibility in feed rates depending on type of multiple chamber incinerator used
- Operating temperature up to 1000°C
- Well-developed technology and equipment for solid disposal

Limitations

- Less solids/air contact compared to rotary kiln and fluidized bed
- Auxiliary fuel firing generally needed when moisture content of wastes exceeds 20%
- High excess air rates required for good air/waste mixing
- Grates and drive mechanisms exposed to high temperature and abrasion, increasing maintenance costs

The final incineration system considered was a starved air combustion system. Starved air combustion uses equipment and process flows similar to incineration except that substoichiometric amounts of air are fed. The process combines pyrolysis and oxidation reactions. One application of starved air combustion is the multiple hearth reactor used in a starved air mode. The reactor gasifies the solid or sludge feed, producing a combustible gas which is burned in an afterburner. Starved air systems have high thermal efficiencies; however, the insufficient oxygen supply can increase the probability of forming hazardous byproducts. Combustible gaseous emissions are undesirable and must be treated in an afterburner.

Advantages and limitations associated with starved air combustion are:

Advantages

- Potential for byproduct recovery
- High thermal efficiency and capacity/unit size

Limitations

- Not tested on hazardous chemical wastes
- Use of substoichiometric quantities of oxygen increases the probability of hazardous byproduct formation
- Afterburner required to burn combustible effluents

3.3.6 Design Discussion

Major characteristics of the incinerator types evaluated for shipboard at-sea application as described in the previous sections are compared in Table 3. 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 application. Relative sizes and capacities of existing units for most of these incinerator types are shown in Figure 13.

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 is capable of attaining the temperature required (up to 1600°C) for highly efficient destruction of toxic materials. It can also be utilized as an afterburner for a solid waste incinerator. Maintenance of this incinerator is low because there are no

TABLE 3. COMPARISON OF CANDIDATE INCINERATOR TYPES FOR SHIPBOARD AT-SEA APPLICATION

	Liquid Injection	Rotary Kiln	Fluidized Bed	Molten Salt	Multiple Hearth	Multiple Chamber	Starved Air
Waste Types							
Pumpable liquids	X	X	X	X	X	X	X
Slurries, sludges		X	X	X	X		X
Tars		X		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	low(a)	med(a)(b)	med(a)(c)	med(a)(d)	high(e)	med(e)	high(e)
Applications	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.

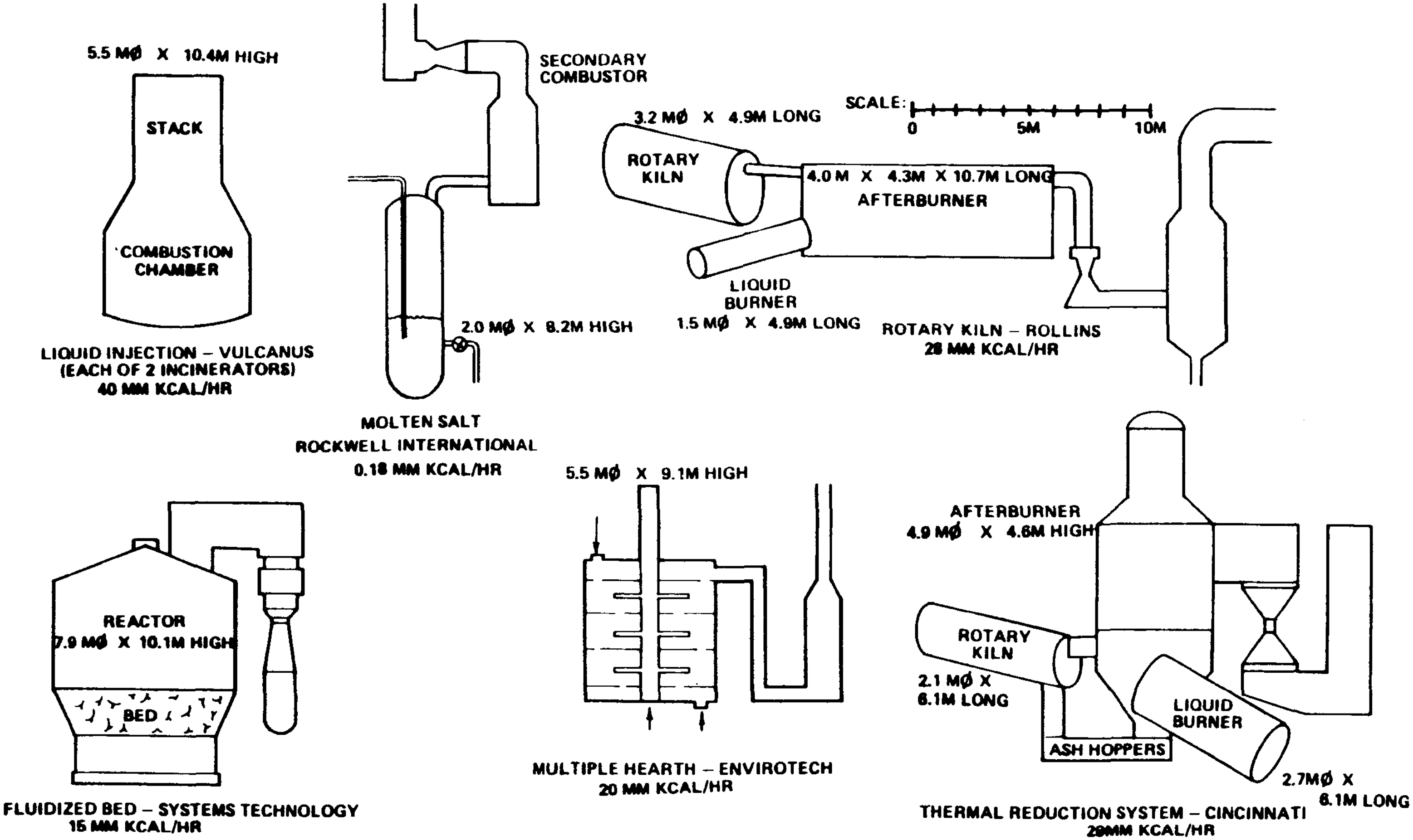


Figure 13. Relative Sizes and Thermal Capacities of Currently Used Incinerator Types

moving parts within the high temperature zone (except for rotary cup atomizers, which are cooled by the waste feed). Liquid injection incinerators are widely used in commercial applications, including shipboard at-sea incineration of hazardous materials.

Rotary kilns are the most versatile incinerators available, capable of handling any combination of liquids, slurries, tars, or solids, including containerized wastes. Temperatures as high as 1600°C can also be attained in the kiln. Rotary kilns represent well proven technology for land based incineration; however, use at sea would be a new application. Shipboard operation would require special mounting and seal modifications to withstand pitch, roll, and vibration conditions at sea. The kiln can be mechanically locked in place during storms. Maintenance would be higher than for a liquid injection system without a rotating drum and seals.

Fluidized bed incinerators are more limited than rotary kilns in range of feed materials, as indicated in Table 3, and are not suited for irregular solids or tarry substances which may plug the bed. 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 as the bed material. 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 up to one day duration, then gradual reheating of the bed is required for start-up. If the bed should become fused or plugged, the unit must be shut down for cleanout and bed replacement.

Molten salt reactor pilot and demonstration units have been used to destroy liquid, slurry, and granular solid waste materials; however, no commercial units are presently in operation. Operating temperature of the salt bed is limited to 980°C. Pitch and roll of 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; however, this necessitates salt recycle or replacement. The salt bed must also be removed from the reactor before solidification during shutdown. A spill of the hot, caustic salt containing toxic contaminants would be dangerous to shipboard personnel.

Multiple hearth incinerators are widely used for sewage sludge disposal, but can also destroy granular solids 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 high because of ship motion as well as thermal stress. Also, the presence of any fusible ash may 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. Slurries and sludges would fall through the incinerator grates and 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 reduced 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 less than the amount required for stoichiometric conditions. Starved air systems have high thermal efficinecies; however, hazardous byproducts may be formed without sufficient oxygen for complete reaction, and an afterburner is required to burn combustable emissions. Use of this mode of incinerator operation is usually limited to byproduct recovery from sludges or solids.

Based upon this engineering study, the incinerator design recommendations for shipboard at-sea application are:

1) The liquid injection incinerator, which has been proven for at-sea shipboard operation and can dispose of liquid wastes at high feed rates, is recommended for the proposed vessel. This incinerator will also serve as an afterburner for the solids incinerator.

2) A rotary kiln is recommended as the most versatile incinerator, capable of disposing of all waste types at high temperature. A standard commercially available

kiln should be installed for evaluation tests. Modifications to the standard kiln mounting and seals are required for shipboard operation.

3) The molten salt reactor, because of its potential for retaining particulate and contaminants in the melt, should be considered for further evaluation and development testing on land. This system is not sufficiently proven commercially to be selected as a solids incinerator for shipboard at-sea application. Also, a spill of molten salt would be dangerous onboard ship.

4) Fluidized bed, multiple hearth, multiple chamber, and starved air incinerators are all limited in operating temperature and waste type handling capability compared to the rotary kiln. None of these incinerator types are recommended for shipboard application.

3.4 WASTE FEED SYSTEMS

The function of the shipboard waste feed system is to retrieve the waste from its storage hold and transport it at a steady rate to the incinerator without spillage. This must be accomplished safely under the vibration, roll, pitch, and heave conditions encountered during shipboard operations. The type of feed system required will depend on the characteristics of the waste material, the nature of the storage, and the type of incinerator.

3.4.1 Liquids

Liquid wastes with a viscosity less than approximately 10,000 SSU, the maximum usually allowable for pumping, can be transported aboard ship and fed to the incinerator(s) by conventional pumps, piping, and valves. Higher viscosity liquids can be pumped by adding heat; however, this method would be more complex and potentially hazardous onboard ship than on land. A preferred method of reducing waste viscosity would be to solubilize the waste in a lower viscosity liquid, such as fuel oil or waste solvents.

Gas blanketed storage tanks should be utilized to contain the wastes prior to incineration. Lined tanks, piping, and pumps should be considered for compatability with corrosive materials. Coatings which might peel or flake off and plug pumps and burners must be avoided. Some particles can be crushed by masticating-type pumps. Solid particles up to 5 cm. in diameter can be crushed by "gorators" such as those in the feed system of the M/T Vulcanus(1,2,7) .

Incinerator burners should be designed for cleanout while the incinerator is operating. This requires multiple burners in each incinerator, so that one burner can be retracted and cleaned while others are maintaining required waste destruction temperatures.

Flowmeters are available for monitoring liquid feed rates onboard ships. Two types of meters, vortex and ultrasonic, have been successfully tested onboard the M/T Vulcanus(7) during incineration of hazardous materials. Either of these meters is suitable for incineration vessels.

3.4.2 Slurries

Slurries and sludges can be transported like liquids if pumpable. Only those slurries which do not settle out to compact cakes or whose settled cakes can be readily redispersed should be considered suitable for shipboard transit. All other slurries should be handled in a fashion similar to solids. In fact, it would be safer to regard all questionable slurries as solid materials rather than risk clogging up a feed system, with the resultant down time and cleanup requirement.

3.4.3 Bulk Solids

Waste solids can be expected to be of any size, shape, and hardness, and to be wet with volatile, hazardous liquids. Enclosed screw feeds and conveyors, which work well on land with dry, granular solids, cannot be expected to handle irregular, wet solids in rough seas without clogging. Such solids should be loaded into sealed, transportable containers which can be lifted individually to a charging port on the incinerator and dumped through a sealed connection. Ash from the incinerator can be loaded into the empty containers for land disposal.

Standardized containers, as shown in Figure 14, are commercially available. These containers each hold the same volume as 10 standard 55 gallon steel drums, and are transportable by truck or rail car. Automated systems can be provided to move these containers from the ship's hold and lift them to a sealed unloading device (Figure 15) mounted on the incinerator charging port.

3.4.4 Containerized Solids

Irregular, nonhomogeneous solids or slurries which tend to settle into compact cakes can be pre-packaged into containers small enough to be charged whole into a rotary kiln incinerator. Standard fiber drums, with metal rims, of approximately 30 gallons capacity are commonly used for land based incineration operations. Drum liners are available to seal wet wastes within the container. Automated systems can also be developed to transfer fiber drums from storage holds to incinerator charging ports. Care must be exercised to prevent puncturing and resultant leakage from fiber drums.

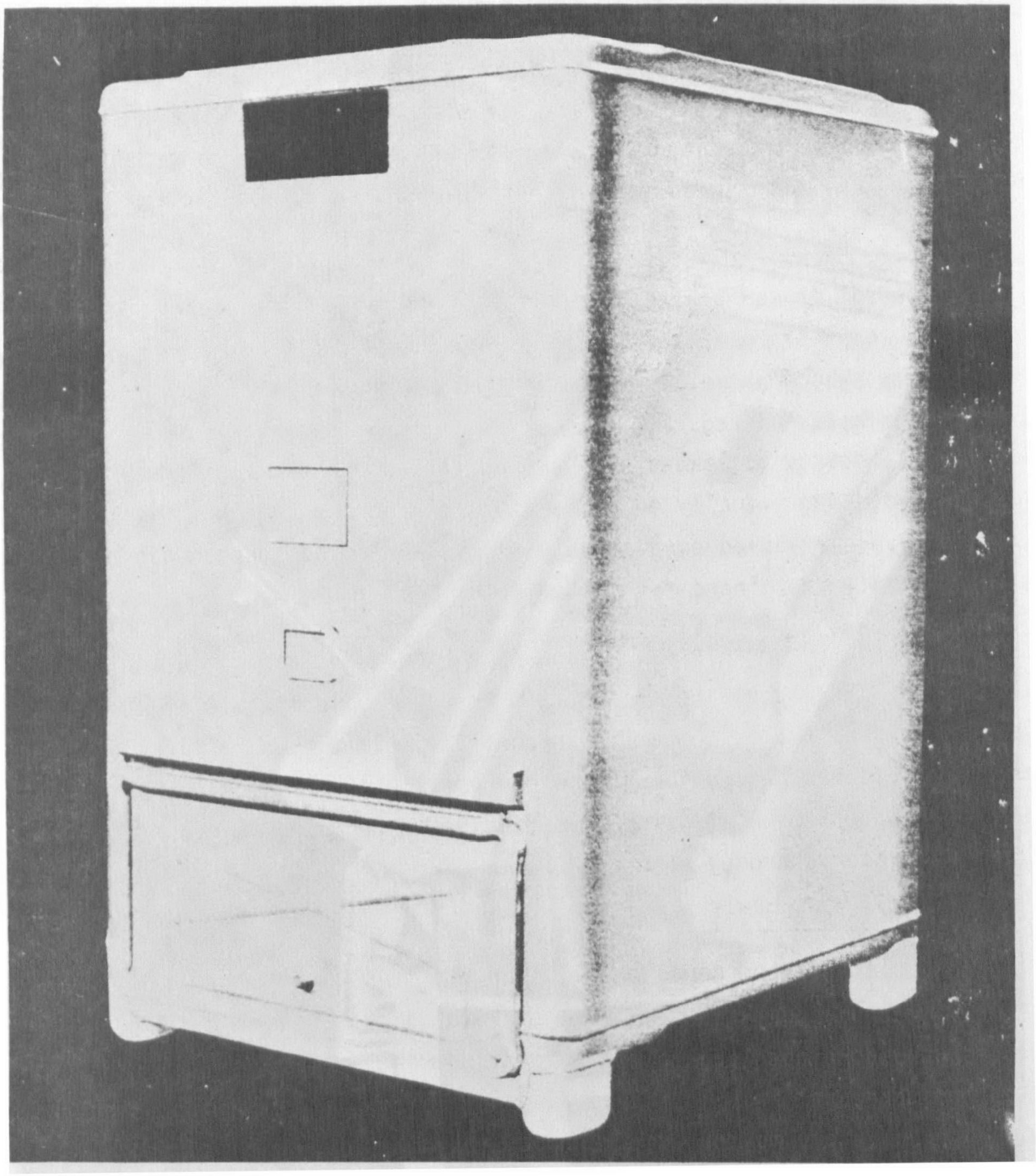


Figure 14. Bulk Material Container

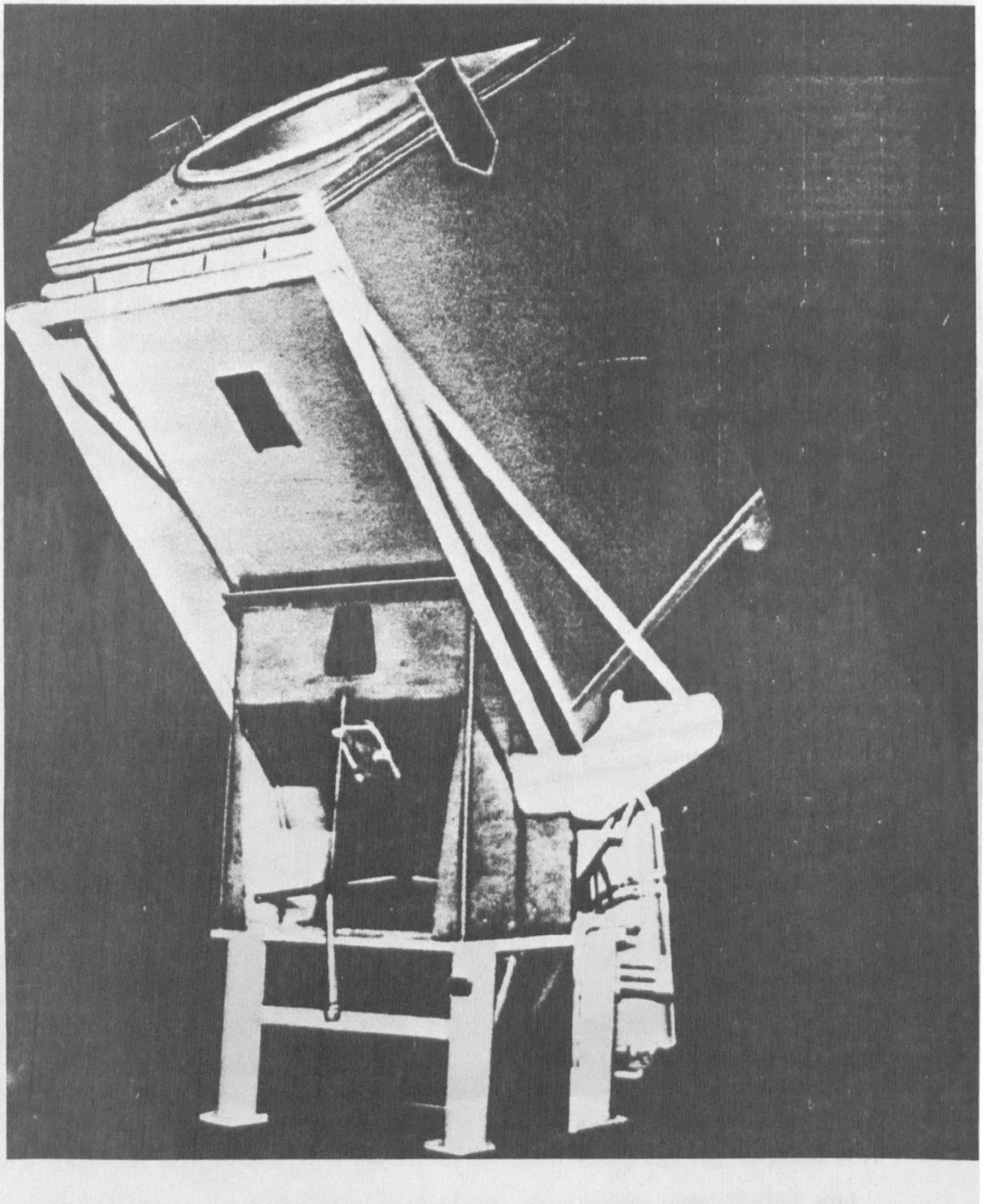


Figure 15. Bulk Material Container and Unloading Device

3.4.5 Recommendations

The recommended feed system for liquid wastes is similar to that presently used onboard the M/T Vulcanus, consisting of tanks, pumps (including masticating devices capable of crushing reasonably-sized solids), and plumbing enabling any burner to be fed by any tank onboard the ship. In addition, gas blanketed storage tanks and lined tanks should be used. Liquid waste flowmeters are also recommended(7). Some slurries, which are pumpable and do not settle out, may be handled as liquids; however, it is safer to treat any questionable slurries as solids to avoid system plugging and costly downtime and cleanup.

Solids can best be handled by loading wastes into sealed containers on land. These containers may be small enough to be fed directly into the incinerator, or bulk containers may be used which can be fed into the charging door through a sealed connection. These bulk containers can be used to store and transport ash for disposal on land. Handling of 55 gallon steel drums, particularly potential leakers, and shredding operations involve too much risk to be performed onboard ship. Proposed technical guidelines for incineration at sea(11) state that damaged containers should not be taken on board. Liquids or vapors from leaking containers present danger of fire or explosion onboard ship or during loading.

3.5 EMISSION CONTROL DEVICES

In this section emission control systems suitable for removing gaseous and particulate contaminants from incineration of hazardous wastes at sea will be identified. Major advantages and disadvantages of each system will be discussed.

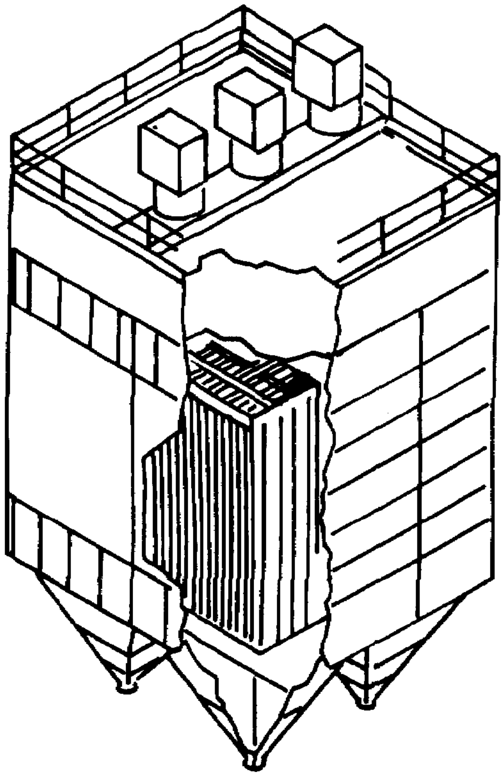
Control equipment commonly considered suitable for the reduction of particulate and gaseous emissions from combustion sources includes wet scrubbers, electrostatic precipitators, and fabric filters. These systems can also be applied to control emissions from hazardous waste incineration. In addition, molten salt scrubbers offer some unique advantages for at-sea incineration of hazardous wastes aboard ship although their use is not as common as the other three scrubber types. To date, the use of wet venturi and packed bed scrubbers has been predominant in controlling emissions from combustion of solid and liquid wastes in hazardous waste incineration facilities. Aboard ship, a different set of criteria will govern selection of the most appropriate scrubber system. These criteria will be reflected in the following discussion of the four most applicable types.

3.5.1 <u>Electrostatic Precipitators</u> (13)

Electrostatic precipitators (ESPs) have been widely used in controlling particulate emissions from utility boilers. They are not generally used for the more corrosive gas streams associated with hazardous waste incineration. Both wet and dry operation is possible with ESPs. Dry ESPs remove only particulate emissions, while wet ESPs are also capable of removing some gaseous emissions.

Figure 16 depicts a typical dry ESP. The dimensions shown are for an inlet gas flowrate of 140,000 actual m^3/hr (83,000 ACFM) at 177°C (350°F) and an inlet grain loading of 300 mg/m^3 assuming 95 percent removal.

Electrostatic precipitation is a process by which particles suspended in a gas are electrically charged and separated from the gas stream. In this process, negatively charged gas ions are formed between emitting and collecting electrodes by applying a sufficiently high voltage to the emitting electrodes to produce a corona discharge. Suspended particulate matter is charged as a result of bombardment by the gaseous ions and



OUTER DIMENSIONS

WIDTH = 6.4 m (21 ft)
HEIGHT (inc. hoppers) = 13.1m (43 ft)
LENGTH = 13.4 m (44 ft)

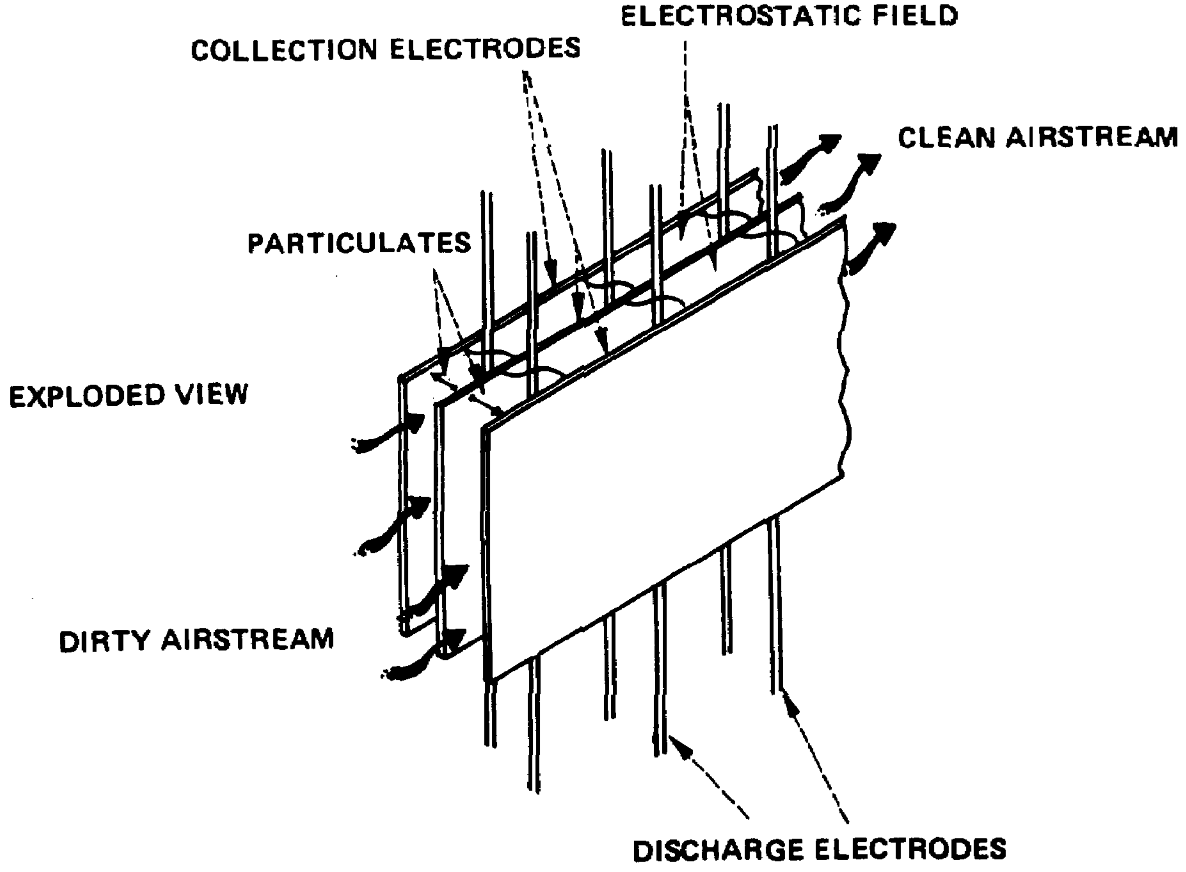


Figure 16. Electrostatic Precipitator

migrates toward the grounded collecting electrodes due to electrostatic forces. Particle charge is neutralized at the collecting electrode where subsequent removal is effected by periodically rapping or rinsing the electrode. A majority of industrial ESPs used today are the single-stage, wire and plate type; charging and collection take place in the same section of the ESP. Two-stage ESPs, often called electrostatic filters, utilize separate sections for particle charging and collecting, and are not generally employed for controlling particulate emissions from combustion sources.

The wet ESP is a variation of the dry electrostatic precipitator design. The wet ESP overcomes some of the limitations of the dry ESP. The operation of the wet ESP is not influenced by the resistivity of the particles. Further, since the internal components are continuously being washed with liquid, buildup of tacky particles is controlled and there is some capacity for removal of gaseous pollutants. In general, applications of the wet ESP fall into two areas: removal of fine particles, and removal of condensed organic fumes. Outlet particulate concentrations are typically in the 2 to 35 mg/m^3 range.

The two major added features in a wet ESP system are: 1) a preconditioning step, where inlet sprays in the entry section are provided for cooling, gas absorption, and removal of coarse particles, and 2) a wetted collection surface, where liquid is used to continuously flush away collected materials. Particle collection is achieved by introduction of evenly distributed liquid droplets to the gas stream through sprays located above the electrostatic field sections, and migration of the charged particles and liquid droplets to the collection plates. The collected liquid droplets form a continuous downward-flowing film over the collection plates, and keep them clean by removing the collected particles. To control the carryover of liquid droplets and mists, the last section of the wet ESP is often operated without continuous sprays, so that electrostatically charged liquid droplets cannot penetrate and mists can be collected by baffles.

Although dry ESPs have been in operation for a long time, wet ESPs are relatively new and are not commonly used.

Advantages and limitations of ESPs as applied to hazardous waste incineration at-sea are listed below:

Advantages

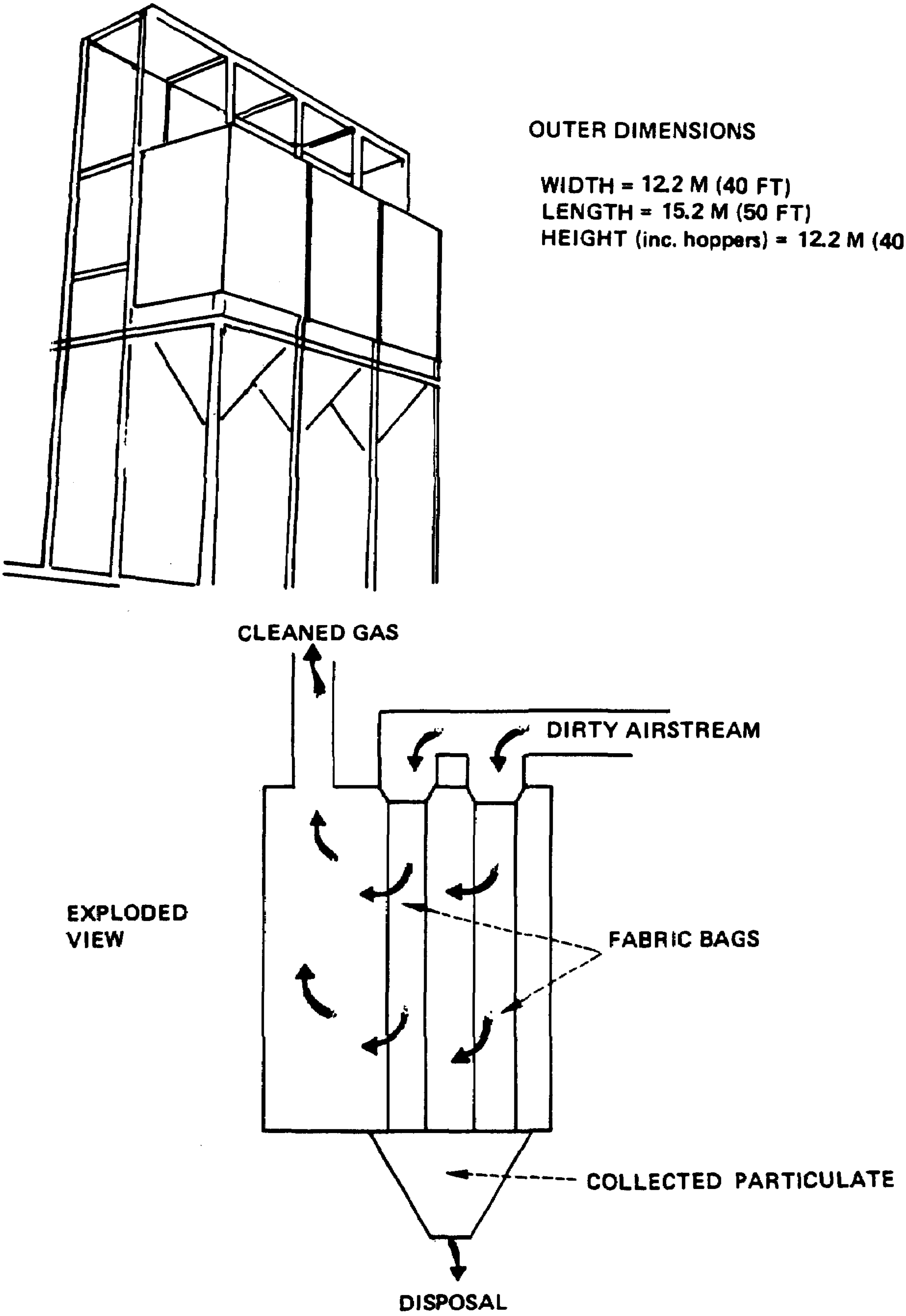
- High removal efficiency for particles < 1μm in diameter
- Potential removal of heavy metals
- No waste sludge generated by dry ESP
- Low pressure drop (<2.5 kPa or 1.0" H_2O)
- Low power requirement (0.4-0.7 KW/m^3/sec)
- Some commercial incinerator applications, but not with corrosive gas streams
- Wet ESPs remove some gaseous components.
- Wet ESPs control tacky particle buildup.
- Wet ESPs not affected as significantly by particle resistivity

Limitations

- Separate primary collection required for removal of particles > 1μm in diameter
- Low resistivity materials not readily removed
- Most efficient at constant conditions (10% increase in flow yields 50% increase in emissions for 99% efficient ESP)
- Corrosive gases may deteriorate electrodes, shell, rapper rods, high voltage frame, and gas distribution plates
- Anti-corrosion materials very costly
- Demister may be required for wet ESP
- High capital costs compared to wet scrubbers
- Extensive pilot testing required for hazardous waste incineration application
- Constant motion and vibration of ship could cause electrical shorting to occur frequently
- Dry ESP has no capability for removing corrosive gases; wet ESP has limited capability
- Very heavy (∿ 100 metric tons)

3.5.2 Fabric Filters (13)

In general, fabric filters are capable of removing only particulate emissions; however, by incorporating dry sorption principles into the design of fabric filter systems, some gaseous pollutants can also be removed. Figure 17 depicts a typical fabric filter. The dimensions shown



OUTER DIMENSIONS

WIDTH = 12.2 M (40 FT)
LENGTH = 15.2 M (50 FT)
HEIGHT (inc. hoppers) = 12.2 M (40 FT)

Figure 17. Fabric Filter

are for the same baseline conditions given in Section 3.5.1, except that greater than 99 percent particulate removal can be expected.

Fabric filter systems consist of a filter surface made of woven natural, synthetic or glass fibers through which the flow of dust laden gas is directed. Particles are collected on the upstream filter surface and in the interstices of the fabric, by inertial impaction, interception and diffusion, while the cleaned gas passes through. The collected dust layer also acts as a filter medium although periodic removal is required to maintain an acceptable unit pressure drop and flow rate. The filter surface is generally a system of tubular bags although rectangular envelopes are also used. Dust retained on the fabric is periodically shaken or blown off and falls into collection bins for subsequent disposal. Fabric filters are high efficiency particulate emission control devices and typically provide removal efficiencies exceeding 99 percent with pressure drops ranging from 0.5 to 2 kPa (2 to 8 in H_2O).

Dry sorption as discussed here involves contacting the gas stream with a solid phase that has the property of selectively removing one or more of the gaseous contaminants. Two types of dry sorption process have potential application for gaseous emission control in hazardous waste incineration facilities: 1) adsorption, and 2) adsorption followed by chemical reaction.

Adsorption--For gaseous emission control by adsorption devices, physical adsorption is the primary mechanism for contaminant removal. Characteristically, the adsorbate molecules diffuse from the gas phase across a boundary-layer to the surface of the adsorbent, where they are held by fairly weak physical (van der Waals) forces. Commercially important adsorbents include activated carbon, and simple or complex oxides typified by aluminum oxide, silica gels, fuller's, diatomaceous, and other siliceous earths, and molecular sieves. Activated carbon is effective in adsorbing organic molecules. The oxygenated adsorbents, on the other hand, show much greater affinity for polar than for nonpolar molecules, and therefore, will not be effective in adsorbing organic contaminants.

Adsorption devices are not currently used for gaseous emission control at hazardous waste incineration facilities. This can be attributed to several limitations of adsorption processes. At high concentrations of gaseous contaminants, the accumulated heat of adsorption may raise the temperature of the adsorbent bed to a level that impairs its adsorbent capacity. Additionally, high gaseous contaminants levels will lead to rapid saturation of the adsorbent. Particles and water vapor act as obstructants to adsorption of gaseous contaminants. Gas stream temperatures above 38°C (100°F) may cause significant reduction in adsorbing capacity. Incinerator exhaust gases must therefore be pretreated and precooled for removal of the major portion of gaseous and particulate contaminants, along with lowering of gas stream temperature and humidity, before adsorption processes can be considered. Conceivably, at a dedicated facility for incineration of highly toxic materials, adsorption can be added as the last polishing stage of a gas cleanup system to remove any possible last traces of contaminants.

Adsorption with chemical reaction--A much more promising method for simultaneous gaseous and particulate emission control is to inject solid reagents, or fine sprays of solutions or slurries containing the reagents into the gas stream, followed by collection of the reacted dry sorbent material on fabric filters or electrostatic precipitators. When fabric filters are used, an added advantage is that the amount of reagent required can be based on average emission levels, since surges in emission levels can be handled by unreacted reagents retained in the bags. Although there are no hazardous waste incineration facilities that currently employ this method to control gaseous and particulate pollutants, similar experiences with treating effluents from coal-fired boilers, glass furnaces, secondary aluminum smelters, and municipal incinerators, as discussed here, are directly applicable.

Advantages and limitations of fabric filters as applied to hazardous waste incineration at-sea are listed below:

Advantages

- High particulate collection efficiency, >99%
- Up to 95% removal of particles <0.1 μm in diameter
- Removal of heavy metals
- No sludge or liquid wastes
- No liquid freezing problems
- Low pressure drop (0.25 to 2 kPa or 1 to 8" H_2O)
- Can include dry sorbent injection to remove gaseous pollutants

Limitations

- Gas cooling required prior to fabric filtration; maximum temperature of 290°C although more practical limit for halogenic contaminants is about 95°C
- High efficiency demisting required after prefiltration cooling with water
- Fabric life reduced by acid or alkaline particles
- Fabric blinding caused by acid mists, condensed moisture, tars, tacky particles, and deliquescent organics
- Not capable of appreciable removal of gaseous pollutants without extensive modification
- Removal of damaged filters may require protective clothing and respirators for personnel
- Relatively large system, high costs
- If dry sorbent reactant used, storage required; storage and disposal required for waste cake and spent materials
- No commercial experience with hazardous waste incineration
- Very heavy ∿150 metric tons

3.5.3 Molten Salt Bath (14, 15)

A relatively new entry into scrubber technology is the molten salt scrubber as shown in Figure 18. Currently, only Anti-Pollution Systems,

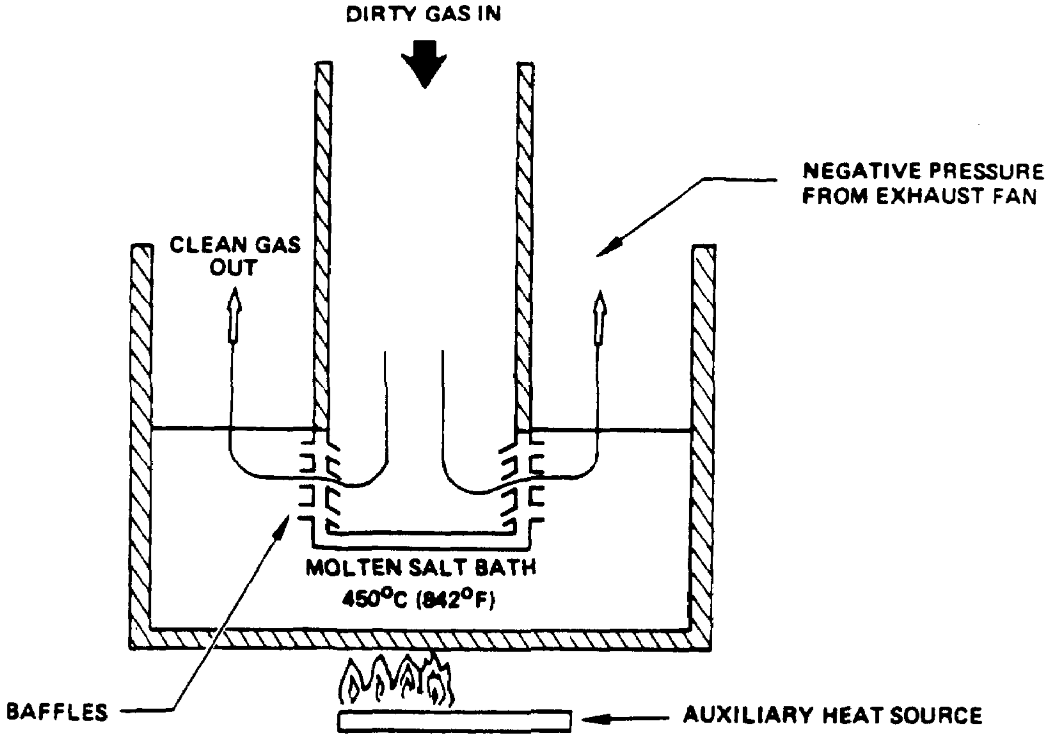


Figure 18. Molten Salt Scrubber

Inc. (APS) offers a molten salt scrubber for emissions from hazardous waste incinerators. A pilot scale combined molten salt incinerator/scrubber has been developed and commercialized by Atomic International Div. of Rockwell International, Inc. (AI). AI no longer offers a molten salt scrubber.* APS has also pilot tested a combined incinerator/scrubber unit on chlorinated hazardous wastes with, reportedly, excellent results. APS further reports that five units are currently in operation.† In this section, only the APS molten salt scrubber unit is discussed.

The APS molten salt scrubber is capable of removing high levels of particulate and gaseous emissions in a single bath. In choosing the bath, it is important that the salts do not themselves chemically interact with any of the waste gases. In that way the salts that are used become a permanent part of the system and need never be replaced. Since hazardous

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*Telephone conversation between TRW and Dr. Gehri, Rockwell International, Inc., Canoga Park, CA, 4/8/80.

†Telephone conversation between TRW and Dr. Jacob Greenberg, APS Inc., Pleasantville, N.J., 4/21/80.

wastes may contain a variety of reactive materials it is necessary, in such an uncontrolled situation, to find a salt bath of high thermodynamic stability. In these instances mixtures of alkali sulfates are used. In order to lower the melting point of the mixture, lithium sulfate is included. This addition not only forms a melt at 477°C but also inhibits the adsorption of water under ambient conditions. The reason for this is that the lithium sulfate forms a stable monohydrate that does adsorb continuously. It is important that the salts be dry upon rapid heating in order to prevent some hydrolysis from occurring. In other salt media the adsorption of water is obviated by simply keeping the salts at a temperature above ambient.

Although the initial salt charge is a permanent part of the system and is never changed, the salt has to be cleaned periodically of carbon, inert materials and compounds that have been formed in removing noxious products. There is a paucity of information on scrubber bath operation, regeneration times and regeneration steam requirements. At least 10 hours of continuous scrubbing would be required aboard ship for this process to be feasible.

During regeneration, carbon may be removed mechanically or by passing steam through the molten salts. Steam reacts with carbon in the bath at 593°C to form carbon monoxide and hydrogen (the water gas reaction). Inert materials, such as aluminates and silicates, are insoluble and sink to the bottom where they can be removed mechanically.

In those instances where the salt bath is used as a reaction medium in which sulfur or nitrogen oxides are combined with a metal oxide there is a continuous removal of reaction product. (15)

In the design of the system it has been found easier to bring materials to the salt bath rather than to spray or circulate the molten salts. The system is a simple bubbler constructed of stainless steel. It is a simple matter to convert such a scrubber assembly to an all-purpose (liquid or solid) incinerator. This is done by placing a box into another box. The inner box or trough floats on a 7.6 cm (3 in) depth of salt. Such a layer of alkali sulfates has a heat capacity at 593°C equivalent to a 38 cm (15 in) bed of cast iron. Liquids (containing water in any concentration) or solids are introduced into the center box where they are exposed to a flame. All resulting gases are then sucked through the scrubber baffles in the side walls before exiting. This bubbling action is made to occur by means of an induced draft fan. When the fan is turned on it creates a negative pressure on the exit side of the diffuser baffle. This causes a rise in the liquid level with a concomitant drop in the liquid level on the other side of the baffle. In this manner a liquid front is created into which exhaust gases are made to impinge. The reason for inserting the floating inner trough is to make ash removal simple and to preclude any problems associated with the introduction of water directly into the molten salts.

The ability to scrub submicron particles has been demonstrated by APS and by others. Using less than 15 cm (6 in) of water vacuum on the induced draft fan (and less than 2.5% of the weight of liquid that would be needed in a water scrubber), they have been able to remove particulates in the submicron range.

Since the gases that are introduced into the liquid are both rapidly heated and also distorted by the presence of the electrostatic field in the molten salts, rapid ignition at lower-than-expected temperatures is observed for unburned organic substances.

The reaction of sulfur dioxide with calcium oxide occurs in milliseconds in a molten salt. The reaction is stoichiometric not only for sulfur oxides but for nitrogen oxides. Gas flows containing 4700 ppm sulfur dioxide were reduced to 3 ppm sulfur dioxide. In trapping sulfur dioxide by combination with a metal oxide, it is desired that the resultant compound be economically viable. Aluminum sulfate has major value in its use in settling sewage solids, and in pharmaceutical products. Aluminum oxide, although an inert material in aqueous media at ambient temperature, is chemically active in a molten salt bath. It is the active ingredient for the extraction of aluminum in the Hall process at 700°C.*

From a conversation with Dr. Greenburg, of APS, Inc., a unit capable of treating a 90,000 m^3/hr gas stream would occupy a cubical space of

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*The Hall process is an electrolytic process for manufacturing metallic aluminum.

approximately 6 m per side. One-half or 3/8" 300 series stainless steel would be used. The total installed cost of this system would lie within the $200,000 to $500,000 range.

Advantages and limitations of molten salt baths as applied to hazardous waste incineration at sea are listed below:

Advantages

- One molten salt scrubber system is commercially available.
- Incineration and scrubbing of particulate matter and gaseous contaminants in a single device
- Excellent thermal contact between heat source and hazardous material
- Handles liquid or solid wastes
- Heavy metals can possibly be removed.
- Hot incinerator gases can be used to preheat the salt bath.
- Molten, caustic salt bath is stable, nonvolatile, relatively inexpensive, non-toxic, and recyclable.
- Salt bath operates as afterburner.
- Chlorinated hydrocarbon wastes have been treated in the APS system.

Limitations

- One developer, AI, has dropped scrubber process because of complexity
- Demonstration testing needed - at least slip-stream testing
- Process is batch - after saturation, molten salts must be regenerated or disposed of
- System reliability cannot be assessed due to limited commercial experience
- Operating costs are not available
- In an accident salts are highly reactive and pose grave danger to personnel onboard ship.

3.5.4 Wet Scrubber (13, 15, 16)

Wet scrubbers can be used to remove both gaseous and particulate pollutants. Wet scrubbers are very commonly used in controlling emissions from incineration of hazardous waste and municipal solid waste. As control devices, wet scrubbers represent old, well-established technology.

The removal of gaseous contaminants in wet scrubbers is a gas absorption process that depends on intimate gas/liquid contact. The unit mechanisms for particle collection from gas streams depend upon one or more of the following basic particle deposition phenomena: inertial impaction, interception, gravitational force, Brownian diffusion, electrophoresis, diffusophoresis, and thermophoresis.

Following the classification system developed by Calvert, wet scrubbers suitable for gaseous emission control can be categorized into four generic groups: plate, massive packing, preformed spray and gas-atomized spray. Figure 19 illustrates typical examples and dimensions for each type based on an inlet gas flowrate of 140,000 actual m^3/hour (83,000 ACFM) at 177°C (350°F) and an inlet grain loading of 300 mg/m^3. Specific designs can be conducted for each type of scrubber except the spray tower to insure high removals of halogens and particulate matter.

Plate towers are vertical, cylindrical solumns with a number of plates or trays inside. The scrubbing liquid is introduced at the top plate and flows successively across each plate as it moves downward to the liquid outlet at the tower bottom. Gas comes in at the bottom of the tower and passes through openings in each plate before leaving through the top. Gas absorption is promoted by the breaking up of the gas phase into little bubbles which pass through the volume of liquid in each plate.

Packed bed scrubbers are vessels filled with randomly oriented packing material such as saddles and rings. The scrubbing liquid is fed to the top of the vessel, with the gas flowing in either cocurrent, countercurrent, or crossflow modes. As the liquid flows through the bed, it wets the packing material and thus provides interfacial surface area for mass transfer with the gas phase.

In preformed spray scrubbers, the scrubbing liquid is atomized by high pressure spray nozzles into small droplets, and then directed into a chamber which gases pass through in either countercurrent, cocurrent, or crossflow direction. In this case, the scrubbing liquid is the dispersed phase and gas is the continuous phase. Since mass transfer occurs at the liquid droplet surface, gas absorption is enhanced by finer droplets. However, there is a practical limit below which the droplets become entrained.

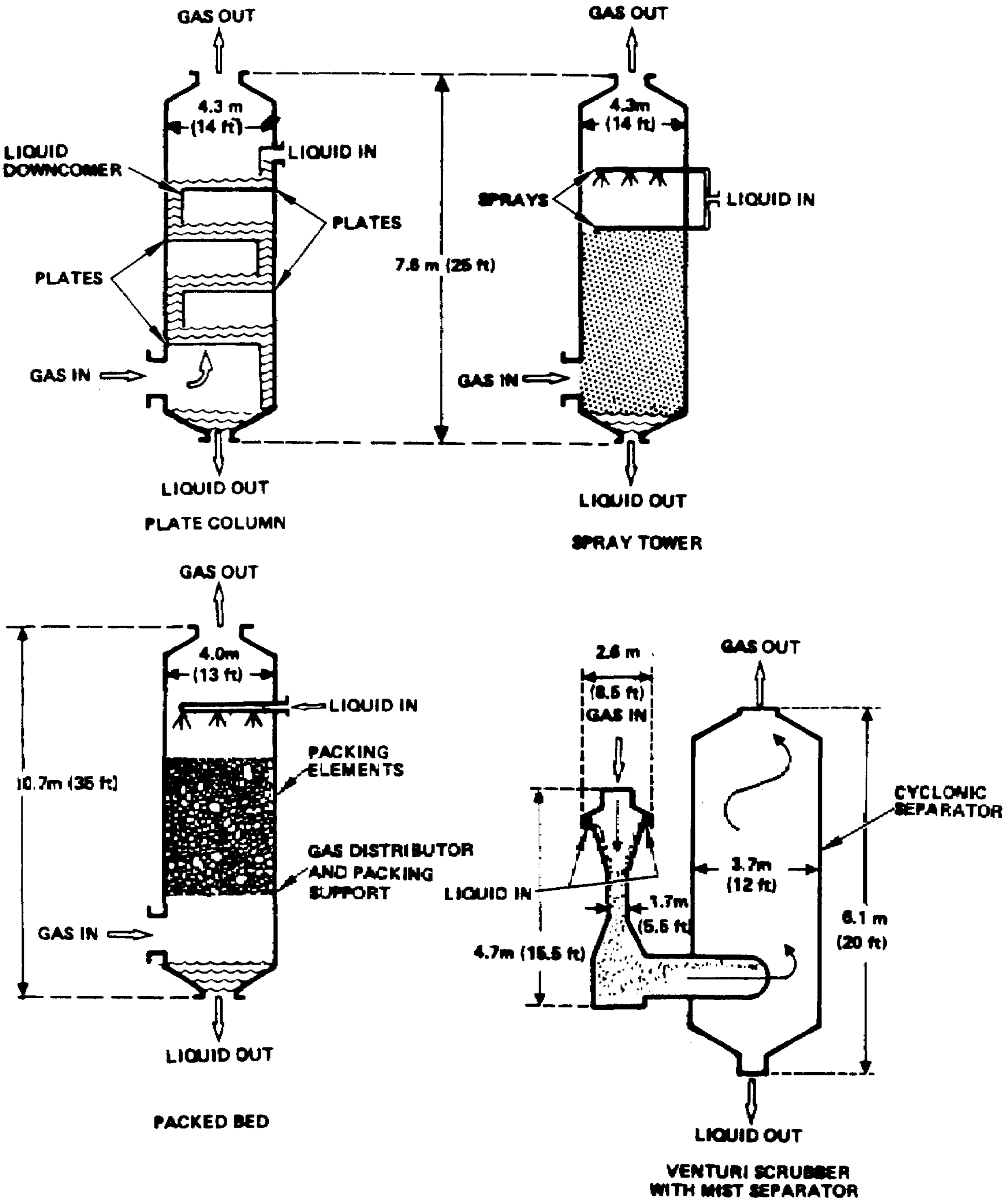

Figure 19. Wet Scrubber Types

Gas-atomized spray scrubbers utilize the kinetic energy of a moving gas stream to atomize the scrubbing liquid into droplets. Typical of these devices are the venturi scrubbers and orifice scrubbers. In the venturi scrubber, liquid is injected into the high-velocity gas stream either at the inlet to the converging section or at the venturi throat. In the process, the liquid is atomized by the formation and subsequent shattering of attenuated, twisted filaments and thin cup-like films. These initial filaments and films have extremely large surface areas available for mass transfer. The spherical droplets formed later have less surface area per unit volume of liquid than do the attenuated films and filaments. Because of the enhancement of mass transfer by the presence of these attenuated films and filaments, venturi scrubbers provide higher efficiency for noxious gases removal than preformed spray scrubbers.

Advantages and limitations of wet scrubbers as applied to hazardous waste incineration at-sea are listed below:

Advantages

- Particle removal efficiency >99% for particles >0.5 μm in diameter (high pressure drop venturi scrubber)
- Gas quenching and cooling
- High gas flowrate variability (or turndown capability)
- High removal efficiencies for gaseous pollutants such as SO_2, HCl and HF (tray tower and packed tower)
- Heavy metals removal
- Effective scrubbing with fresh water or sea water
- Some types not subject to plugging (venturis)
- Corrosion resistant materials available such as FRP and resin coatings
- Relatively low capital costs
- Commercial experience with hazardous waste and municipal solid waste incineration

Limitations

- Large settling pond and neutralization equipment required for closed loop system
- Waste sludge generated if closed loop system used
- Lime slurry or caustic solution needed onboard ship

- Single pass sea water system may concentrate pollutants in local area of ocean
- Multiple units generally required for removal of both particulate and gaseous pollutants
- Not generally effective for particle sizes <0.5 μm in diameter
- Some scrubber types (packed beds, sprays, and tray towers) high susceptable to plugging, especially with salt water
- Additional corrosion problems with sea water
- In tray towers, motion of ship will result in uneven weir heights.
- Pilot testing required if sea water to be used
- Heavy metals will be discharged to the ocean, thereby converting an air pollution problem to a water pollution problem.
- High energy cost for particulate collection

3.5.5 Conclusions and Recommendations

In summary, Table 4 lists major advantages and limitations for all the scrubber types suitable for at-sea incineration of hazardous wastes aboard ship which were discussed in the previous four sections.

Based on advantages and limitations listed for the four most applicable scrubbers systems for control of particulate and gaseous pollutants from hazardous waste incineration aboard ship, the following recommendations are made:

1) A high energy venturi scrubber and mist eliminator tower should be considered utilizing sea water due to its high removal efficiency for particulate matter and expected moderate removal efficiency for gaseous pollutants in a once through system. Medium cost resin-coated FRP vessels with teflon nozzles are available for halogenic gaseous pollutants.

2) A once-through wet scrubber using sea water should be considered if a method can be found for dispersing the effluent stream in the ocean.

3) Closed loop wet scrubber systems cannot be considered using fresh water because large quantities of water and a large settling pond would be required aboard ship.

TABLE 4. 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 efficency ● 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

- Continued -

TABLE 4. (Continued)

Device	Advantages	Limitations
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 0.5 um 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 susceptable to plugging • Requires downstream mist eliminator • Design based on experience and experimental testing • Settling pond required for closed loop operation
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

4) The molten salt bath should be considered either as a scrubber or combination incinerator/scrubber because it requires no pre-quenching, while removing high levels of particulate and gaseous emissions, including trace metals. Also, the unit does not require recirculation of molten salts for scrubbing purposes, although it does require periodic regeneration of the salt bath.

5) Since the molten salt scrubber has little commercial experience, demonstration testing of the unit should be conducted in the harsh environment expected at sea by treating a slipstream in a sub-scale unit.

6) A spray tower should not be used due to its predicted low removal efficiencies for both gaseous and particulate removal for comparable size equipment and power requirement.

7) Neither a tray tower nor a packed tower should be considered unless it is used in conjunction with a highly efficient primary particulate removal device.

8) Fabric filters would not be appropriate since they cannot handle very hot halogenic inlet gas streams or remove gaseous pollutants.

9) The dry electrostatic precipitator would not suffice due to its inability to remove gaseous pollutants, quench the inlet gas stream, or handle corrosive gases. Also, electrostatic precipitators may short out because of motion and vibration aboard ship.

10) The wet electrostatic precipitator would not be adequate, either, due to its inability to remove high levels of gaseous pollutants.

3.6 SHIPBOARD LABORATORY

In order to determine whether or not a U.S. Flag incinerator ship should have onboard chemical analysis capability, it is necessary to ask and answer several questions:

- Research and development phase:
  - Types and amounts of R&D information desired
  - Types of wastes to be burned
- Long-term operations phase:
  - Regulatory requirements for sampling and monitoring
  - Nature of wastes (special wastes might require some onboard analysis)
- Costs and benefits

This section will attempt to resolve these questions in relation to appropriate types of analyses, instrumentation required for these analyses, and required support in terms of manpower and facilities. The nature of the shipboard environment, manpower availability, personnel hygiene, and costs and benefits will be factors.

The shipboard environment is a harsh one from the viewpoint of performing chemical analyses. The air contains high levels of sodium chloride, other corrosive salts, and water vapor. Ships are subject to continuous relatively high amplitude, low wavelength vibration from onboard rotating machinery. Ships also are in continuous three dimensional motion: roll, pitch, and heave. Ship's electrical systems are noisy. The radio and radar communications gear onboard causes excess noise in instruments. Lastly, ships generally do not have much room for laboratories.

Many of the adverse effects of the shipboard environment listed above can be ameliorated or eliminated. For example, air to the laboratory could be filtered and conditioned. Instruments could be shock mounted or mounted on gimbals to reduce the effect of vibration and motion. Electrical noise can be reduced through employment of motor generators, isolation transformers, or filters. A ship's cenerating capacity could certainly be altered to provide the power required by instrumentation. Appropriate shielding could be provided to reduce instrument pickup of RF noise. Space is a problem that could be solved by careful choice of instrumentation and design.

Persons possessing certain analytical chemistry expertise (e.g., in gas chromatography - mass spectrometry) are in short supply. Also, extended-duration shipboard living is not an appealing prospect to many persons. Consequently, manpower availability for onboard analysis might be a problem.

Laboratories and chemical analysis and support equipment are expensive. An instrument such as a gas chromatograph - mass spectrometer (GC/MS) costs from $150,000 to $200,000. An additional $50,000 to $75,000 might have to be spent to provide a suitable environment for a GC/MS (high quality filtered air, large volume cooling water system, extra floor support, and spares). An instrument as sophisticated as a GC/MS is difficult to maintain on land much less on a ship, although Scripps Institute of La Jolla, California, has operated a GC/MS on an ocean-going research vessel.

To justify the capital cost of onboard analysis, there needs to exist either or both: 1) a requirement for more rapid analysis turnaround than can be achieved by holding samples for land-based analysis, or 2) a sufficient volume of samples to keep the onboard laboratory busy. The more expensive the instrumentation, the more important these justifications become.

Given the technical difficulties and cost and personnel considerations relative to establishing an onboard laboratory, it is concluded that only a limited capability should be provided. This capability should be sufficient to support permit compliance and R&D objectives through determining destruction efficiency for major organic components of the waste. It is then necessary to determine what kinds of analysis really must be performed onboard in order to support an R&D effort or routine incineration operations. The next section considers this question.

3.6.1 Recommended Analytical Capability

Figure 20 is a flow chart illustrating one type of decision-making process regarding an onboard analysis capability. In general, the decision as to whether or not to perform sampling and onboard or land-based analysis will be based on the following considerations:

- Information about and characterization of the waste
- New or existing regulatory requirements
- Characterizing incinerator performance on previously untested wastes (either R&D or routine operations phase)

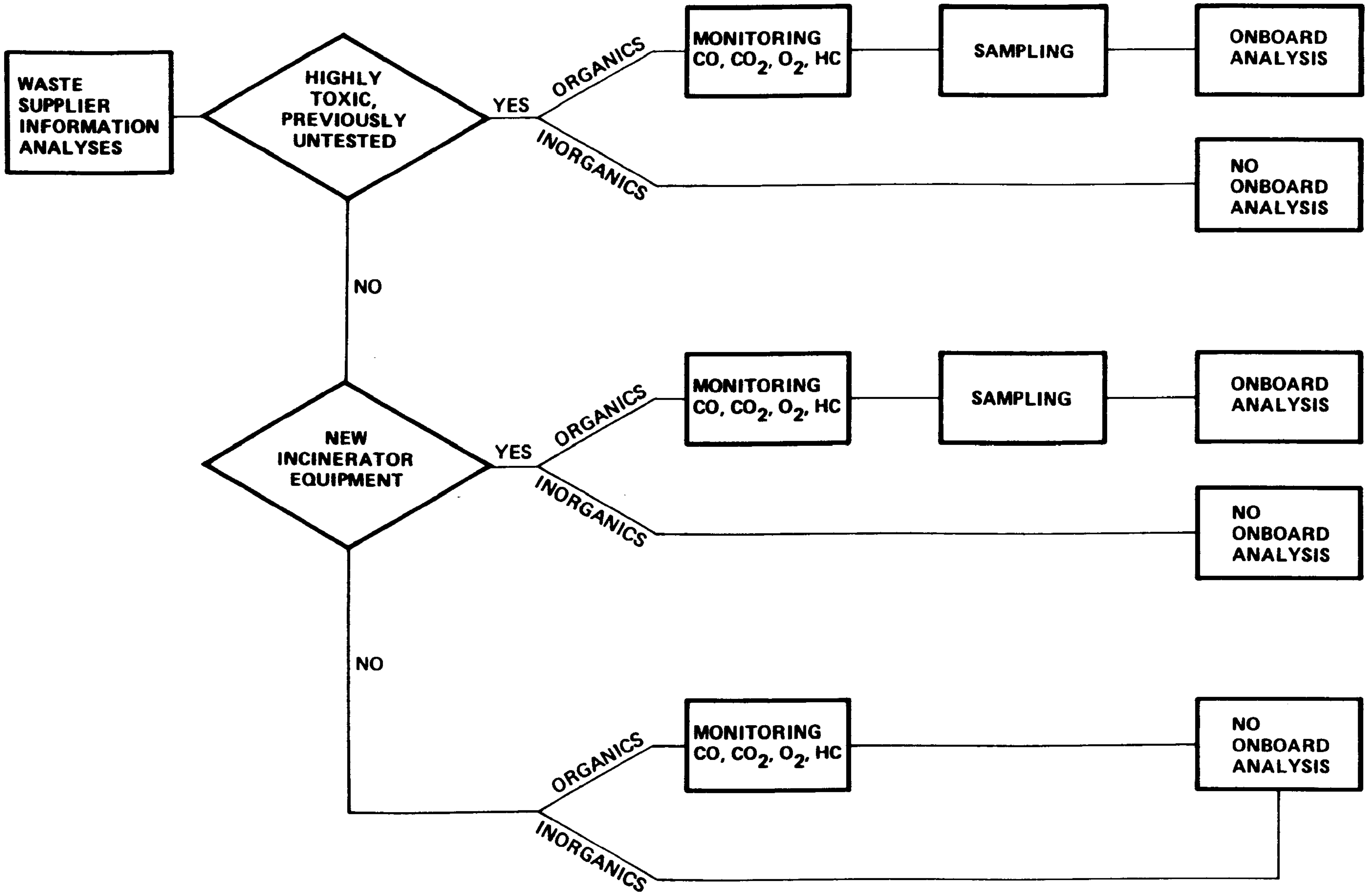

Figure 20. Flow chart showing situations requiring onboard analysis

- Characterizing incinerator performance with new system components (primarily R&D phase)

Discussion of recommended onboard analytical capability is conveniently divided into organic and inorganic analysis, and these are discussed below.

3.6.1.1 Organic Analysis Capability

As described in Section 1, MPRSA does not specifically preclude at-sea incineration of any organic waste. Mandatory regulations under the London Convention permit at-sea incineration of organochlorine wastes and petroleum products when permitted by signatories to the London Convention (11).

As shown in Figure 20, four cases relating to onboard analysis can be distinguished for organic wastes. If the waste contains an unusually hazardous substance (e.g., chlorinated dioxins or PCBs), the ocean dumping permit would probably require onboard analysis to demonstrate in semi-real time that destruction efficiency requirements were being achieved. During the at-sea incineration of Herbicide Orange, daily reports of destruction efficiency were required by the permit. It is expected that onboard determination of destruction efficiency will be required for the proposed at-sea incineration of liquid silvex herbicides.

The second case illustrated in Figure 20 involves a previously untested but not unusually hazardous waste. For this type of waste, the at-sea incineration permit probably would not require onboard determination of destruction efficiency. During routine operations, sampling should be performed, but onboard analysis would not be necessary. During the R&D phase, however, onboard analysis would be appropriate. Additionally, the R&D phase ought to make provision for advancing the state of the art of onboard analysis.

The third case illustrated in Figure 20 involves the R&D phase of testing new incinerator components. In this case, onboard analysis would probably be required in the permit. Further, even if not required by the permit, onboard analysis would be appropriate when new incinerator components are being tested.

The fourth case illustrated in Figure 20 involves routine operations when routine wastes are being burned. Neither sampling nor analysis (onboard or land-based) is necessary.

Perhaps the most generally applicable analytical technique for determining organic compounds is gas chromatography (GC). This is a technique for vapor phase separation and detection of organic compounds. There is a variety of detectors available for quantifying compounds after separation in the GC column. The two most popular and applicable detectors are flame ionization (FID) and electron capture (ECD). The FID is virtually a universal detector which "sees" carbon-hydrogen bonds. It lacks sensitivity to highly chlorinated compounds. The electron capture detector "sees" electronegative atoms or moieties in organic compounds. It is particularly sensitive to halogens and lacks sensitivity to organics containing only carbon and hydrogen. A gas chromatograph equipped with these detectors was operated onboard the M/T Vulcanus during the at-sea incineration of Herbicide Orange (2).

Gas chromatography is applicable to organic compounds which are thermally stable at the temperatures employed and which have sufficiently high vapor pressures. Polychlorinated biphenyls having vapor pressures as low as 6×10^{-5} mm of mercury can be analyzed by GC.

GC provides quantitative but only semiqualitative information about organics. The retention time of a compound is characteristic, but several compounds may have the same retention times. There are several means of gaining additional information on identity. One is to analyze the sample on columns of different polarity and compare retention times with those of authentic standards. Another is to use columns of higher resolving power.

The limitations of GC with respect to compound identification are not expected to be a problem in shipboard analyses. The recommended goal of onboard analysis is detection of major waste components. Thus, chromatograms of stack samples can be compared with chromatograms of the waste being burned. Matching the chromatographic patterns should be sufficient for determining permit compliance with destruction efficiency requirements. However, a full complement of columns should be available; and standards, if available, should be carried onboard.

Many organic compounds are thermally labile or of too low volatility to be analyzed by GC. There is a complementary technique termed high performance liquid chromatography (HPLC) which is used under these conditions. In NPLC, separations are carried out with a liquid mobile phase. Two detectors are widely used in HPLC: the ultraviolet and the refractive index. The ultraviolet detector is considerably more sensitive than the refractive index detector but is sensitive only to compounds that absorb in the ultraviolet. Many pesticides absorb UV radiation. The initial waste characterization will provide information to decide whether GC or HPLC is the method of choice.

Versatile GC and HPLC systems should, therefore, be purchased for use during the porgram. On any particular incineration voyage, only one need be installed in the shipboard laboratory and the other could be used in an EPA laboratory on land.

3.6.1.2 Inorganic Analysis Capability

The situation for onboard analysis of inorganic species is quite different than for organic species. The difference is primarily because incineration does not destroy inorganics. Therefore, there will be no loss of inorganics as a result of incineration. Inorganics present in the waste may be converted to different compounds, but all inorganics fed to the incinerator will be emitted. Trace metals may be emitted as oxides, chlorides, or sulfates, the latter compound types depending on the chlorine or sulfur content of the waste.

Onboard inorganic analysis is not necessary for the following reasons. First, IMCO and MPRSA regulations prohibit absolutely ocean dumping (or at-sea incineration) of wastes containing mercury or cadmium or their compounds unless they are present as trace contaminants. Second, other metals can be present in wastes only below certain concentrations for the waste to be permitted for at-sea incineration. Third, because trace metals are not destroyed by incineration, environmental impacts can be estimated from the initial analysis of the waste and plume dispersion modeling. Therefore, the initial analysis of the waste will determine whether or not the waste can be incinerated. If it can be incinerated, it will be known that harmful inorganic emissions will not occur. Therefore, onboard inorganic analysis is unnecessary.

3.6.2 Required Instrumentation

The recommended instrumentation is a gas chromatograph equipped with flame ionization and electron capture detectors. This instrument should be interfaced to a suitable electronic integrator. A variety of standard columns should be available. Generalized system components are:

- Dual column, temperature programmable gas chromatograph with flame ionization and electron capture detectors
- Microprocessor controlled electronic integrator
- Variety of standard columns
- Vibration mounting for GC and integrator
- Carrier gas supplies (K-bottles) - helium or nitrogen (argon-methane for certain models of ECD)
- Combustion gases for FID (K-bottles) - hydrogen and high purity air
- Regulators and flow controllers for gases
- Isolation transformer for GC and integrator
- Miscellaneous tubing, fillings, syringes, and wiring.

3.6.3 Required Laboratory Support

Perhaps the simplest generally useful stack sampling train utilizes a series of liquid filled impingers to absorb organic compounds emitted from the stack. In many situations, the impinger contents could be analyzed directly by injecting a few microliters into the chromatograph. This approach was used to measure destruction efficiency during the at-sea incineration of Herbicide Orange (2). The train used to provide samples for on-board analyses consisted of benzene filled impingers. The benzene samples were analyzed directly.

The most generally applicable sampling train uses a porous polymer bed, such as XAD-2, to trap organic vapors. The sorbent is then extracted with a solvent, such as pentane or methylene chloride, and the extract is then concentrated and analyzed. (Note that halogenated solvents cannot be used if an electron capture detector is to be employed in the analysis.)

The onboard laboratory will require the following capabilities:

- Equipment for extractions and concentrations
  - Hood
  - Glassware
  - Glassware mounting rack in hood
  - Sand or steam bath, heating mantels
- Solvent storage cabinet
- Standard laboratory benches
- Sink for glassware cleaning
- Gas cylinder storage rack
- Under counter explosion-proof refrigerator.

A conceptual laboratory design is presented in Figure 21. It is a room approximately 6.2 m x 5.0 m (20'2" x 19'4") consisting of a standard chemical fume hood, standard laboratory benches, gas cylinder storage, solvent storage, and a sink. There is sufficient bench top area for other instruments to be installed for special testing.

3.6.4 Recommendations

Only preliminary considerations for laboratory support and design can be presented at this time. These basic recommendations include:

- Onboard analysis for organic compounds only
- Shipboard gas chromatograph with flame ionization and electron capture detectors or high performance liquid chromatograph with ultraviolet and refractive index detectors.
- Laboratory space of approximately 6.2 m x 5.9 m
- Laboratory/monitoring storage space approximately 6.1 m x 6.1 m.

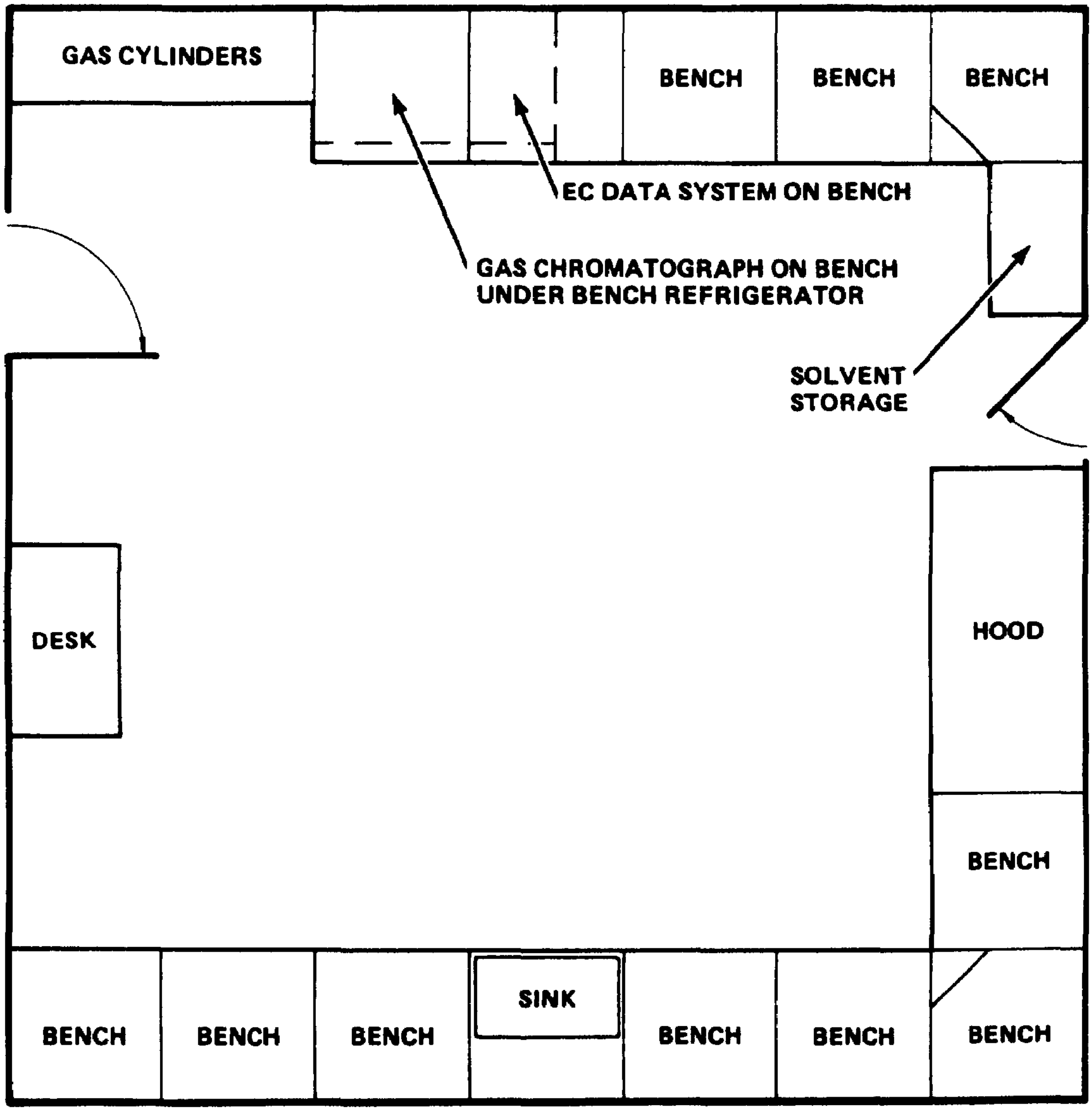

Figure 21. Preliminary shipboard laboratory design

4. *INCINERATION SYSTEM/SHIP INTEGRATION*

Potential integration of incineration systems and ships of various sizes and capacities is illustrated by Figure 22. For these examples, liquid injection incinerators of the dimensions and feed rates of those on the M/T Vulcanus (1,2) are used. These units are 5.5 m diameter by 10.4 m high, with a liquid waste incineration rate of up to 12.5 mt/hr. A standard commercial rotary kiln 3.2 m diameter and 4.9 m long with a solids incineration rate of 1.5 mt/hr is shown in the ship layouts. Ships of three different capacities - 4000, 8000, and 12000 mt of waste - are depicted in the figure.

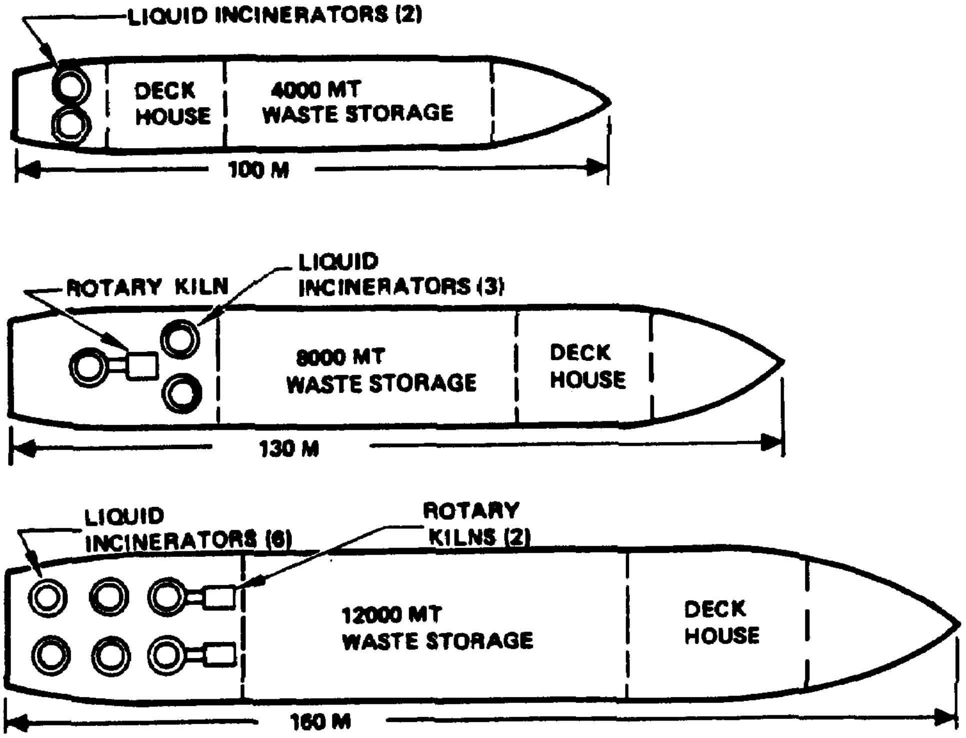

Figure 22. Incineration System/Ship Integration

The smallest ship shown - 100 m long with 4000 mt waste capacity - is approximately the size and capacity of the Vulcanus, which has two stern-mounted incinerators. Liquid wastes are pumped from the tanks to each incinerator burner. At a waste feed rate of 10 mt/hr for each incinerator, this ship would require slightly over eight (8) days of continuous burning to dispose of 4000 mt of waste. The bridge and deck house are shown immediately forward of the incinerators, as on the Vulcanus. A location further forward near the bow would be preferable for the environmental safety of the crew.

In the center of Figure 22 is shown a ship of 8000 mt waste capacity and 130 m in length. Three liquid incinerators burning 10 mt/hr each would dispose of 7200 mt of waste in 10 days. A rotary kiln of 1.5 mt/hr solid waste capacity is shown connected to one of the liquid incinerators, which is utilized as an afterburner. Deck space is provided for addition of rotary kilns to the other liquid units, for evaluation of other incinerator types, and for emission control equipment. Solid wastes are stored in bulk containers, which are transported by conveyor to the kiln. Automated equipment lifts the bulk containers and discharges the solid wastes into the kiln through a sealed hopper. Ash from solids incineration is stored in the emptied containers and returned to land for disposal. The deckhouse for this ship is located forward of the waste tanks, near the bow of the ship.

The third and largest ship is 160 m long with a waste capacity of 12000 mt. Layout of equipment is similar to the 8000 mt vessel, except that six liquid incinerators and two rotary kiln are provided. About eight (8) days would be required to dispose of 12000 mt of waste at the feed rates previously described for each incinerator. Deck space is also provided for additional solids incinerators and/or emission control equipment.

These ship layouts indicate some of the ways that incineration systems can be integrated onboard ships to provide desired incineration capacity and operational time at sea. Optimization studies to determine the number of incinerators and incineration time versus ship loading and transit times can be made for each ship size under consideration.

5. COST AND SCHEDULE ANALYSIS

Approximate costs and estimated delivery times for selected incineration system components and sampling, monitoring, and analysis equipment for shipboard application were obtained by contacting manufacturers of actual or similar commercial equipment. Installation costs for incineration equipment are based upon cost factors received from the Office of Ship Construction, U.S. Maritime Administration (MarAd).

5.1 INCINERATORS

Estimated costs of the recommended incinerator types for shipboard at-sea incineration of hazardous wastes are summarized in Table 5. The equipment will be specially designed or modified for shipboard application.

TABLE 5. INCINERATOR COST ESTIMATES

Incinerator	Approximate Costs ($1000)	Wgt (mt)	Installation[a] Costs ($1000)	Total Cost ($1000)
Rotary kiln (1.5 mt/hr - solids)	900[b]	50	219	1,119
Liquid injection (10 mt/hr-liquids each unit)	2,500[b]	300	1,312	3,812

[a] Installation costs/mt provided by MarAd, Office of Ship Construction

[b] Approximate costs obtained from TR Systems, Inc.

Cost of the rotary kiln incinerator is estimated at $900,000, including special mounting and seals to withstand the pitch and roll conditions of shipboard operation. A conservative estimate for the first liquid injection incinerator is $2,500,000 including 20% design costs. Additional liquid injection units from the same manufacturer would also cost $2,500,000 each.

Delivery time for a rotary kiln incinerator alone, modified for shipboard operation, would be 12 to 18 months. However, design and fabrication of the large liquid injection incinerators for shipboard application would require 18-24 months from order date. Some lead time could be saved by providing $100,000 for preliminary design of the incinerator at an earlier date.

5.2 WASTE FEED SYSTEMS

Waste feed system costs estimated for this study include liquid waste pumps and flowmeters, bulk material containers for solid wastes, and a material container lifting fixture. Liquid waste tanks and piping are dependent upon ship design, and are not included in this estimate.

Liquid waste pumps with electric motor drive, 50 l/min, one pump for each incinerator burner feed line (Viking Pump Division, Houdaille Industries, Inc.)	$300 each 2 weeks delivery
Liquid waste ultrasonic flowmeter systems, one digital readout for each incinerator with one flow transducer for each burner feed line (Controlotron Corporation)	$5,500 each 12 weeks delivery
Bulk material carriers, 1.7 m^3 (440 gallons) capacity, S-110 heavy duty Tote bins (Tote Systems Division, Hoover Ball and Bearing Company).	$1,000 each 18 weeks delivery
Remote operated container lifting and discharge fixture with piston vibrator (Tote Systems Division, Hoover Ball and Bearing Company).	$18,000 each 24 weeks delivery

5.3 EMISSION CONTROL DEVICES

Estimated costs of emission control devices evaluate for shipboard application are listed in Table 6. Unit sizes are based upon a design inlet flow rate of 140,000 actual m^3/hr (83,000 ACFM) at 177°C (350°F) and an inlet grain loading of 300 mg/m^3. Cost of a quench system to reduce incinerator effluent temperature from 1500°C (2700°F) to 177°C (350°F) is not included in Table 6.

TABLE 6. COMPARISONS OF SUITABLE GAS CLEANING DEVICES APPLICABLE TO HAZARDOUS WASTE INCINERATION ABOARD SHIP

	Dimensions (m/ft)				
Device	W	L	H	WT (Metric Tons)	Installed Cost
Dry Electrostatic Precipitator	6.4/21	13.4/44	13.1/43	86	$600,000
Fabric Filter	12.2/40	15.2/50	12.2/40	145	1,050,000

	D_o	D_i	H	WT	Installed Cost
Molten Salt Scrubber	6.1/20	4.3/14	10*	16.5†	Over $1,000,000

	Material	D_o	D_t	H	WT	Installed Cost
Wet Scrubbers‡						
- High Energy Venturi/	316 s.s.	2.6/8.5	1.7/5.5	4.7/15.5	2.7	$86,000
Mist Eliminator Tower	316 s.s.	3.7/12	n.a.	6.1/20	6.8	230,000
- High Energy Venturi/	lined FRP§	2.6/8.5	1.7/5.5	4.7/15.5	0.7	82,000
Mist Eliminator Tower	lined FRP§	3.7/12	n.a.	6.1/20	1.7	219,000
- Tray Tower	316 s.s.	4.3/14	n.a.	7.6/25	10.0#	408,000
- Spray Tower	316 s.s.	4.3/14	n.a.	7.6/25	8.6	441,000
- Packed Tower	316 s.s.	4.0/13	n.a.	10.7/35	17.0**	266,000

Legend

W = width
L = length
H = height, including, hoppers
WT = weight
D_o = outer column diameter
D_i = inner cylinder diameter
D_t = venturi throat diameter
FRP = fiberglass reinforced plastic
n.a. = not applicable

*A height of 10 ft was assumed by TRW for calculational purposes.

†Weight was estimated by TRW based on information received from APS, Inc.

‡316 s.s. would be subject to attack from HF and HCl in incinerator off gases, however, Kynar-lined fiberglass reinforced plastic is available for these conditions up to a temperature of 93°C (200°F). For comparison, FRP data are given for the venturi/mist eliminator scrubber.

§Kynar-lined FRP was assumed.

#Three trays were assumed.

**1.8 m (5.9 ft) of 3.8 cm (1.5 in) polypropylene Rachig rings as packing (which can withstand a maximum temperature of 121°C) was calculated for 99% removal of halogens. If stainless steel packing is used, total column weight increases to 33 tonnes. For HF and HCl gases, Teflon packing may be required.

5.4 SAMPLING, MONITORING, AND ANALYSIS EQUIPMENT

Estimated costs and delivery times for shipboard sampling, monitoring and analysis equipment are listed in the following subsections.

5.4.1 Sampling Equipment

Method 5 trains: 3-4 weeks, 4 at $5,500	$ 22,000
Sorbent traps: 3-4 weeks, 20 at $55	$ 1,100
Water cooled probes: 8-12 weeks, 10 at $5,000	$ 50,000
Fixed alumina probes: 8-12 weeks, 10 at $40	$ 400
Heat traced lines: 8-10 weeks, 300 ft at $10/ft	$ 3,000
Miscellaneous: 8-12 weeks	$ 2,000
	$ 78,500

5.4.2 Monitoring Equipment

CO analyzers: 6-8 weeks, 2 at $5,250 each	$ 10,500
CO_2 analyzers: 6-8 weeks, 2 at $4,650 each	$ 9,300
O_2 analyzers: 6-8 weeks, 2 at $1,625 each	$ 3,250
HC analyzers: 6-8 weeks, 2 at $3,640 each	$ 7,280
Gas conditioners: 8-12 weeks, 2 at $6,000 each	$ 12,000
Equipment rack: 6-8 weeks, 2 at $300 each	$ 600
Recorders: 6-8 weeks, 5 at $2,000 each	$ 10,000
Transformer: 6-8 weeks, 1 at $500	$ 500
Data logger: 6-8 weeks, 1 at $8,000	$ 8,000
Gas cylinder rack: 6-8 weeks, $500	$ 500
Gas cylinders: 6-8 weeks, 4 at $150	$ 600
Regulators: 6-8 weeks, 3 at $350	$ 1,050
Regulators: 6-8 weeks, 4 at $200	$ 800
Shock mounts: 6-8 weeks	$ 2,000
SO_x analyzer: 6-8 weeks, 2 at $5,000	$ 10,000
NO_x analyzer: 6-8 weeks, 2 at $7,500	$ 15,000
Vacuum pump: 6-8 weeks, 2 at $300	$ 600
Miscellaneous fittings: 8-10 weeks	$ 5,000
tubing: 8-10 weeks	$ 1,000
electrical	$ 250
Icemaker:	$ 750
Precleaned resin (approximately $85 per test, 20 test batch)	$ 1,700

Sampling containers	$ 2,000
Design: 60 manhours	$ 2,400
Installation: 80 manhours	$ 3,200
	$108,280

5.4.3 Analysis Equipment

Gas chromatograph (microprocessor controlled, dual flame ionization and single electron capture detectors): 6-8 weeks	$ 22,000
Data system (with interface for HPLC): 6-8 weeks	$ 6,850
GC accessories: 6-8 weeks	$ 1,000
High performance liquid chromatograph (refractive index and UV detectors): 6-8 weeks	$ 24,000
HPLC accessories: 6-8 weeks	$ 2,000
Solvent storage cabinet: 6-8 weeks, $300	$ 300
Chair: 6-8 weeks, 2 at $75	$ 150
Desk: 6-8 weeks, $200	$ 200
File: 6-8 weeks, $50	$ 50
Gas cylinder rack: 6-8 weeks, $500	$ 500
Bench: 6-8 weeks, 3 at $454	$ 1,362
Bench: 6-8 weeks, 1 at $264	$ 264
Bench: 6-8 weeks, 1 at $336	$ 336
Bench: 6-8 weeks, 1 at $356	$ 356
Bench: 6-8 weeks, 1 at $302	$ 302
Bench: 6-8 weeks, 1 at $356	$ 356
Hood base: 6-8 weeks, 1 at $354	$ 354
Hood + blower: 6-8 weeks, 1 at $2,083	$ 2,083
Bench: 6-8 weeks, 1 at $302	$ 302
Bench: 6-8 weeks, 2 at $496	$ 992
Bench: 6-8 weeks, 1 at $374	$ 374
Refrigerator: 6-8 weeks, 1 at $612	$ 612
Wall cabinets: 6-8 weeks, 3 at $288	$ 864
Bench top: 6-8 weeks, 48 feet at $65/ft	$ 3,120
Glassware: 8-10 weeks	$ 3,000
Rack for hood: 6-8 weeks	$ 200
Regulators: 6-8 weeks, 4 at $200	$ 800
Gas cylinders: 6-8 weeks, 6 at $50	$ 300
Miscellaneous: 8-10 weeks	$ 2,000
	$ 75,027

6. ENVIRONMENTAL MONITORING

Requirements for environmental monitoring during at-sea incineration are imposed by two sources. The first source is regulations pursuant to the Marine Protection, Research, and Sanctuaries Act (MPRSA) (40 CFR 220-229) and the mandatory regulations adopted under the London Convention (11) (the mandatory regulations went into effect in the U.S. in March of 1979). These regulations impose minimum operational monitoring requirements for protection of the marine environment. The second source of monitoring requirements is the permit for at-sea incineration. Specific permit requirements were imposed on the at-sea incineration disposal actions for organochlorine wastes (1) and Herbicide Orange (2).

Two general cases involving different degrees of environmental monitoring can be distinguished, and these are discussed below.

6.1 INITIAL INCINERATION MONITORING

The London Convention regulations (and thus the MPRSA regulations) require a survey during the first use of an at-sea incineration facility to determine compliance with the regulations. The survey requires stack gas sampling and analysis; monitoring of the stack gas for CO, CO_2, O_2, total hydrocarbons, and halogenated organics; and combustion and destruction efficiencies of at least 99.9%. The survey must be repeated every two years.

It is envisioned that monitoring requirements in excess of the minimum regulatory requirements would be required under the following conditions:

- An unusually hazardous waste (e.g., PCBs) or a waste containing an unusually hazardous substance (e.g., Herbicide Orange and its 2,3,7,8-TCDD contaminant) is to be incinerated
- The first time a new type of waste is to be incinerated unless it was similar to a previously tested waste
- When a new incinerator, a new type of incinerator, or extensive system component changes are made

When any of these three situations occur, it is expected that stack sampling followed by shipboard and/or land based analysis of the samples will be required. Additionally, samples of any other incinerator effluents would be required (e.g., solid residue from a rotary kiln incinerator, and influent and effluent from a scrubber).

When wastes containing appreciable amounts of sulfur and/or nitrogen (e.g., greater than 5%) are to be incinerated, stack gases should be monitored for oxides of sulfur and/or nitrogen. Additionally, during the R&D phase, provision should be made to monitor oxides of nitrogen to establish baseline values.

In some cases, sea water sampling could be required to determine actual impacts of incinerator effluents on sea and marine organisms. Marine water and organism sampling was performed (1) during the first two (Research permits) burns of organochlorine waste in the Gulf of Mexico. Marine water samples were taken during the first (Research permit) burn of Herbicide Orange (2). The R&D phase would be a good time to perform more extensive marine monitoring for long-term impact studies of at-sea incineration.

6.2 ROUTINE INCINERATION MONITORING

MPRSA and London Convention mandatory regulations do not require environmental monitoring during routine operations. These regulations do, however, provide for protection of the marine environment by requiring operational monitoring. The operational monitoring requirements are:

- Flame temperature not less than 1250°C (unless studies on the incinerator have shown that a lower temperature will achieve the required combustion and destruction efficiencies)
- Combustion efficiency is at least 99.95 ± 0.05%, based on

$$CE = 100 \times \frac{C_{CO_2} - C_{CO}}{C_{CO_2}} \qquad (7)$$

  Where C_{CO_2} and C_{CO} are, respectively, concentrations of carbon dioxide and carbon monoxide in the stack gas. Thus, monitoring of CO_2 and CO are required during routine operations.
- No black smoke or flame extension above the exit plane of the stack

The London Convention mandatory regulations also direct that Contracting

Parties "take full account of the Technical Guidelines". However, these guidelines have not yet been adopted by the Contracting Parties, therefore they do not have the force of law in the U.S.

The Technical Guidelines would impose additional operational requirements. Several relevant guidelines are:

- Minimum 3% oxygen in stack gas near the exit plane of the stack. (This has been a requirement in permits issued by EPA for incinerations in U.S. waters.) It should be noted that this is satisfactory for a unit-construction incinerator such as those in current incinerator ships where there can be no air infiltration. However, for a combined unit, such as a rotary kiln liquid injection incinerator, air infiltration could cause a reading of 3% excess oxygen at the stack exit, while there could be under 3% excess oxygen in the combustion zone of the rotary kiln.
- Incinerator wall temperature should be not less than 1200°C (unless tests on the unit have shown that adequate waste destruction can be achieved at lower wall temperatures).

7. OPPORTUNITIES FOR R&D EVALUATION

A U.S. incineration 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; second, it provides a safe site to continue EPA's research and development efforts in hazardous waste incineration. Much of the research in hazardous waste destruction is conducted with laboratory and pilot scale incinerators. An incineration vessel would expand the experience in the large scale processing of hazardous waste materials. The effects of process variations in a commercial scale incineration operation on hazardous waste destruction efficiencies needs to be investigated, including many types of wastes not yet tested.

Corrosion studies to determine which wastes or their by-products will deteriorate the commercial scale equipment can be performed with the shipboard incinerators. Evaluations can be made of corrosion resistant materials. Investigations into generation of hazardous intermediate products and destruction optimization studies could be conducted.

A shipboard incineration system can also be used to evaluate the performance of pollution control equipment. Presently, the effects of incinerating different hazardous wastes on scrubber performance is largely unknown. Scrubber performance is usually measured in terms of criteria pollutants, and a shipboard incinerator could be used to study the efficiency of scrubbers on toxic organic compounds which appear in the flue gas. A shipboard incinerator could also be used for research in process instrumentation and control as they apply to hazardous waste incineration.

Development testing of improved sampling and monitoring equipment and methods could be performed onboard an incineration vessel. For example, particulate sampling is not presently performed on incineration ship stacks. Sampling probes need to be developed that can carry out this function under shipboard operational conditions. Marine monitoring will also be required to determine environmental effects of at-sea incineration.

The following is a list of some of the R&D activities which could be performed onboard the incinerator ship:

- Conduct incineration tests to establish conditions for safe disposal of specific wastes.
- Investigate the thermochemistry of many hazardous compounds not presently characterized.
- Perform mathematical modeling of large-scale incinerators.
- Investigate toxic product generation by incineration and fate of these products (ash, flue gas, etc.).
- Perform corrosion studies with different types of wastes, their products, and materials.
- Evaluate the performance of air-pollution control equipment for toxic organics.
- Perform incinerator instrumentation and process control research, and systems safety analyses.
- Evaluate sampling and monitoring equipment and methods.
- Collect economic data for incineration of various materials.

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APPENDIX C

TO

REPORT OF THE INTERAGENCY AD HOC WORK GROUP FOR THE CHEMICAL WASTE INCINERATOR SHIP PROGRAM

CONCEPT DESIGN OF

U.S. FLAG VESSELS

FOR THE

CHEMICAL WASTE INCINERATOR SHIP PROGRAM

PD-246

September 19, 1980

U.S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION
ASSISTANT ADMINISTRATOR FOR
SHIPBUILDING AND SHIP OPERATIONS

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SUMMARY

The concept designs in this report represent alternatives for a U.S. flag chemical waste incinerator ship. Other maritime technologies may offer equivalent methods for initiating a chemical waste incineration system in the U.S. Among the commonly available technologies, integrated tug-barge combinations, standard tug with barge, or barge-carrying ship designs should also be evaluated as candidates for a chemical waste incineration at sea system. Separate solid waste and liquid waste incinerator ship systems should also be evaluated before construction of the combination incinerator ship is begun.

The concept designs and cost estimates for two ships were prepared as part of the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program study to support a FY 1982 funding request for the conversion or construction of a U.S. flag Chemical Waste Incinerator Ship. The ship would be part of a hazardous waste disposal system and would destroy organic chemical wastes generated by U.S. industries or the federal government. The ship would operate in EPA-designated incineration zones off the U.S.coasts.

This concept design study presents two new ship alternatives and discusses alternative technologies for use as an incinerator ship. Each ship is outfitted with three liquid injection incinerators and one experimental solid waste rotary kiln incinerator,plus the auxiliary equipment and the cargo systems needed to support the incineration plant. The new vessels should be able to burn a total of 7200 metric tons of liquid waste and 360 metric tons of containerized solid waste during ten days of continuous burning.

Each design must conform to the highest standard of marine chemical cargo protection and containment. The PD-246A can carry a full load of the most hazardous chemical cargoes, those rated Type I according to the IMCO Bulk Chemical Code. Because few chemicals now require Type I protection, the PD-246A is a more flexible design. The other ship design, the PD-246B,is a combination Type I/Type II ship, which carries the same amount of waste cargo in a slightly smaller hull. Most candidate chemicals for incineration at sea are Type II chemicals that could be adequately protected by this hull design. The Type I cargoes could be carried only in the ship's centerline tanks.

A conversion alternative, PD-246C, was evaluated using a Landing Ship Dock (LSD) as the baseline ship for a Type I hull chemical waste incinerator ship. However, because the available space for the liquid cargo tanks is flanked by the existing propulsion plant, the LSD has been determined to be inappropriate for use as a liquid waste incinerator ship equivalent to either of the new ships. A different conversion of a capacity equal to the new ship designs can be done, however, any conversion would require such estensive modification to the existing ship that it would not be a likely efficient investment

for the program. In addition, the LSD may still be useful as a research platform for solid waste incineration at sea, as the containerized solid cargo can be safely handled within the cargo well space.

The estimated cost and construction schedule for a single ship of each new ship design, including installing incineration equipment, are shown below.

DESIGN	NEW TYPE I	NEW TYPE I/II
NAME	PD-246A	PD-246B
LENGTH	129.5m(425'-0")	121.9m(400'-0")
BEAM	25.0m(82'-0")	23.8m(78'-0")
DEPTH	13.4m(44'-0")	12.5m(41'-0")
COST(millions)	80	75
SCHEDULE(mos.)	30	30

I. INTRODUCTION

These concept designs of alternative incinerator ships to destroy hazardous organic chemical wastes were prepared as part of the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program. These design studies and the accompanying cost estimates will support an appropriations request for the construction or conversion of a U.S. flag Chemical Waste Incinerator Ship. Similar ships have operated in western Europe during the past decade to destroy liquid industrial organic chemical wastes, but no ship has been built to serve the U.S. market for chemical waste disposal. The following report addresses alternative U.S. flag vessels equipped to carry and incinerate extremely toxic hazardous chemicals, that would operate in EPA-designated incineration at sea zones off the U.S. Atlantic, Pacific, and Gulf coasts.

Since the Environmental Protection Agency has the federal regulatory responsibility for hazardous waste disposal, it is also interested in advancing the state of the art for hazardous waste disposal technology. The incinerator ship designs therefore include an experimental solid waste incinerator and solid waste handling system. Incorporating both liquid and solid waste incineration systems on a common platform has complicated the designs in several instances that are detailed in the remainder of the report.

These designs assume that a landbased collection and delivery system for hazardous wastes exists to support the chemical waste incinerator ship. In particular, the ship will require storage terminals, chemical laboratories and loading facilities separated from other port facilities. While these facilities have been assumed. no design or cost estimate for these aspects of the incineration system has been included in this study.

The following report will present an overview of the major design constraints and assumptions, the design alternatives which were available, and the concept designs that were prepared for cost estimating purposes. For these designs, hull, machinery and incineration systems are described. Finally, estimates for ship construction schedules, construction costs, and operating costs for each design are presented.

Since these designs are intended primarily to provide information for cost estimating purposes, no final design or estimate is presented. However, the information provided herein does establish a basis for discussion and further development of the Chemical Waste Incinerator Ship Program.

II. CONSTRAINTS AND ASSUMPTIONS

A. Materials to be Incinerated

The candidate chemicals for at sea incineration are primarily toxic, hazardous organic chemical residues from petrochemical processes, such as plastic, pesticide and synthetic textile manufacturing. Because of their toxicity, these wastes present an extreme pollution hazard. Many of these are highly chlorinated combustible compounds that are difficult to incinerate on land because they generate corrosive flue gases that must be thoroughly "scrubbed" to prevent creating acid rain. At sea, however, the combustion effluents are neutralized by the oceanic environment. These wastes may be either pumpable liquids or slurries, sludges, tars, or discrete solid objects.

The liquids and slurries are highly variable mixtures, with specific gravities as low as .85 for kerosene-based pesticide solutions to as high as 1.3 for some refinery distillation residues. For these concept designs, a specific gravity of 1.0 has been assumed for the liquid wastes.

The solid wastes to be incinerated will also be highly variable mixtures, but they must be known to have properties suitable for loading into an incinerator without manual contact by the incinerator operators. That is, either a screw feed or similar automatic unloading mechanism must successfully empty the solid waste container. Unidentified "abandoned site" mixtures are not acceptable wastes for at sea incineration.

No waste chemicals that contain significant amounts of heavy metals can be accepted for incineration at sea, since the dumping of heavy metals at sea is strictly regulated by national laws and international conventions. Likewise, inorganic wastes that have low heating values are not likely to be accepted for incineration.

These ships therefore are designed to carry and incinerate only wastes that are combustible, organic hazardous chemicals, including organohalogens and other petrochemicals whose combustion generates very corrosive flue gases. In the remainder of this report, the cargo chemicals will be referred to as simply "liquid wastes" and "solid wastes."

B. Incinerator Systems

The Ad Hoc Work Group has determined that the chemical waste incinerator ship should be capable of incinerating both liquid and solid wastes. Liquid incineration has been successfully demonstrated at sea and the technology for handling incinerable liquids at sea is well developed, since it is similar to standard tanker cargo handling. Solid waste incineration has never been successfully demonstrated at sea, however, so that an experimental solid waste incinerator would be a valuable research and development tool to investigate the technical criteria for successful solid waste incineration at sea. EPA is particularly interested in having a solid waste incineration capacity aboard the vessel, as EPA has regulatory responsibility for hazardous waste management and is interested in expanding the available options for responsible, effective waste disposal. Future ship designs may include a sea water scrubber, or similar device, to remove the acidic effluent from the airborne incinerator flue gases, though none has been installed on either of these ships.

As a result, the PD-246 designs each have three liquid injection incinerators and one experimental solid waste rotary kiln incinerator. Detailed information about the incinerators and their auxiliary equipment is available in the report "Design Recommendations for a Shipboard At-Sea Hazardous Waste Incineration System", which is enclosed as Appendix B. The same report is independently produced by TRW, Inc. as EPA contract No. 68-03-2560, August, 1980.

The major information about the incineration systems specified for the PD-246 designs is presented below.

INCINERATION SYSTEM CHARACTERISTICS

Liquid Waste Incineration System

Incinerators: Three vertically mounted liquid injection units
Capacity: Ten metric tons/hour each
Cargo Tanks: Epoxy lined mild steel
Waste Feed: From any tank to any incinerator, via a common pumproom.

Solid Waste Incineration System

Incinerator: Rotary kiln, mounted on centerline of main deck
Capacity: 1.5 metric tons/hour
Cargo Storage: Two metric ton containers loaded before delivery to ship, 180 containers per shipset
Cargo Stowage: Main deck container cell guide structure
Waste Feed: From deck storage area to kiln, on secured conveyor
Residues: Retained in ash pit for shore analysis

C. Operating Scenario

The conceptual designs for the first U.S. flag incinerator ship are based on the following design and operational constraints:

*Two week operating cycle, with ten days continuous burn "on site".

*Both liquid and solid wastes accepted;

*No unidentified "abandoned site" wastes to be accepted;

*Solid waste precontainerized before loading onto ship;

*Wastes loaded at terminal by automatic equipment;

*Drifting or slow steaming during incineration operations;and

*Heading into wind maintained by bow thruster during incineration.

The two week operating cycle combined with the specifications for three liquid incinerators, has determined the size of the ship.

The ship will have two days to load the 7200 metric tons of liquid cargo and the 360 tons of solid waste containerized cargo, as well as fuel oil and ship's stores. The vessel will then proceed to a designated offshore waste incineration site, about 100 miles offshore and perhaps 175 miles from the loading terminal. The ship will operate at a service speed of 12 knots, since there is no need for fast propulsion. The incinerators will be preheated during the last six to ten hours of this passage so that chemical burning can begin upon arrival at the burn site. Incineration will continue for ten days, during which time the vessel will drift and maintain a heading into the wind (about 60 to 90 degrees), so that the plume from the incinerators blows away from the ship, rather than falling onto the ship's deck. A bow thruster will be used to maintain the optimum heading to the wind. After completing the incineration, the vessel will return to the loading terminal.

D. Regulatory Requirements and International Conventions

The final PD-246 vessel designs must conform with all U.S. Coast Guard regulations applicable to incinerator ship design and construction, such as are listed below:

33 CFR 155 and 157, Pollution Prevention Regulations

33 CFR 159, Marine Sanitation Devices

46 CFR 30 through 35, Tank Vessel Regulations (requirements in 46 CFR 153 take precedence over requirements in 46 CFR 30 through 35)

46 CFR 42, Load Line Regulations

46 CFR 50 through 64, Marine Engineering Regulations

46 CFR 98.30 and 98.35, Handling and Storage of Portable Tanks (for solid waste containers)

46 CFR 110 through 113, Electrical Engineering Regulations

46 CFR 153, Safety Rules for Self-Propelled Vessels Carrying Hazardous Liquids (for special requirements for incinerator ships

use the IMCO Interim Guidelines for the Application of the Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk to Ships Engaged in Incineration at Sea)

49 CFR 176.76(g)(3) and 49 CFR 176.83, Stowage and segregation of portable tanks (for solid waste containers).

The PD-246 vessel designs must also comply with the IMCO Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IMCO Resolution A.212(VII)). The IMCO Bulk Chemical Code identifies three classes of chemicals, based on the fire, health, water or air pollution, or chemical reactivity hazards they present. These classifications are the basis for ship cargo protection and survivability standards. The chemical types are:

Type I, products that require maximum preventive measures to preclude escape of such cargo;

Type II, products that require significant preventive measures to preclude escape of such cargo;

Type III, products that require a moderate degree of containment to increase survival capability in a damaged condition.

The PD-246A design further incorporates some proposed amendments to the IMCO Bulk Chemical Code that address pollution hazards. In so doing, the vessels have been designed to the highest standards of marine chemical cargo containment and protection.

The vessel designs must also comply with all the customary U.S. commercial maritime standards,such as those of the U.S. Public Health Service. Finally, as a commercial vessel, the chemical waste incinerator ship would have to satisfy the standards of a classification society, most likely the American Bureau of Shipping, for the purposes of insurance coverage.

E. Design Alternatives

In addition to the single-hulled ship developed for this report, several other options may be viable for a chemical waste incineration at sea system. Any design for this mission must include the following:

*Precontainerize hazardous waste solids and collect liquid wastes;

*Load the wastes with no handling that requires contact with humans;

*Transport the containers and tanks of wastes to the incineration zone in the open ocean;

*Provide a suitable, stable platform for the incinerators, so that incineration can continue under the widest possible range of acceptable weather conditions;

*Return the empty waste containers and any incineration residues to land;

*Make it as easy as possible for the waste generator to deliver wastes to the incineration at sea system.

Among proven technologies of the ocean development industry, alternative approaches to transport and incinerate waste chemicals could include:

1. As an alternative to conventional hull incinerator ships, it is possible to build an integrated tug/barge (ITB) unit. Typically, an ITB is a ship-shaped barge propelled by a specially designed pushing tug that is mechanically linked to the barge stern. The tug-to-barge link is generally rigid, with the two hulls mechanically joined. Alternatively, the ARTUBAR (articulated tug/barge) system connects the tug to the barge by large bearing pins that allow the tug and barge to articulate separately, reducing the hull stresses. The two units move together in rolling and transverse motions, however.
As compared to the conventional hull designs presented, a typical ITB would have the arrangements reversed. With a pushing tug, the incinerators are at the barge's forward end, to be as far from the tug accomodation area as possible. The incinerators must also be placed far outboard to allow clear visibility over the bow on centerline of the tug.

2. A barge-carrying ship system. Fully loaded waste containing barges are collected in the terminal area and then loaded onto the ship. Waste generators adjacent to navigable waterways could even load waste directly into a tank barge at the generating site and deliver the waste to the terminal by waterway. The ship, which is the incinerator platform, would remain outside the heavily trafficked port while the waste containing barges were delivered by tugs. The barge-carrying ship need not enter the inner harbor, so long as sea conditions make it possible to load the barges on the ship.

3. Tethered tug-barge combination. A traditional tug and tethered incinerator barge design would limit the project costs to the barge construction and the tug hire fees. As with the integrated tug-barge system, the tethered barge has inherent flexibility because separate barges can be built for solid and liquid waste disposal systems. The tethered barge also separates the incineration platform from the propulsion platform that has the crew aboard.

4. A ship conversion. In addition to new construction, existing ships may be converted for use as an incinerator ship. However, converting a ship imposes the restrictions of equipping the incineration plant and auxiliary systems within the existing hull.

However, converting a ship can be significantly less expensive than constructing a new ship and the conversion can be completed much sooner, provided that incinerators are available. A converted ship could therefore begin incineration operations earlier than could a specially built ship. On the other hand, the converted vessel could not be expected to stay in service as many years as could a new ship. An existing tanker may be the most easily converted ship.

5. A tug/supply vessel. Using either existing vessels or new vessels, a solid waste incineration platform can be developed. A new vessel of a stock design can be delivered in about 12 months. Tug/supply vessels have a large deck area aft of the forward deckhouse where a solid waste incinerator and material waste canister stowage can be installed. Using this type vessel would allow more than one vessel to be in operation, permitting as many as four vessels to operate from one terminal and burn zone.

III.CONCEPT VESSEL DESIGN DESCRIPTIONS

A. PD-246A AND PD-246B: TWO IMCO TYPE NEW INCINERATION SHIPS

1. Overview

The concept designs presented here are typical cargo ship hulls equipped with extensive auxiliary processing systems to handle and incinerate hazardous chemical waste. The incineration plant, liquid cargo pumps and unattended ship's electric propulsion motors are located aft, with the accommodations, laboratory and attended ship's propulsion diesel-generator machinery spaces located forward, to achieve the maximum separation between the incinerator plant and the ship's personnel. This arrangement increases the safety of the people aboard the vessel, since the separation between the incinerator plant and the forward deckhouse reduces the chance of chemical contamination of the crew or the analytic lab that monitors the incinerators' performance. The enclosed Figures 1 and 2 present the general arrangement of each vessel.

The two designs, PD-246A and PD-246B, are a Type I hull and a combination Type I/Type II hull, respectively. Both the designs carry the same incineration equipment and the same liquid and solid waste cargo capacity. Both ships have diesel-electric generators that provide electric power to both the propulsion motors and to the incineration plant. The PD-246A has five 1,000 kw diesel generators (GM/EMD MG8E7) and the PD-246B has five 800 kw units (CAT-D399). Fitting each ship with five generators provides the most flexible power generating installation to meet the ship's widely varying power requirements. Selecting the diesel-electric power plant also makes it possible to use one power plant for both propulsion and incineration plant loads, rather than the separate power plants which are usually required. Additionally, a 500 hp bow thruster provided on both vessels enables the ship to maintain a constant heading into the wind while it drifts within the burn zone.

The Type I design, the PD-246A, is the more flexible, based on the most stringent IMCO standards for marine chemical cargo containment. Though the Type I standards now apply to only a few chemicals, the IMCO Bulk Chemical Hazards Committee intends to amend the present hazard rating to include pollution risks involved in any ship collision or grounding as well. Therefore, many present Type II candidate chemicals for incineration at sea are likely to be upgraded to require Type I standard cargo containment.The resulting PD-246A ship design is also the more expensive of the two new construction alternatives.

The Type I/Type II combination design, PD-246B, provides the same cargo capacity in a smaller hull. The centerline tanks provide Type I protection and the port and starboard tanks provide Type II protection. Most candidate chemicals for incineration at sea are now rated as Type II chemicals and some will remain Type II even with the amended hazard ratings, so this design will be able to accomodate rating changes. Because of its smaller size and the reduced internal compartmentation, the combination Type I/ Type II design is the less expensive of the two new construction alternatives.

The principal characteristics, lightship weight summary, and table of deadweight and displacement, for both the PD-246A Type I ship and the PD-246B Type I/Type II combination ship concept designs are presented below.

Principal Characteristics

Item	PD-246A	PD-246B
Length overall	137.2m(450'-0")	129.5m(425'-0")
Length bet.perp.	129.3m(425'-0")	121.9m(400'-0")
Beam,molded	25.0m(82'-0")	23.8m(78'-0")
Depth,molded	13.4m(44'-0")	12.5m(41'-0")
Draft, full load	6.9m(22'-9")	7.5m(24'-7")
Propulsion,max	3500HP	3320HP
Service Speed	12 kts.	12 kts.
Range,naut.miles	5000	5000
Accomodations	40	40
IMCO Ship Type	Type I	Type I/II combination

Lightship Weight Summary

Item	PD-246A	PD-246B
Steel	4890	4469
Outfit *	1986	1898
Machinery	400	320
subtotal	7276	6767
margin(10%)	728	677
LIGHTSHIP	8004	7444

* Outfit includes 1000 tons for incinerators and solid waste stowage system.

Table of Deadweight and Displacement

Item	PD-246A	PD-246B
Liquid Waste	7200MT(7088LT)	7200MT(7088LT)
Solid Waste	360MT(355LT)	360MT(355LT)
Other Deadweight	883.8MT(870LT)	883.8MT(870LT)
DEADWEIGHT	8445MT(8313LT)	8445MT(8313LT)
DISPLACEMENT	16,576MT (16,317LT)	16,007MT (15,757LT)

2. Hull

General Arrangements

Forward Deckhouse

On both the PD-246A and the PD-246B, the deckhouse is located forward of the cargo areas and incinerator plant for the purpose of locating personnel living and working spaces as far away from the incinerator plume, heat and potential chemical contamination as possible.

The current IMCO and USCG regulations state that the accomodations must be aft of the cargo areas on chemical carriers. However, the USCG has agreed that a forward deckhouse is reasonable for this special vessel. It is still necessary for IMCO and the Coast Guard to formally determine that the house forward arrangement provides equivalent protection and safety to the present regulations, but it is likely that a waiver could be granted to locate the deckhouse forward of the cargo spaces for an incinerator vessel design.

The forward deckhouse contains the accomodations spaces for all ship's personnel. A chemical analysis lab for plume and waste sample studies is provided on the main deck level aft of the accomodations spaces. The lab has a separate entrance to the main deck and to the interior passageways of the deckhouse, so that chemical samples need not enter the main deckhouse. Lab storage space is located adjacent to the lab space.

Showers and clothing change facilities are also provided immediately aft of the deckhouse on the main deck level. This area includes lockers for crew clothing and work gear, so that crew members can leave dirty or contaminated gear at the entryway, rather than having to enter the accomodations area to disrobe. This also avoids the crewmembers' storing dirty gear in their own quarters. The shower facilities also provide emergency first aid washdown for any people who are accidentally contaminated by the waste chmicals. Medical equipment and a hospital outfit are provided on board to competently provide emergency care for chemical-related injuries and illnesses, such as burns or contamination sickness

Cargo Containment

The cargo containment area is located in the mid-portion of the vessel. Both liquid waste tanks and the solid waste container storage area are located in this area.The U.S. Coast Guard regulations and IMCO require strict isolation of hazardous zones, such as cargo areas, so that detailed design will have to focus on the methods of integrating both cargo systems in the same area. However, the preliminary report will not develop the detailed designs at this time.

The ship is required to dispose of 7200 metric tons of liquid waste per voyage. The specific gravity of the wastes may vary between 0.85 and 1.30, but for this design, a specific gravity of 1.0 has been assumed for the average liquid cargo. When more dense cargo is carried, the vessel's load lines, which indicate the maximum draft legally permitted for that ship to sail, will limit the cargo carried and will prevent the ship from being accidentally overloaded. Since the actual capacity of the incinerators depends on the waste thermal characteristics, as well as the weight of the wastes, this assumption was acceptable. Therefore, 7200 metric tons of tank capacity are provided on both new ships.

The liquid cargo tanks are all stiffened by external structure giving all tanks a smooth internal surface in order to simplify tank cleaning and minimize the possibility of contamination and corrosion in the tanks. Some structural stiffening is in cofferdam spaces between the tanks. These cofferdams provide the cargo separation which is required for incompatible cargoes. Vertically corrugated bulkheads were also used for some tank bulkheads within the cargo areas. The tanks are specified to be internally epoxy coated, but the epoxy is likely to be a special formulation, since the broad spectrum chemical wastes that are expected cargoes for this ship will require especially resistant tank coatings. The selection of tank linings or the development of new tank lining materials for hazardous waste carriage deserves much more attention in the later stages of the chemical waste incinerator ship program.

Tank arrangements differ between the two new ship designs, as is shown in Figures 1 and 2. The PD-246A, which is designed to carry a full load of the most hazardous Type I cargo, has eight tanks of 900 cubic meters each. Type I liquid wastes must be located inside the boundaries of 1/5 the beam of the hull and all cargo tanks must be protected by adequate double bottoms and wing tanks. Designing the ship with the capability to carry exclusively Type I cargoes results in a large amount of ballast tankage, which can be sequentially filled to help the ship maintain a constant draft and uniform ship motions as the cargo wastes are incinerated.

The PD-246B, which is designed to carry combination of 45% Type I and 55% Type II cargo wastes by volume, has twelve cargo tanks, of which only the four centerline tanks can carry Type I cargoes. Chemical wastes of lesser hazards can also be carried in these tanks. The eight port and starboard cargo tanks, which can carry Type II wastes, extend outside the Type I boundaries, but are still protected by wide wing ballast tanks greater than the minimum 760 mm(2'-6") required for Type II protection.

The ship is required to carry ten days worth of solid waste for the rotary kiln, so 360 metric tons of solid waste will be carried. Safety requirements dictate that solid waste be stored topside; therefore, solid waste will be stored on deck within the same boundaries as is the liquid cargo. The solid waste is prepackaged and placed within commercially available containers measuring 1.3m(4 feet) square by 2.6m(8 feet) high. The containers will be secured within a container guide framework, equipped with machinery to transfer the container to the rotary kiln. Each container holds two metric tons of solid waste, so 180 containers will be stowed on the main deck, single height.

Solid Waste Stowage Arrangement

Coast Guard regulations require that all sources of ignition or combustion be at least eight feet above the cargo tanks and ten feet fore and aft of the cargo tank areas, or be provided with equivalent protection. As a result, the solid waste cargo stowage area and handling equipment directly above the liquid waste cargo tanks are separated from the liquid cargo tanks by a three foot high inert gas filled cofferdam void space that extends the full width of the cargo area. This system is expected to provide equivalent protection to the two cargo areas as does the physical separation required in the present regulations. However, this inert gas protection does leave the entire stowage structure well within the boundaries of the hazardous zone. Further design will have to include developing and justifying a system that provides equivalent protection, in order to receive formal approval from either the Coast Guard or IMCO.

The Incineration Plant Area

The incinerators and their auxiliaries are located aft. Also located aft are the incinerator machinery room, the incinerator control room, an equipment room used to store special plume monitoring devices, the propulsion motors, and the cargo pumproom. There should be adequate space both on deck and below decks for research and testing areas desired by EPA. Personnel may travel from the deckhouse to the incinerator area via enclosed passageways located port and starboard immediately below the main deck.

The experimental rotary kiln is located aft of the cargo area, flanked on both port and starboard by the two forward liquid injection incinerators. This location is exposed to ship pitching motions, but placing the kiln here is considered least disruptive to the kiln operations. Adequate distance is provided between the kiln and the liquid injection incinerator that serves as afterburner for the rotary kiln flue gas exhaust. The kiln/liquid injection incinerator combination is on the ship's centerline, with the two other liquid injection incinerators located outboard of the kiln's forward end. The clearances between and around all the incinerator units on both the new construction designs should be sufficient for all anticipated deck operations.

Structure

The material for both new vessel designs is mild steel. No unusual structural problems are anticipated which would require extensive use of high strength steel.

Stability

Intact: Trim and stability calculations were done for full load departure (in port) and ballast departure (on site) conditions. Both conditions have satisfactory intact stability. Because there is a large amount of available ballast capacity in the PD-246A and a lesser amount in PD-246B, the trim and stability for other conditions will be satisfactory with proper adjustment of ballast.

Damage: Damage stability calculations were done for a number of operating conditions and locations of damage. In order to meet USCG and IMCO requirements on the PD-246A, open crossflooding is necessary between pairs of port and starboard wing tanks. As a result of open crossflooding, a loading restriction is required such that each pair of wing tanks is either full pressed-up or empty at all times to avoid large free surface effects. For the PD-246B, a forecastle was added above the main deck forward of the deckhouse in order to meet USCG and IMCO requirements. Open crossflooding between pairs of tanks is not required because of the different tank arrangements.

Speed and Power

The PD-246A and PD-246B vessels are designed to maintain 12 knots cruising speed with a service power of 3500 HP and 3320 HP, respectively.

Seakeeping

The roll period for both new construction designs is estimated at 14.5 seconds, well above the most frequent wave periods for most seas. As a result, resonant roll should be an infrequent problem. This is crucial since the vessel will be drifting between 60 degrees and 90 degrees off the wind when the incinerators are burning. Preliminary estimates of the maximum pitch angle are about 2 1/2 degrees (single amplitude) for both designs. This is unlikely to disrupt the operations of the kiln. A detailed seakeeping analysis should be undertaken for more advanced levels of design. Future designs will investigate the use of passive tank stabilizers as a means of controlling the platform motions to some extent.

3. Propulsion and Electrical Machinery

The new Chemical Waste Incinerator ship will have a service speed of twelve knots,provided by a diesel electric propulsion plant. Two attributes of the diesel electric machinery determined its selection. First, the diesel generators that supply the power to the electric propulsion motors can be located apart from the motors. In this ship design, the propulsion motors must be located aft, below the incineration systems. The diesel generators, however, are installed forward, below the accomodations deckhouse, so that the attended machinery space, where the ship's crew will spend most of the voyage, is separated from the incineration system and the waste cargo spaces. Second, the power produced by the diesel generators can be used for the incineration plant when the propulsion plant is idle or operating at reduced speeds. This "power pool" arrangement makes it possible for the ship's total power needs to be supplied by a single installation, rather than having separate ship's propulsion and ship's service generator installations.

Five diesel driven AC generators will be installed. They will be connected via a common bus to two propulsion motors, through a silicon controlled rectifier (SCR) that converts the AC generated power to DC propulsion power. The propulsion load is easily accomodated by four diesel generators, always leaving the fifth as a backup. However, linking multiple generators to a common bus allows the flexibility to accomodate the ship's varying power and propulsion conditions without severely overloading or underutilizing the individual units. Likewise, the two tandem-mounted propulsion motors are preferred because one can be shut down during the ship's reduced speed (6 knots) operation while the ship is in the incineration zone. For the reduced speed conditions, the tandem motors also provide greater redundancy for emergency backup.

A 500 HP bow thruster will enable the ship to maintain a constant heading into the wind as the ship drifts in the incineration zone. The bow thruster can also assist the vessel's docking or undocking at the waste loading terminal.

The incineration plant electric power can be supplied from the same installed propulsion diesel generators, since simultaneous incineration and full speed propulsion is not planned. During the ten day incineration operation, propulsion will be limited to six knots steaming or intermittent bearing adjustments that can be accomplished with the bow thruster alone. Neither of these conditions requires more than 500 HP, which leaves ample power for the incineration plant's operations.

Likewise, the customary ship service load can be supplied by the installed diesel propulsion generators.The ship service load is estimated to be about 540 HP(400 kw).

The basic information on the installed machinery follows.

Propulsion and Electrical Machinery

Item	PD-246A	PD-246B
Diesel Generators	5 @ 1,000KW	5 @ 800KW
Propulsion Motors	2 @ 2,000HP	2 @ 1750HP
Required Propulsion Power,approx.max.	3500HP	3320HP
Req'd Incineration Power,approx.max.	1500HP	1500HP

4. Incineration Systems

Both liquid waste and solid waste incineration systems are provided on the PD-246 new construction concept designs. Each system is sized for ten days continuous operation and consists of a waste stowage system, a delivery or feed system to transfer waste to the appropriate incinerator, the incinerators, and auxiliary equipment, such as combustion air blowers and combustion monitors.

Any contamination of the ship by its hazardous waste cargoes must be avoided. In addition, the extreme service conditions for the incinerators and the cargo containment systems make it important for the ship to be able to continue operations on a partial basis, even if some equipment is shut down for maintenance or repairs. Modular component design has therefore been emphasized for both the solid and liquid incineration systems. For example, the rotary kiln is securely mounted on a deck foundation, but could be easily removed from the ship if necessary.

Liquid Incineration System

Three vertically mounted, liquid injection incinerators are to be installed in the stern deck area. Each can burn ten metric tons/hour, so that the plant capacity is 30 metric tons/hour. The capacity of the liquid injection units, combined with the ten day operations assumption, set the size of the PD-246 new construction concept designs.

Liquid wastes will be loaded into the ship's epoxy lined cargo tanks using shoreside pumps and dockside loading gear at the ship's terminal. At the burn zone, the wastes will be fed into the preheated incinerators via uncoated extra heavy mild steel pipes and cargo pumps. The waste feed and transfer system will be arranged so that any incinerator can take waste from any cargo tank and deliver it to any liquid injection incinerator.

Additionally, one of the three liquid incinerators will be the afterburner for the experimental solid waste rotary kiln, to complete the destruction of the solid phase chemicals that may be only vaporized in the kiln. The other two liquid injection units will have no attached kilns. However, any large scale expansion of the solid waste incineration capacity would require that the other two liquid injection units also be used as afterburners for any kilns added later.

Solid Waste Incineration Plant

The solid wastes rotary kiln is the most experimental facility in the PD-246 concept designs. The 1.5 metric ton/hour rotary kiln unit selected is well proven in landbased operations, but is entirely untested for use aboard a ship moving in a seaway. The problems of safely loading, handling, and incinerating the solid wastes have affected the overall ship design in several respects. Specifically, the kiln's operations and solid waste cargo transfer to the kiln are likely to be affected by the ship's motions and some compensations have been provided in the concept designs.

The rotary kiln incinerator is a 3m(10') diameter by 5m(16') length drum mounted at an angle along the longitudinal axis, with one end of the drum higher than the other end. Gravity "tumbles" the wastes along the length of the incinerator drum, so that wastes loaded into the upper end of the drum are completely burned by the time they tumble to the lower end of the drum. The combustion "residence" time of the wastes in the kiln can be adjusted by either slowing or speeding up the incinerator's rotation. Adequate residence time of the solid wastes in the kiln is critical for achieving complete thermal destruction. The drum will be mounted with its axis parallel to the ship centerline to minimize the effect of roll on the waste residence time. However, the kiln will still be vulnerable to the ship's pitching motions and large pitching angles could conceivably tumble the material out of the kiln before combustion is complete. Preliminary estimates are that the maximum pitch angle will be about 2 1/2 degrees, which is unlikely to disrupt the rotary kiln's operation.

The ship's vibrations and roll motions impose additional loads on the kiln's external rotary drive. However, two major vibration sources aft, the propulsion motors and the propeller, will be idle much of the time that the solid waste incinerator is operating. They will otherwise be operating at a reduced load. Also, the diesel generators, another major source of induced vibration, are located forward, remote from the incinerators. Therefore, ship source vibrations should not be disruptive to the rotary kiln. Vibration isolation mountings and a modified rotary drive will alleviate the effect of vibration and roll. A more detailed analysis of this equipment would be part of further design development.

The residue ash from the kiln will drop into a quench pit at the exit end of the kiln. The ash is estimated to range from one percent to twenty-five percent of the waste, but ten percent is a reasonable allowance. The ash will be retained on board until the ship returns to its loading terminal, where it can be removed by shoreside equipment. Although it is possible to discharge solid waste ash overboard if the material is inert, the design has conservatively provided a quench pit large enough to handle residues from the 360 tons of solid waste to be carried.

Solid Waste Stowage and Incinerator Waste Feed System

Solid wastes will be stowed on deck in intermediate size bulk containers, each of which can hold about two metric tons of wastes. One hundred eighty container stowage cells will be provided on deck above the liquid cargo tanks. Dockside cranes will place each container into a specified cell of the solid waste stowage structure, much as dockside cranes load standard transportation containers into cell guides on cargo ship decks. The waste container, once locked in place, will not be released until it is delivered to the waste incinerator. Only one container per hour needs to be delivered to the incinerator, so that only one container at a time needs to be removed from the stowage area. A light duty crane, mounted on the overhead structure of the waste container stowage area, will remove each container from its cell and deliver it to the transporter on the ship's centerline. The transporter will lock onto both the container and the conveyor and will move the container to the incinerator.

At the incinerator, a lifting mechanism specifically for use with these containers will elevate the container to the incinerator feed chute. The container hatch will be automatically opened and the solid wastes will be fed into the chute. After the container is emptied, the door will be automatically closed and the container will be lowered to the transporter. The transporter will return the solid waste container to the stowage area, where it will be returned to its cell. Stowing the waste containers in specific cells will permit waste incineration to be sequenced based on the known contents of the waste containers, so that adequate residence time and adequate combustion can be assured. A programmed burn sequence would also make identification of the incinerator contents simpler, in case of accident or incinerator shutdown.

B. PD-246C: Converting a National Defense Reserve Fleet Ship to a Chemical Waste Incinerator Ship

Since the Maritime Administration/ Maritime Subsidy Board has offered to make a National Defense Reserve Fleet ship available for conversion to a chemical waste incinerator ship, the NDRF was investigated as a source of a lower cost single hull alternative. However, the selected conversion scheme was neither attractive nor satisfactory. The ships, for one reason or another, could not be made to meet regulatory body requirements without an exceptional amount of modification and extra cost. The basic design of many NDRF ships make it impractical and expensive to place the attended machinery spaces and accomodations forward of the cargo area and separated from the incineration plant area. This arrangement is desirable to ensure maximum distance between the personnel on board and the incinerators, as well as to ensure that the incinerator exhaust plume does not impinge on the living and working areas of the ship.

The selected NDRF vessel for a practical and satisfactory conversion was an LSD-12 class (Landing Ship Dock) ship, a former Navy vessel. The LSD vessel has accomodations and navigation spaces forward and a large cargo well amidships and aft that opens to the sea by a stern gate when the ship is partially submerged. It also has twin machinery and twin screws, port and starboard amidships in the wingwalls of the hull on either side of the cargo well. It appeared that the desired separation between incinerators and the accomodations and attended machinery could be attained with this vessel. A design study, PD-246C, was made, with new independent liquid cargo waste tanks in and over the center well, aft of the house. Liquid waste incinerators and solid waste rotary kiln were located aft of the area, with solid waste stowed over the cargo tanks, as in the new ship designs, PD-246A and PD-246B, which are presented in this report.

The conversion would have been less than ideal, however, as the vessel's draft was greatly increased, which created poor seakeeping and propulsion characteristics. Also, even at a deeper draft, the LSD could not carry the desired load capacity within the available cargo conversion spaces. Finally, the PD-246C design would not meet U.S. Coast Guard requirements that the machinery be clear of the cargo tanks. The conversion design would need a complete new propulsion plant located in a different part of the ship, which would be prohibitively expensive to install. This coupled with other conversion costs and the design disadvantages already noted, eliminate the PD-246C conversion from further consideration at this time.

However, though the LSD is inappropriate for a chemical waste incinerator ship equivalent to the new ship designs, the LSD may still be a useful platform for alternative projects in the Chemical Waste Incinerator Ship Program. Specifically, the LSD would probably be satisfactory as a platform for a "solids only" incineration at sea plant. The restrictions against the proximity of machinery and packaged "dry cargo" are not as stringent as are those between machinery and liquid cargo. There is ample room within the cargo well for a research and development scale rotary kiln and cargo stowage system. Besides the cost of installing the solid waste stowage handling and incineration equipment, however, there would be other large costs: reactivating the old vessel; putting it "in class" with the classification societies as a commercial vessel, rather than its original Navy designation; renovating and modernizing the existing obsolete steam power plant; renovating and modernizing the accomodations; and extensive replacement or strengthening of old and pitted steel hull plating.

Further evaluation of an LSD or any other NDRF ship conversion to a chemical waste incinerator ship was not pursued.

IV. CONSTRUCTION SCHEDULES

A. PD-246A: A New IMCO Type I Chemical Waste Incinerator Ship

About thirty months will be required for the PD-246A design's construction, based on the anticipated 870,000 labor hours involved in the project. An expected start fabrication date after six months leaves twenty-four months to construct the vessel from start of fabrication to delivery.

B. PD-246B: A New IMCO Type I/Type II Combination Chemical Waste Incinerator Ship

About thirty months will also be required for the PD-246B design's construction, as it is estimated to require 790,000 labor hours to complete.

V. CONSTRUCTION COSTS

JULY 1980 BASE PRICES	PD-246A	PD-246B
Contract Drawings	$ 1	$ 1
Construction Contract (1)	$53	$50
Spares, Plan Approval and Inspection	$ 1	$ 1
TOTAL=	$55	$52
ESTIMATED FINAL COSTS (2)=	$80	$75

NOTE (1) Each alternative includes $14 million for the subcontracted incineration systems.

(2) Estimated final prices are based on a contract award date of October 1982 and a delivery date of March 1985 for both ships. 10% per annum inflation rate is assumed.

B. Incineration System Equipment

July 1980

INCINERATION SYSTEM EQUIPMENT
COST AND WEIGHT ESTIMATES

Incinerator	Approximate Costs($1000)	Weight (mt)	Installation Costs($1000)	Total Cost ($1000)
Rotary kiln (1.5 mt/hr solids)	900	50	219	1,119
Liquid Injection Unit (10 mt/hr)	2,500	300	1,312	3,812
Two additional Liquid Injection Units	5,000	600	2,624	7,624
Total Costs & Weights	8,400	950	4,155	12,555

Reference: TRW, Inc. Report, August 1980.

VI. OPERATING COSTS

A. Chemical Waste Incinerator Ships

For both the Type I and Type I/II ship, an operating crew of thirty three is estimated to be needed, in addition to the scientific and incinerator operating crews. The estimated vessel operating expenses per typical two week voyage are given below:

Ship Type	Type I	Type I/II
Wages	$6340	$6340
Subsistence	290	290
Stores, Supplies, Eqpt.	300	290
Maintenance & Repair	832	790
Insurance *	2040	1890
Other	100	100

Daily Vessel Operating Expenses are $9900 for the Type I ship and $9700 for the Type I/II ship. The vessel operating costs per voyage are therefore approximately $138,600 and $135,800 for each ship, respectively.

* Insurance estimates include coverage for Hull and Machinery, Protection and Indemnity (P&I), and War Risk, but do not include protection against liabilities arising from water and/or air pollution.

Additionally, fuel costs for propulsion fuel alone are about $29,000 per voyage for each ship, based on a fuel consumption of 115 metric tons and a fuel price of about $250.00 per metric ton.

Therefore, vessel operating costs, independent of laboratory and incineration plant costs are approximately $167,600 per voyage. Additional insurance for coverage of the ship's particular mission will increase that cost.

B. Incineration Plant

The operating costs for the incineration plant are not included in the standard operating costs for this vessel. Large cost elements in the operating costs for the incineration plant are the personnel required to operate the incinerators, the personnel required to perform environmental and chemical analysis of the burn in progress, and the auxiliary fuel used to "boost" the combustion of low thermal value chemical wastes.

The incinerators are specified to operate continuously, so that round the clock incinerator operator crews have been anticipated. Three people are likely to be needed to fully monitor the liquid and solid waste destruction, so nine incinerator operators are needed. These people are likely to be paid similarly to engineering officers on the ship operating crew.

The number of environmental monitoring personnel will depend on several factors: whether the waste to be burned has been monitored already, whether full scale chemical analysis will be done on the ship or at the shore terminal, and whether a periodic full spectrum performance analysis on the incinerators and their effluents is to be included in the monitoring on a long term basis. Though all these varying circumstances mean that the number of environmental monitors could change frequently, preliminary estimates for the crew have been developed. Much more detail in this category should be developed for further stages of the Chemical Waste Incinerator Ship Program.

The preliminary estimates are given below.

ENVIRONMENTAL MONITORING PERSONNEL

Senior Chemist	1
Senior Technician	3
Junior Technician	1

Auxiliary incinerator fuel will also be required for three purposes. First, fuel will be needed to heat the combustion chamber before self-combusting chemical waste is injected into the incinerator. Fuel is also needed to ease the thermal shock to the combustion chamber as it cools after waste combustion is stopped. Second, fuel will be needed to blend with some waste cargoes in order to guarantee sufficient heat value to completely destroy the waste. Third, fuel will be needed to "thin" some viscous cargoes to a pumpable liquid that can be incinerated efficiently.

Diesel fuel alone is burned for warming up the incinerators and for gradual cooldown. Each liquid injection unit burns about five metric tons of fuel per hour during warmup or cooldown. During a ten hour warmup, the three incinerators will burn about 150 metric tons of fuel and an additional five hour cooldown would consume about 75 metric tons. At about $250 per metric ton, incinerator auxiliary fuel for warmup and cooldown will cost about $56,250.

Fuel costs for the second usage, blending with waste cargoes, is much more difficult to predict quantitatively. The ideal cargo will self-combust and many cargoes can be burned with no auxiliary "booster" fuel. The cost of incinerating low heat value waste cargoes will include the cost of the additional fuel that is needed to successfully incinerate the low heat value waste. If high heat value wastes can be blended instead, the additional fuel cost can be avoided.

Finally extremely viscous wastes can be thinned with either fuel or other liquid wastes. As with the previous case blending different wastes to reduce viscosity will eliminate additional fuel costs.

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APPENDIX D

to

REPORT OF THE INTERAGENCY AD HOC WORK GROUP FOR THE CHEMICAL WASTE INCINERATOR SHIP PROGRAM

DESIGN REQUIREMENTS FOR A WATERFRONT FACILITY TO SUPPORT CHEMICAL WASTE INCINERATOR SHIPS

FINAL REPORT

by

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CONTENTS

FOREWORD

This appendix describes the preliminary design of a waterfront facility as part of the U.S. flagship system for incineration of chemical waste at sea. This facility will do the following:

- receive liquid and solid hazardous wastes either by land or by waterborne barge transport
- analyze, blend, shred, and containerize or package the materials as appropriate for incineration at sea
- load the waste aboard ship in a safe and efficient manner
- remove and receive residues from the incinerator ship for analysis and disposal either on land or at sea, in the case of incineration of wastes producing a collectable residue during disposal

This design deals only with the equipment and processes located within the waterfront facility and does not consider transportation of the chemical waste to and fromthe facility or the ultimate disposal of the waste, other than to provide for the interface with the appropriate transportation modes. This design is preliminary and site-independent. More detailed design requires selection of a site and further analysis.

The discussion in this appendix begins with a definition of the criteria for the design and proceeds with descriptions of both the process flow and the actual facility. Capital and operating cost estimates are presented, and a survey of existing terminals which could be used as chemical waste waterfront facilities is summarized.

SUMMARY

Several design criteria were used in the preliminary design and will also apply for subsequent design stages. The facility must accommodate wastes in almost any physical form and in several types of containers, some of which may be older, corroded, and possibly leaking. Ideally the facility would service three transportation modes of delivery of wastes: truck, rail and barge. The facility must consecutively accommodate up to two incinerator ships, each of which is on a two-week cycle. The required waste storage capacity of the facility is as follows:

Liquid Waste	30,000 m^3 (181,000 bbl)
Solid Waste	1,800 m^3 (64,000 ft^3)

The facility must also provide for preparing and blending wastes for optimum transfer and combustion, and for unloading ash residue from the incineration process from each ship.

The ideal site for the facility would be located where potential environmental impact is minimal, transportation time for the various modes are minimal, and topography is convenient. Structural standards must be carefully followed, and these are normally 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 reach soil, water, or air. In general these criteria are specified by federal regulations.

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, along with the tanker decontamination rinse, will also be blended and pumped to the storage tanks.

Solid waste arriving at the site will be unloaded at the unloading rack, prepared for incineration by shredding, and placed in bulk material containers (BMC) to be loaded on the ship.

The 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.

The waterfront facility is designed to prevent emission of hazardous materials; to contain spills, leaks and other accidents; and to minimize harm to personnel in the event of accidents. Planned measures include the following:

- collection and disposal systems for vapors from waste transfer
- detailed material balance audits
- dry break valves which prevent spillage during disconnecting
- above ground plumbing and convenient access to fittings
- use of corrosion resistant materials
- pipes sloped away from points of potential discharge
- complete fire prevention and control systems
- security provisions including guards and continuous fencing around facility
- special training in hazardous wastes for personnel
- effluent and media monitoring in and around facility.
- dikes around liquid storage areas

The facility is expected to require approximately 75,000 square meters (18 acres) of land and will require a staff of approximately 40 to operate on a two-shift schedule.

Capital costs for the installed facility (excluding dock rental and land costs) are estimated to be $19 million in 1980 dollars. Land costs will vary greatly depending on the location and are expected to be in the range $5 to $20 million. The operating costs, including labor, maintenance, depreciation, power and ash disposal, are estimated to be $4 million annually.

This excludes insurance costs and potential land and dock rental costs. Insurance premiums are estimated to be $3 million to $6 million annually. In case the land and dock will not be purchased, lease costs will be at least $300,000 annually.

The survey of existing terminal facilities in the United States found that 139 ports and 1,221 terminal docks, piers or wharves on the East, Gulf, and West coasts of the continental U.S. have sufficient water depth and space to receive the incinerator ship. These terminals are concentrated primarily in the states of Texas, New Jersey, Louisiana, California and New York. Most terminals are privately owned. These owners feel that compliance with regulations not yet finalized is the major determinant of their ability to handle hazardous wastes. The technical feasibility to handle these wastes is a secondary question. Several military depots appear to have capability for handling both liquid and solid hazardous wastes and this possibility should be explored further.

None of the bulk liquid terminal operators thought it advisable to provide solid waste service at a bulk liquid terminal, primarily because of differences in the handling characteristics of the wastes. Although separate facilities for liquid and solid wastes are not necessarily a recommendation of this report, it is suggested that this apparent concern be investigated further.

D.1 DESIGN CRITERIA

The waterfront facility must meet several sets of external requirements and constraints imposed by pertinent regulations and by considerations associated with the functioning of the entire system for shipboard incineration of chemical waste. These requirements and constraints translate to design criteria and fall into four categories: system requirements, facility location, structural criteria, and safety, health, and environmental criteria.

D.1.1 System Requirements

This section defines the requirements of the waterfront facility as a part of the entire system design for chemical waste disposal using incinerator ships. These requirements include waste types, transportation modes that the facility must accommodate, the necessary waste throughput and storage capacity, the preparation necessary before loading onto the incinerator ship, and the capability to handle the ash residue from solid waste combustion.

The waste type to be expected at the facility has been defined in Appendix C of this report:

> "...combustible, organic hazardous chemicals, including organohalogens and other petrochemicals whose combustion generates very corrosive flue gases."

It must be expected that waste delivered to the facility could take almost any physical form, including bulk solids, liquids, pulp, granular solids, slurries, and mixtures of any of these. Some waste will be delivered in mobile tankers, other waste will be in containers. Common forms of containers expected for the delivered waste are 55 or 30 gallon steel drums, fibrous drums, and bulk containers filled with bottles and cans of miscellaneous size. Most containers (especially older containers) holding liquids will be corroded and leaking.

The ideal facility would service three transportation modes for delivery of waste: truck, rail, and barge. Access to the facility from transportation corridors, appropriate unloading equipment, and decontamination areas must be provided for each of the actual modes.

The facility must consecutively accommodate up to two incinerator ships, each of which is on a two week cycle. This cycle is described in Appendix C. The capacity of each of these ships is as follows, where the cargo weights for liquid and solid wastes have been equated to volumes by assuming that the specific gravity of the liquid waste is 1.0 and the bulk density of shredded solid waste is approximately 0.8 g/cm^3 (50 lb/ft^3).*

	Cargo Weight	Cargo Volume
Liquid Waste	7200 metric tons**	7200 m^3 (45,300 bbl)
Solid Waste	360 metric tons	450 m^3 (16,000 ft^3)

These values also represent the weekly throughput of waste from the facility It is recommended that the storage capacity of the facility represent four weeks of throughput. The required volumetric storage is as follows:

Liquid Waste	30,000 m^3 (181,000 bbl)
Solid Waste	1,800 m^3 (64,000 ft^3)

The waste delivered to each ship must be prepared and blended for combustion. Shredding will be required for some solids, and liquids will be blended to optimize the heating value of the waste stock in storage at the facility and to improve the properties of liquids (such as viscosity) during transfer operations. In some cases, it will be necessary to add fuel oil to the waste to provide the necessary combustion temperature. It is recommended that this fuel oil be blended with the waste at the facility, although it is possible for the ship to add fuel oil during combustion at the burn site.

The facility must also provide for unloading the ash residue from the incineration process from each ship, storing it, and loading it for transport to ultimate disposal. If this ash represents 10 percent by volume of

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*This value is used here to calculate a conservative volumetric requirement for storage. The actual average density is difficult to estimate. Actual material and bulk densities range widely.

**1.0 metric ton = 0.98 long ton

the original solid waste, the weekly throughput of residue will be 45 cubic meters (1,600 cubic feet). Four weeks of storage is equivalent to 180 cubic meters (6,400 cubic feet).

D.1.2 Facility Location

This section defines the locational requirements for the facility in conjunction with port shiploading facilities for incinerator vessels. Major considerations in the selection of potential sites for locating such a facility include public safety, protection of the equipment, and cost. The ideal site would:

- not be located in a heavily populated area
- not be located in a fault area nor in a 100 year flood plain (Resource Conservation and Recovery Act (RCRA) requirement; 40 CFR 250.43-1)
- be located so as to minimize transporation time and distance to the facility
- be located in close proximity to an existing or potential hazardous waste landfill
- be located where port facilities are adequate for safe harboring and loading of incinerator vessels.

The ideal facility would service three transportation modes for delivery of wastes including truck, rail and barge. Locating the facility near existing transportation corridors will minimize system costs and reduce some safety risks inherent in transporting hazardous materials long distances.

The standards applicable to transporters of hazardous waste are addressed by RCRA. These standards are coordinated with applicable U.S. Department of Transportation regulations for identification and transport of hazardous materials, 49 CFR Parts 171-173 and 179.

Also of concern in locating the terminal is the proximity to a landfill approved for disposal of hazardous wastes. The terminal will receive hazardous incineration residues which must be disposed of in an environmentally acceptable fashion on land. RCRA 40 CFR Parts 264 and 275 are standards applicable to owners and operators of hazardous waste treatment, storage and disposal facilities. These standards will apply to the waterfront facility and will also delineate land disposal facility requirements for hazardous waste.

From the system design standpoint, it is optimal that the facility be located at the waterfront, although it may be necessary, depending on the specific site, to locate the unloading and storage subfacilities away from the water. In order to preserve the general applicability of this appendix, the terminal design has been based on the assumption of a waterfront facility. The adequacy of the terminal facilities must be addressed with local port authorities. The port must provide safe harboring and loading facilities, and be capable of meeting the 7 meter (23 foot) draft, 25 meter (82 foot) beam, and 140 meter (450 foot) length requirements of the incinerator vessel.

D.1.3 Structural Criteria

Structural criteria depend largely on local conditions and local building codes. Earthquakes on the West Coast and high winds due to hurricanes on the Gulf of Mexico coast would be primary considerations for structural design of facilities in those areas. Another factor varying locally is the bearing capacity of the soil at the site. An example of an appropriate building code is the South-East Region Uniform Building Code (UBC) used by many municipalities in the Gulf Coast region. Under the UBC, the wind velocity used for structural design in these areas is 110 mph. In addition, structural design must be consistent with local zoning plans and all local, state and federal regulations.

Particular attention must be paid to the strength of the storage tanks *and the vulnerability of pipelines carrying hazardous materials to heavy* winds and earthquakes. In addition, all structures should be designed to withstand explosions, and storage tanks and other facilities coming into direct contact with hazardous wastes must be designed of materials which are resistant to corrosion.

D.1.4 Safety, Health and Environmental Criteria

This section addresses the safety, health, and environmental requirements for the waterfront facility. Design and equipment requirements for the facility will be influenced by regulations dealing with the handling, storage and disposal of the most toxic and/or hazardous substances. Pertinent regulations concerning safety, health and environmental criteria include standards for facility monitoring, personnel health and safety, environmental protection and contingency planning.

Facility Monitoring. Standards in RCRA for owners and operators of hazardous waste treatment facilities require that operators prevent air emissions which would violate standards or regulations promulgated under sections 110-112 of the Clean Air Act. Control and disposal of vapors and other discharges of hazardous substances as a result of facility operations are essential for the protection of personnel and the environment. To insure that no federal, state or local air or water quality regulations are violated, proper facility design and an adequate monitoring program are necessary. The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) part 165 also recommends the establishment of monitoring systems at pesticide waste disposal facilities. At a minimum, samples from the surrounding air, water, wildlife and plant environment should be tested in a regular program to assure minimal environmental impact. Analysis should be performed in accordance with Association of Official Analytical Chemists (AOAC) methods and standard methods described in federal environmental regulations. It is important that testing protocols and schedules be carefully defined during consequent stages of the facility design process.

Personnel Safety. Regulations controlling the health and safety of personnel in the working environment are addressed in the OSHA Safety and Health Standards, 29 CFR 1910, Subpart H (Hazardous Materials) and Subpart Z (Toxic and Hazardous Substances).

Under section 19a of FIFRA, procedures and regulations are established for the disposal or storage of pesticides and pesticide containers. Under Subpart C, section 165.10, safety precautions are delineated.

The maintenance of personnel safety requires the implementation of an effective personnel hygiene program and appropriate safety procedures. A comprehensive health and safety plan must be developed for the waterfront handling facility. This plan should be in compliance with pertinent regulations and include basic requirements for effective personnel hygiene and equipment.

Contingency Planning. Key elements of a contingency plan include preparedness, prevention, notification, and emergency procedures. Although site specific details cannot be addressed in this appendix, the basic features of these elements can be discussed. Upon selection of a facility location, a detailed contingency plan must be prepared in accordance with RCRA regulations in 40 CFR 265.5 and Section 311 of the Clean Water Act.

Design of the facility should provide for emergency control. Emergency equipment such as safety suits, shovels, brooms, pails, and sandbags should be prominently located and available for use in containment activities. Site personnel must be trained in the use of emergency equipment as well as the maintenance of facility storage and handling equipment. Local hospitals, fire departments and emergency response teams must be apprised of facility operations.

The facility emergency coordinator should be completely informed of any release of chemical waste that either reaches or has the potential to reach soil, water, or air. All incidents must be documented with respect to time, location, severity, cause, type of pollutant, etc. The recommended notification format is the U.S. Air Force Pollution Incident Notification Format, AFR 19-1, Items 1 through 12. Standard forms have been developed and are readily available for this purpose.

Incidents which are judged to be major by the facility emergency coordinator also require immediate notification of the facility supervisor and the following:

- EPA Regional Administrator or his designee
- Oil and Special Materials Control Division, Spill Prevention and Control Branch, EPA, Washington, D.C.
- U.S. Coast Guard (USCG) National Response Center (NRC), Washington, D.C.
- Director, Center for Disease Control, U.S. Public Health Service, Atlanta, Georgia.

For incidents that occur during non-duty hours, the NRC will use a list of on-call personnel from the Oil and Special Materials Control Division, EPA, Washington, D.C., to implement notification.

Incidents which have the potential to reach coastal waters are under U.S. Coast Guard jurisdiction. In those cases, initial spill notification will be made to the appropriate USCG District Headquarters. Previously listed notifications will be made immediately following Coast Guard notification.

All agencies must be contacted in the above scheme. If notifying personnel are unable to contact a listed agency, the next listed agency should be contacted. This procedure continues until all agencies have been contacted.

In the case of minor spills, leaks or discharges, the facility emergency coordinator can determine the appropriate cleanup procedures. Minor incidents must also be documented, although notification requirements are not as extensive as for major incidents. The recommended notification format is the U.S. Air Force Pollution Incident Notification Format, AFR 19-1, Items 1 through 12.

D.2 PROCESS DESIGN

Figure D-1 is a generalized process flow chart. Although it may be found preferable in subsequent design phases to have separate waterfront facilities for liquid and solid wastes, this appendix considers only the case of a combined facility. The advantages of separate facilities will depend on existing locations and more detailed analysis of operational considerations.

Each of three major waste streams is processed in a different manner Liquid waste in drums and other containers will be sent through a shredde in the dedrumming facility. Liquid from both the containers and the decontamination of the containers will be blended for incineration, if necessary, and pumped to storage tanks. Liquid waste arriving in tank trucks or tank cars will be transferred to the receiving and testing tanks. Then, along with the tanker decontamination rinse, these wastes will be blended, as necessary, for incineration and pumped to the storage tanks.

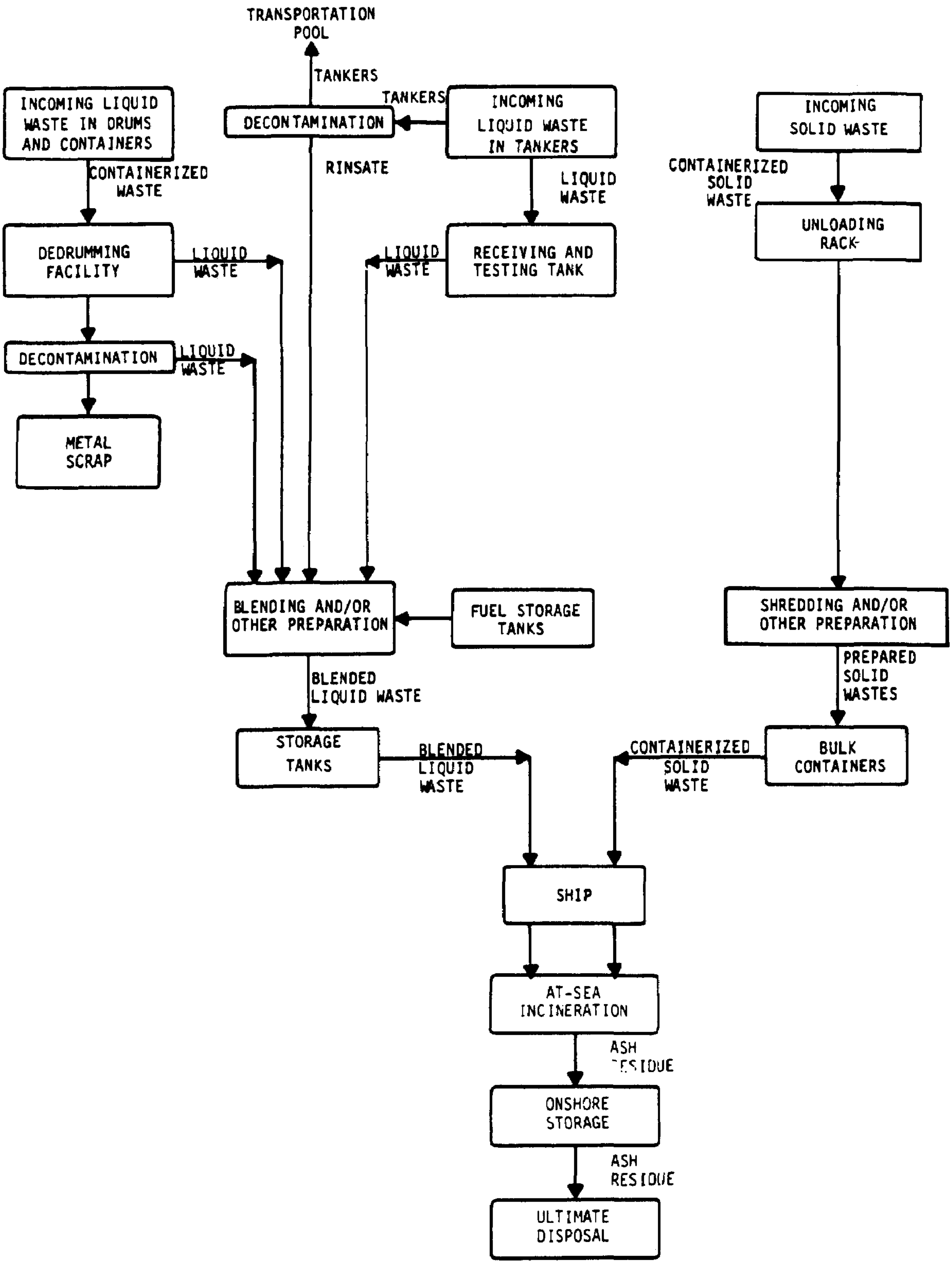

Figure D-1. Waterfront Facility Process Flow

Solid waste arriving at the site will be unloaded at the unloading rack, prepared for incineration by shredding, and placed in bulk material containers (BMC) to be loaded on the ship.

The 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.

Detailed records must be kept at all stages of the flow of wastes through the site. Mass balances will be calculated to help prevent loss of hazardous material. Particularly important are records of incoming waste quantities, amount of solvent used in decontamination, blending ratios, amounts of material in storage, amounts loaded on ship, and quantities of ash residue returning to and leaving the site. Care must be taken to continuously inventory waste disposition. This will allow proper blending practices and, in the event of a spill or leak, identification of the source will be sufficient to identify the material and decide on appropriate action.

D.3 PRELIMINARY FACILITY DESIGN

The waterfront facility area, occupying approximately 75,000 square meters (18 acres), includes a support building; chemical waste receiving, preparation, and storage facilities; and ship loading and unloading facilities. Figure D-2 shows a conceptual layout of the facility. (The layout for the actual site will be somewhat different due to specific topographical and property considerations.) Open space for expansion of these various facilities is also provided. The perimeter of the site is enclosed with a fence having rolling gates at the road entrance and at the rail siding entrance. The access road enters the complex and leads to the receiving tanks, the tanker decontamination facility, the solid waste storage area and the residue storage area. The rail siding provides access to both the receiving tanks and the tanker decontamination facility.

D.3.1 General Features

The waterfront facility is designed to prevent emissions of hazardous materials; to contain spills, leaks and other accidents; and to minimize harm to personnel in the event of accidents. Several measures will be

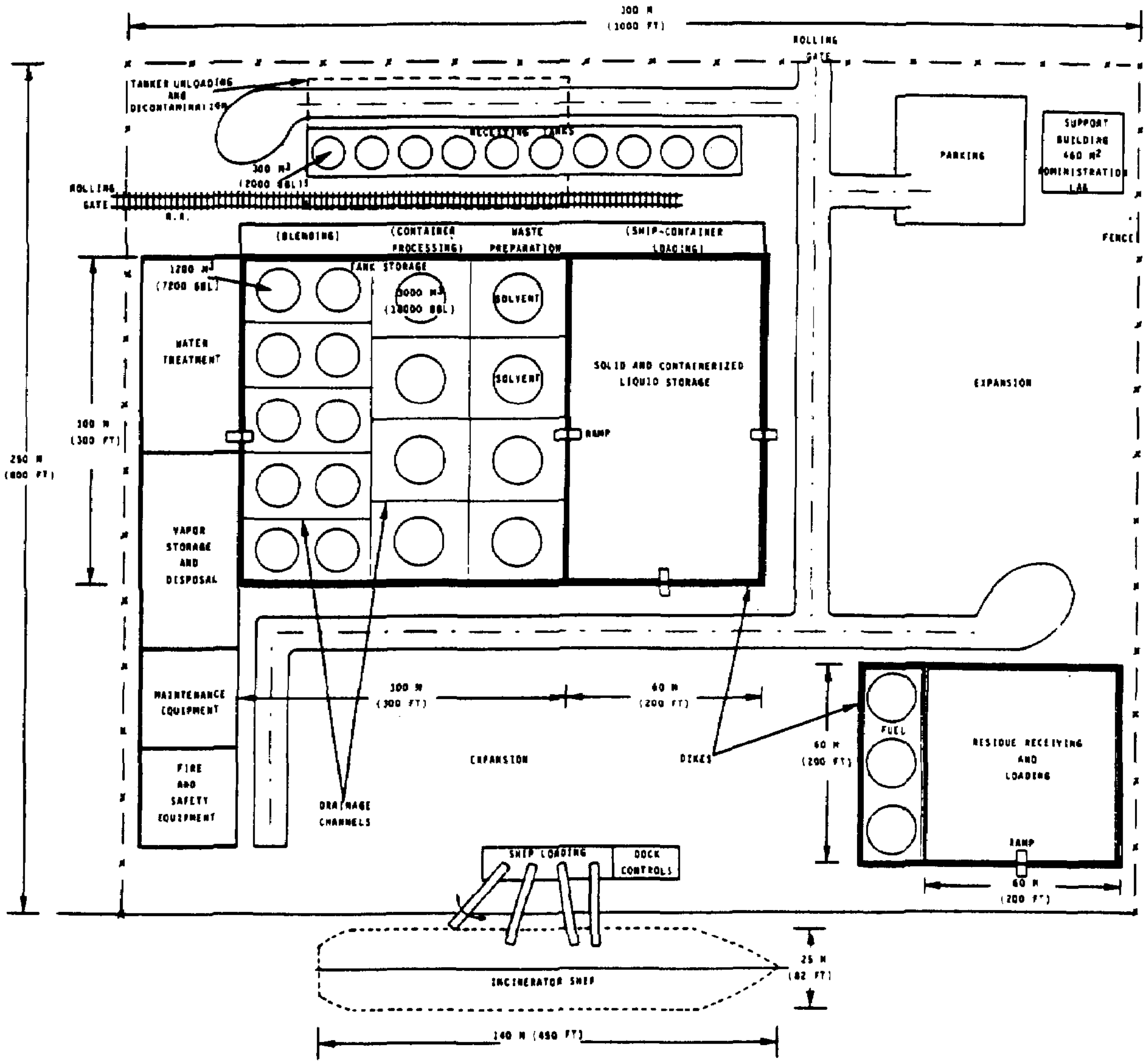

Figure D-2. Waterfront Facility Layout

employed to avoid emissions of hazardous wastes during handling. Vapor collecting systems will be installed throughout the facility to capture vapors released during loading and unloading of wastes. The vapors will be routed to a surge tank and processed through a vapor disposal system. Articulated loading arms with vapor shields and closed-loop return lines will be used for loading liquid wastes into the ship. Piping, manifolds, pumps and valves interfacing with marine loading arms will drain back to receiving tanks where the liquid can be returned to storage. Buildings housing waste processing and transfer operations will be maintained at a slightly negative pressure. All tanks, piping, pumps, manifolds and valves will be located above ground for ease of installation, inspection, maintenance and replacement. All connections will use dry break valve fittings, which prevent loss of liquid when the pipes are disconnected. Piping will slope away from initial connections so as to eliminate leakage if a valve failure should occur. The tanks themselves must be constructed from materials resistant to corrosion over long periods of contact with a wide variety of hazardous wastes.

Safeguards against accidents will be included in the design. It is essential that all personnel responsible for handling and loading the hazardous wastes are properly trained to prevent accidents. The laboratory will be equipped with the appropriate safety equipment, and the entire facility including the interior of the support building will be monitored to detect hazardous material emissions. Both fugitive emissions and ambient air quality will be monitored extensively. In addition, the water sediment,and soil in the area will be monitored. The detection system will be connected with local emergency alert systems. Testing protocols consistent with the protection of workers, the environment, and public health must be developed specifically for this facility.

In the event of leakage, the site and its operations are designed to prevent or minimize impacts. Curbs surround the tanker unloading area and dikes surround all of the hazardous waste storage areas to retain spills. The dikes will be high enough to contain a volume of liquid equal to the capacity of the largest storage tank and the curb loading area will hold at least the maximum capacity of any single tanker unloading at the site, plus 0.3 meter (one foot) of freeboard in each case. The storage areas themselves are lined with reinforced concrete to render the diked area essentially leakproof, and a drainage system will contain and remove any spilled liquid waste. The entire complex has an impermeable barrier to prevent toxic wastes from entering aquifers, estuaries or other nearby waterways. This barrier remains impermeable in the event of a fire or explosion, so that wastes will still be contained.

Provisions are made to minimize injury to site personnel from accidents. First aid stations and deluge shower facilities are located in all areas, including the laboratory and the unloading areas, where personnel might come in contact with the toxic materials. In addition to first aid supplies, personnel with proper first aid training should be on site at all times. Personnel protective equipment, such as respirators and self-contained breathing apparatus, will also be available on site for emergencies.

Fire prevention measures must also be designed into the facilities. Overhead sprinklers, deluge showers, hose racks, portable extinguishers and hydrants are located in appropriate areas throughout the complex. The hydrants and portable extinguishers will be located according to local ordinances. Communications with local fire emergency services will also be provided.

Security measures for the site, designed to protect property as well as to improve safety, include guard personnel at the gates, a night watchman, and a seven foot chain link security fence topped with three strands of barbed wire.

A total of forty people are required to operate the facility two shifts daily. Table D-1 lists the required personnel, their duties, and the shift requirements. Actual staffing will vary from this general plan according to the specific site plan and location. All operators, maintenance, and security people will be trained in emergency procedures and assigned specific responsibilities to be carried out during spills and spill cleanup.

Table D-1. Personnel

Position	Description of Duties	Number Per Shift		
		Day	2nd	3rd
Facility Supervisor	Oversees and directs operations throughout the facility, throughout the day	1		
Second Shift Supervisor	Oversees and directs operations during the second shift		1	
System Operator	Manages the flow of liquid wastes, fuel, and solvent throughout the facility (unloading, blending, ship loading)	3	3	
Forklift Operator	Handles all waste containers, (unloading, moving to and from storage and shredder, loading ship)	2	2	
Container Processor	Operates shredders and directs flow of material to and from shredding facility	2	2	
Water Treatment Operator	Operates water treatment facility	1	1	
Analytical Chemist	Designs analytical procedures and supervises analysis of incoming wastes, blended wastes, ash residue and monitoring samples	1	1	
Laboratory Technician	Collects and prepares samples for analyzers; carries out standard analytical procedures	3	3	
Secretary	Does clerical work	2		
Maintenance	Handles mechanical, electrical, plumbing and carpentry work, performs both routine and emergency maintenance on all equipment	3	3	1
Security	Keeps out unauthorized personnel and checks on employees working alone	1	1	
Night Watchman	Patrols the facility during the third shift when operations are shut down[a]			1
Janitor	General cleanup	1	1	—
		20	18	2

[a] The night watchman will also stay in contact with the night maintenance worker and any other employees working the third shift under special circumstances.

D.3.2 Subfacility Descriptions

The important subfacilities in the design are discussed below. Since this design is preliminary, both the exact location of each subfacility in the site plan and the design details for each subfacility cannot be specified completely.

Tanker Unloading. An unloading facility is located between a branch of the access road and the rail siding and is capable of removing solid or liquid wastes from tank trucks and tank cars. In addition, equipment designed to unload wastes from barges is located on the waterfront. Liquid wastes transported in bulk are then pumped to the receiving tanks. Cranes and conveyors are also on site to unload drums, other containers, and bulk solids. Portable bins will be used to store both small containers and solid wastes which cannot be processed immediately. Provision will be made to sample the waste, both before and after preparation for incineration, so it can be analyzed in the laboratory.

Container Processing. Drums and other containers of liquid and solid wastes are moved to the container processing facility. The containers are fed by a conveyor or forklift into shredders located within enclosures vented to a vapor collection and treatment system. Two shredders (or sets of shredders), one for liquid wastes and the other for solid wastes, process both drums and smaller containers.

The shredder for liquid waste containers will drain off the liquid, rinse the container shreds with an appropriate solvent, and send the liquid waste and rinse to the blending facility (see Figure D-3). The container shreds will be disposed of by landfill or salvaged. Some container shreds may require thermal decontamination prior to disposal or salvage, depending on the waste type and suitability of solvents.

Containers of solid wastes will also be shredded, and both the containers and wastes will be put in bulk containers which eventually will be loaded on the incinerator ship (see Figure D-4).

Low speed, high torque, 150 horsepower, shear-type shredders will be used. This type of shredder is capable of handling almost all types of materials and containers, and is virtually jam proof. Shear-type shredders produce a minimum of fines and do not agglomerate the material. Such shredders are available in many combinations of speed and torque and can be chosen to suit the type and amount of material to be handled at the site.

Although many safety features are designed into this type of shredder to minimize noise, chances of explosion, and hazards of flying objects, it is advisable to take additional precautions regarding explosion because of the potentially severe consequences of accidents at this facility. One option is to allow only an inert or evacuated atmosphere in the shredding enclosure and to electrically ground the shredder blades to minimize frictional sparking. Highly explosive materials, presenting great danger in the shredder, will require special handling procedures.

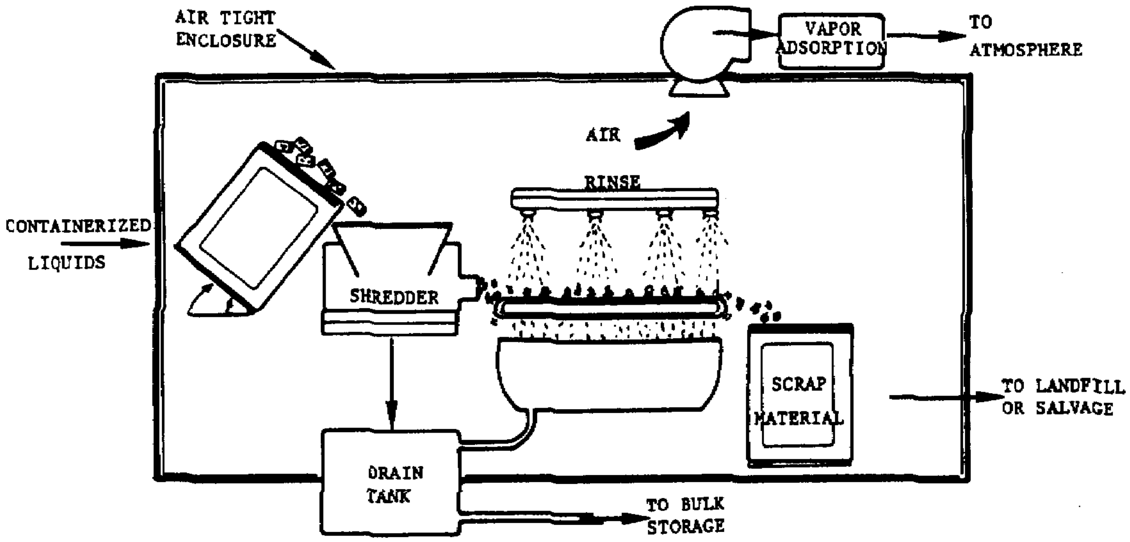

Figure D-3. Containerized Liquids Processing

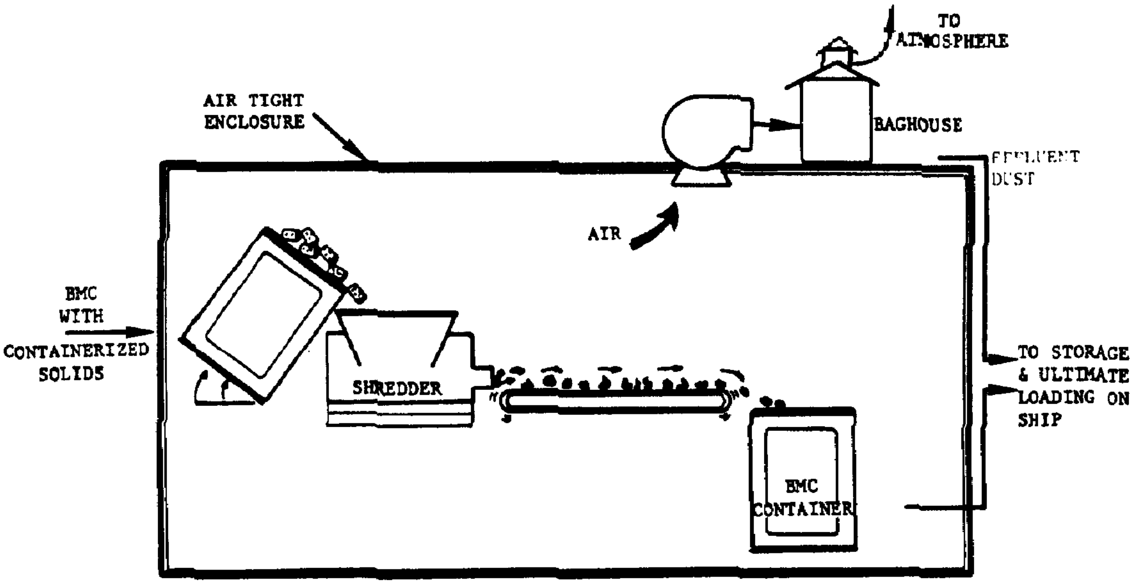

Figure D-4. Containerized Solids Processing

Decontamination. In close proximity to both the rail siding and the access road is the tanker decontamination facility. This facility will be designed to decontaminate the barges and ship containers as well as tank cars and tank trucks. A multiple-rinse procedure will be used for decontamination. Rinse solvents, depending on the waste remaining in the tank or container, may be water, fuel oil, or other liquid.

Preparation and Storage. Once removed from tankers or containers to the receiving and test tanks, the liquid wastes are, if necessary, blended with either fuel oil or other waste liquids to produce a mixture with a heat content sufficient to burn properly in the ship incinerators (approximately 13,000 kJ/kg (5500 Btu/lb). For example, a liquid hazardous waste with a very low heat content may be mixed with another waste with a very high heat content in order to produce a waste mixture which will burn well at sea.

Solid wastes coming either directly from train, truck, or barge, or from the shredding facility are placed in bulk containers which are loaded on board the incinerator ship.

Storage facilities able to handle both liquid wastes and solid waste are necessary. Two adjoining areas, one for liquids and one for solids, each surrounded by a dike, will hold wastes until they are put aboard ship. Liquid wastes will be stored in an 8,400 square meter (90,000 square foot) area containing tanks totalling 30,000 cubic meters (181,000 barrels) in volume. Tanks containing solvent will also be in this area. The adjacent area of 5,600 square meters (60,000 square feet) is designed to store both solid wastes and liquid wastes in containers. Ramps over the dikes provide access into and between the storage areas. The storage areas are located away from the dock to help prevent accidental spillage or leakage into the harbor.

Vessel Loading. Along the dock is a series of articulated loading arms designed to load the liquid hazardous wastes on board the incinerator ships. The loading arms are equipped with vapor shields and closed-loop return lines designed to prevent accidental emission of hazardous wastes. Vapor collection systems route emissions to a central vapor disposal system (i.e., an incinerator or absorption unit).

Also along the dock are cranes able to load the containers of solid wastes onto the deck of the ship. In addition, tanks for storage of ship fuel are located near the dock.

Vapor Control. A variety of collection and disposal systems may be employed to prevent emissions produced during the loading, unloading and storage of hazardous liquid wastes. Safety is a principal concern in the management of the vapor collection/disposal system. To prevent the collected vapor emissions from reaching an explosive mixture, precautions are required. Saturation and dilution are common alternate methods used to prevent explosions. Dilution is typically employed for vapors containing low concentrations of hydrocarbons, which are characteristics of the heavy hydrocarbons comprising the hazardous waste liquid mixtures. High volume blowers provide dilution air and the motive force collecting the vapors.

The best means of vapor disposal is combustion by incineration. The diluted gas mixtures are combined with fuel and additional combustion air (if necessary) at the burner to obtain very high destruction efficiency. A scrubber will also be used to remove inorganics in the combustion gases. The incinerator combustion efficiency will be monitored according to requirements of the appropriate permitting authority, and operating parameters such as temperature and excess oxygen may also be regulated based on initial performance tests.

Such incinerators are commercially available and allow a wide flexibility for varying capacity and concentration. Often, however, the collected vapor is routed to a vapor holding tank to permit more consistent, efficient and economical operation of the incinerator. When vapor holding tanks are employed, adsorption units (e.g., activated carbon) may be used as an alternative to incineration for efficient removal of organics. Since many variables affect the selection of the collection and design system, a complete economic analysis would be necessary to determine the optimal design.

Residue Receiving and Storage. In addition to loading the ships with hazardous wastes, shore facilities must also be designed to unload the ash residue from returning ships. A 3,700 square meter (40,000 square foot) storage area to hold the residue in containers prior to removal from the site is located adjacent to the unloading equipment. This waste can be directly removed by truck via the access road or transported up to the rail siding and removed by rail.

Support Building. The Support Building provides 460 square meters (5,000 square feet) of space for offices, a laboratory and toilets. The laboratory is made up of three rooms, a receiving and storage room of 40 square meters (400 square feet), a preparation area of 60 square meters (600 square feet) used to prepare samples of waste for laboratory analysis, and an area for analytical work, also occupying 60 square meters. The laboratory will be capable of performing both physical and chemical analyses of the wastes to be loaded on the ships and of the residue returned to land after incineration. A typical inventory of equipment is shown in Table D-2. Other standard laboratory equipment, such as microscopes, heat sources, reagents, and glassware have not been included in this table for the sake of brevity. The primary value of the gas chromotograph (GC) and high pressure liquid chromatograph (HPLC) is to help assess performance of the shipboard incinerator during the implementation phase. Requirements for organics identification during the routine operation of the incineration system could be satisfied by contractor laboratories, depending on required turnaround. Purchases of a GC and a HPLC have been included in the capital cost estimate to be conservative. The laboratory gives the operator of the site the ability to analyze the incoming wastes accurately and quickly so that proper preparation procedures and incineration procedures may be decided. Analyses of returned incineration residue will allow sound storage and disposal decisions to be made.

In addition to local laboratory and toilet ventilation, the Support Building will have an Environmental Control System (ECS) incorporating air conditioning for warm weather and heating for cold weather.

Table D-2. Equipment List for Laboratory Analysis of Waste

Instrument	Purpose
Physical Analysis	
Laboratory-size shredder (2)	Solid sample preparation
Calorimeter (5)	Heating value and combustibility
Specific gravity balance (3)	Specific gravity of liquids
Brookfield viscosimeter (3)	Viscosity measurement of liquids and sludges
Imhoff cones and centrifuge with graduated tubes (2)	Percent solids by volume
Cleveland open cup flash point detector (3)	Flash and fire point determinations
Muffle furnace, oven, and balances (4)	Percent ash, solids, and moisture by weight
Differential thermal analyzer (2)	Explosion characteristics and fusion temperature
Juno meter or equivalent (1)	Radioactivity
Chemical Analysis	
Gas chromatograph[a] (1)	Organics identification
High pressure liquid chromatograph[a] (1)	Organics identification in low-volatility wastes
Atomic absorption spectrograph (2)	Metals concentration
pH meter and automatic titrator (4)	Acidity and alkalinity
C, H, N, Cl, and S analyzer (1)	Elemental composition

[a] May be required only during implementation phase of incineration system.

Utilities. Fuel gas service from the local public utility will be used at the complex for the hot water heater in the support building and for burner outlets in the laboratory. A maximum of approximately 1.7 cubic meters (60 cubic feet) per hour will be required. A delivery pipe will run from the property line to the support building.

The facility will utilize commercial electric power also from the local public utility. Power is needed for lighting, convenience receptacles, and environmental control systems in the support building, as well as electrical equipment, such as pumps, used throughout the facility.

Municipal water and sewage systems will also be used. Only the drains from the toilets and the laboratory will be connected to the sewage system, and laboratory waste will be sampled regularly to avoid emissions of hazardous waste by this path. Waste sample residues from the laboratory and all other waste generated on site will be separately contained for disposal by other means (ship incineration or landfill) to avoid putting toxic wastes in the local sewage system.

Storm Runoff and Water Treatment. An onsite water treatment facility will treat water contaminated by hazardous wastes. The entire unloading and storage area is designed so that any liquid on the ground will flow downhill into drainage channels leading to a catch basin. Normal storm runoff will proceed to the water treatment facility and, if no treatment is required, or if it is cleaned sufficiently, on into the port waters. However, in the event of a spill beyond the capacity of the water treatment facility, the outlet of the drainage system will be closed and the liquid will be retained until it can be pumped to the storage tanks. The outlet of the treatment facility will be monitored to help avoid any discharge of hazardous materials. Storm runoff bypassing the treatment facility will also be monitored.

Fire and Safety. Also located on the site is a building housing fire and safety equipment. Included are extra fire extinguishers, hoses, and a large quantity of adsorbent to temporarily contain small spills. The fire and safety building is shown on the Figure D-2 layout, but its location is somewhat arbitrary.

Expansion. Chemical waste generation is projected to increase during the coming years and land disposal is becoming less satisfactory. Therefore it is important that the site is designed to accommodate expansion. The facilities most likely to be expanded are the storage areas and, therefore, open space is located near each of the three storage areas.

Miscellaneous. A maintenance building and dock controls are also included among onshore facilities. While these facilities are shown in Figure D-2, their locations are somewhat arbitrary.

D.4 COSTS

Capital costs are based on information supplied by vendors and on unit costs developed for the onshore support facility in the Offshore Platform Feasibility Study (2). The major costs involve engineered systems which are not available as off-the-shelf items. These systems require extensive design before accurate cost estimates can be developed. Costs for these systems have been estimated here based on vendors' knowledge of costs for similar systems previously supplied for analogous applications in other industries. For those standard off-the-shelf items which can be identified at the preliminary design stage, costs were provided by vendors based on list costs of the equipment.

Operational costs include labor, supplies, utilities, maintenance, and depreciation of equipment and buildings. A yearly maintenance cost factor of eight percent of the installed equipment cost was assumed, and depreciation costs were based on a 15-year period for equipment and buildings. The cost of labor has been estimated for each of the labor categories based on wage information presented in the Platform Study (2). Significant utilities costs are based conservatively on a peak load requirement of 400 kw extended throughout the two-shift work period.

D.4.1 Capital Costs

Table D-3 summarizes capital costs for major components of the facility preliminary design. Dock construction and land costs are excluded from this table. The major cost items involve engineered systems such as the marine loading terminal, the bulk unloading rack, and the facility plumbing system. Although some standard off-the-shelf items may be purchased for direct installation, most equipment will have to be engineered into an appropriate system before it may be utilized. The terminal equipment is described in terms of subfacilities, since a detailed examination of the individual system components for the numerous design alternatives is not consistent with the intent of this preliminary study. Subsequently, many of the subfacility cost estimates presented here should be considered rough estimates (±50% accuracy).

Table D-3. Capital Costs of Waterfront Facility Installation

Description of Equipment	Total Installed Cost (1980 Dollars)
Activated carbon water treatment system for rinse and washdown wastewaters (1,400 m^3/day)	$ 900,000
Bulk material containers (3.3 m^3). 1,900 bins for storage of incoming miscellaneous containers of solid and liquid waste, containers for shredded solids, and 70 containers for ash residue from incineration.	2,200,000
Dock loading crane (10 metric ton capacity at 30 m)	500,000
Marine terminal loading dock apparatus (including meters, valves, loading arm assemblies, control systems and support structures	4,000,000
Tanker bulk liquid unloading rack (including tanker decontamination system)	2,000,000
Monitoring instrumentation (including gas analyzers, recorders, sampling equipment)	125,000
Security-accountability system (software to inventory wastes, sources, disposition, cost information, potential hazards)	120,000
Liquid waste storage tanks (carbon steel, fixed cone roof) and tank site preparation	
8 each 3000 m^3 capacity	1,270,000
10 each 1200 m^3 capacity	910,000
10 each 300 m^3 capacity	400,000
Epoxy coating for 14,750 m^2 of tank interior	430,000
Fuel tanks (2) of 2,370 m^3 capacity	250,000
Installation, plumbing, and system controls for waste storage tanks, blending, and fuel tanks	3,000,000
Vapor collection and disposal system (incinerator and scrubber) for bulk unloading racks, marine terminal loading, storage tanks, container decontamination, and container shredding	1,500,000

Table D-3. Capital Costs of Waterfront Facility Installation (Continued)

Description of Equipment	Total Installed Cost (1980 Dollars)
Enclosed system to process containerized solids for incineration	
Bin unloading mechanism	$ 5,900
Shredder (2.3 metric tons/hr)	67,000
Conveyor	4,200
Plumbing and drain tank	5,000
Emission collection system (baghouse and blower)	30,000
Enclosure (6m x 21m)	60,000
Enclosed system to process containerized liquids for incineration	
Bin unloading mechanism	5,900
Shredder (2.3 metric tons/hr)	67,000
Conveyor	4,200
Plumbing and drain tank	10,000
Vapor collection system	10,000
Enclosure (6m x 21m)	60,000
Safety and fire equipment	40,000
Site preparation	37,000
Paving-concrete (22,500 m^2 diked areas)	350,000
Paving-asphalt	87,000
Railroad siding (240m)	53,000
Fencing (750m)	34,000
Administrative buildings and laboratory (460 m^2)	235,000
Heating, ventilating, air conditioning	22,000
Electrical	215,000
Laboratory Equipment	360,000
Total Capital Cost of Installed Facility (excluding dock construction and land costs)	$19,000,000

All facility costs include contractor overhead and profit (25%), contingency (10%) and engineering (10%).

No land acquisition or dock construction costs have been included in the cost estimates. These costs will vary greatly depending on the location. Based on data presented in the National Port Assessment (16) the average construction cost of a single berth at a seaport terminal facility for transport of liquid bulk petroleum is $5 to $20 million. The cost of seaport terminals handling hazardous liquid waste would be substantially greater than the typical petroleum handling terminal. However, these costs may be minimized if federal dock facilities and nearby property are available.

The number of bulk material containers (BMCs) required at the terminal was estimated based on the storage capacity of the standard BMC and the total solid or containerized liquid wastes which will be stored at the terminal. It was assumed that the quantity of liquid wastes received in small containers is equal to 20 percent of the total liquid waste received, and that one-half of these containerized liquids have been processed and routed to bulk storage while the other half are stored in BMCs awaiting processing. The amount of solid waste which is stored is 1,440 metric tons and the amount of incinerator ash residue stored is 144 metric tons. The density of the waste material was assumed uniform and the capacity of each BMC was estimated conservatively as two metric tons. Vendors place the cost of the BMC at $937 each.

The capital cost of the water treatment system was based on cost estimates published for the treatment system evaluated in the Platform Study (2). The cost was adjusted according to the system capacity requirement, which was estimated based on the quantity of wastewater runoff which would be expected from the diked areas during a 24-hour rainstorm producing five centimeters (two inches) of rain, plus wastewater produced by normal daily washdown and decontamination rinse operations.

The cost of laboratory equipment has been estimated based on consultation with analytical chemists who participated in pertinent related studies (2, 3, 4, 5, 8, 11). The costs of required accessories and support equipment were conservatively estimated at 50 percent of the cost of the major equipment items listed in Table D-3. Contractor costs for engineering, overhead, fee, and contingency were also included in the overall estimate.

The total capital cost of the terminal is estimated to be $19 million. This value is consistent with the $20 to $50 million range of cost estimates provided by Henry (9) and with costs estimated for the smaller facility of the Platform Study (2). The annualized capital cost, amortized over a 15-year economic lifetime at an interest rate of 10 percent, is $2.5 million.

D.4.2 Operational Costs

Table D-4 summarizes costs of operation for the waterfront facility. Insurance costs are not included in the estimate. This cost will vary greatly depending on several factors (e.g., toxicity of waste, trip lengths) and may exceed all other operational costs combined. It is estimated that insurance coverage to allow $50 million per incident for the entire at-sea incineration enterprise would be available at annual premiums of $3 to $6 million (9).

Also omitted in the cost summary are potential land and dock rental costs (in case land and dock will not be acquired). Lease costs vary greatly by location. Costs investigated for the Mobile, Alabama area in the Platform Study (2) were assessed at $3.90 per square meter ($0.36 per square foot) of industrial land with intermittent access to dock facilities. Applying this rental rate to the present facility design, annual lease costs would be approximately $300,000. However, this lease rate should be considered a low estimate since the magnitude of the proposed terminal operations would require total dedication of the docking facilities.

Table D-4. Annual Operating Costs

Item Description		Annual Cost
Total Labor (including overhead)		$1,100,000
- Facility supervisor, 2 at $79,000/yr	$158,000	
- System operator, 6 at $40,000/yr	240,000	
- Forklift operator, 4 at $26,000/yr	104,000	
- Container processor, 4 at $26,000/yr	104,000	
- Water treatment operator, 2 at $29,000/yr	58,000	
- Analytical chemist, 2 at $60,000/yr	120,000	
- Laboratory Technician, 6 at $29,000/yr	174,000	
- Secretary, 2 at $24,000/yr	48,000	
- Security guard, 2 at $36,000/yr	72,000	
- Janitor, 2 at $20,000/yr	40,000	
Maintenance (8% of installed equipment costs)		1,520,000
Depreciation (based on 15 year economic life)		1,270,000
Electrical power (based on 400 kw during working hrs)		57,000
Disposal of 1900 metric tons of incinerator ash residue (haul distance 80 km)		26,000
Total annual operating cost		$4,000,000

Note: Insurance and lease costs for land and dock (if necessary) have been omitted from this table. (See text.)

Maintenance of equipment is expected to be the principal operations expense, but the cost of labor and depreciation of the facilities are comparable. The total annual operating cost for the facility is estimated to be $4 million. The total annualized cost of the hazardous waste terminal facility, including the annualized capital cost, is $6.5 million. Based on the expected annual throughput of 400,000 metric tons of hazardous waste, the cost of receiving, processing, and dispensing hazardous waste at the terminal facility will be approximately $16 per metric ton of hazardous waste.

D.5. EXISTING TERMINAL FACILITIES IN THE UNITED STATES

Since there are no single existing marine terminal facilities in the United States which have the capability of providing terminal services for large volumes of both dry solid hazardous waste and liquid hazardous waste, the approach used for this survey consisted of four steps. Existing facilities that regularly accommodate vessels similar in length and draft to the vessel described in Appendix C 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 meters (25 feet) were included. This list of terminals was then reduced 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 or development into a liquid and/or 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. Finally, on the basis of information developed, preliminary findings, conclusions, and recommendations were documented.

The sources of information used for this survey are references numbered 13 through 16 in the reference list for this appendix, current U.S. military publications (unclassified) covering military installations that provide terminal services for fuel and for ammunition and explosives, and personal and telephone interviews with officials in the following U.S. Government agencies and companies:

Maritime Administration

Environmental Protection Agency

U.S. Coast Guard

General Services Administration

Navy Supply Systems Command, Field Operations Division

Military Traffic Management and Terminal Command

Selected hazardous waste management companies

Dow Chemical Company

American Association of Port Authorities

Selected port authorities

Selected port officials

Selected commercial bulk liquid terminal operators

This survey found that 139 ports and 1,221 terminal docks, piers or wharves on the East, Gulf, and West coasts of the continental U.S. have sufficient water depth and space to receive the conceptually designed chemical waste at-sea incineration vessel. 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. Ownership of terminals other than military terminals is predominantly private as opposed to governmental.

Of those terminal companies having membership in the Independent Liquid Terminals Association, several specifically offer terminal services for liquid chlorinated hydrocarbons as well as other commodities and solvents having compatible handling characteristics. Almost all major terminals handling cargo in containers (of various sizes and descriptions, both standard/intermodal shipping containers and specialized commodity containers) handle some hazardous cargo. The volume, however, is relatively low, thus minimizing the need for special storage and handling equipment. A number of the major oil and chemical companies can provide terminal facilities that are capable of handling liquid bulk waste. It was from such a facility that waste was loaded for initial at-sea incineration of U.S. wastes. The availability of these facilities for waste generated from non-company sources would, however, not seem likely.

At U.S. military terminals, liquid hazardous commodities such as fuel and dry hazardous commodities such as ammunition and explosives are generally handled in separate facilities. Furthermore, none of the bulk liquid terminal operators contacted thought it advisable to provide solid waste terminal service at a bulk liquid terminal. The extreme differences in the handling characteristics for the two types of commodities seemed to be a major factor. Personnel handling bulk liquids did not usually have what was considered to be the expertise that would be needed to handle solid hazardous waste. Military bulk fuel depots and terminals do not handle large volumes of ammunition and explosives at the same terminal, nor do the ammunition and explosive depots handle large volumes of fuel. For the handling of large volumes of dry bulk commodities (usually free flowing solids), specialized terminals are used. Smaller shipments of such commodities may be handled in standard bulk commodity intermodal containers, in packages or bags in intermodal containers, or on pallets.

The larger the volume of the commodity handled, the greater are the chances for finding development of a specialized handling system developed for that particular commodity from point of commodity origin to point of final destination.

Most of the major and many of the smaller bulk liquid terminal companies that offer terminal 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, they are not only familiar with long existing local, state, and federal regulations for handling liquid waste (which are more concerned with fire, explosion and safety matters), but are also familiar with recent Environmental Protection Agency regulations for implementing the Resource Conservation and Recovery Act. Several of these companies plan to file "Notification of Hazardous Waste Activity," EPA form 8700-12, with EPA regions in order to qualify terminals for "interim" status. Their knowledge and expertise could contribute to development of a waterfront facility.

Terminal services to incinerator ships for wastes of European origin have developed within existing bulk liquid terminals handling commodities with similar physical and chemical characteristics. A major European terminal handling liquid waste for loading on incinerator ships is at a port 67 kilometers (36 nautical miles) from the North Sea.

Discussions with bulk liquid terminal operators as to their offering hazardous waste bulk liquid terminal services indicate it is not so much a question of their availability and ability to handle such wastes as it is of the additional costs that may be incurred in order to comply with regulations yet to be finalized. Investment capital, although available, still seeks investments where the risk factor is less in doubt.

Several of the U.S. military ammunition and explosive stations and/or depots appear to have potential for handling dry hazardous waste. Also, the Naval Construction Battalion Centers at Port Hueneme, California, Gulfport, Mississippi, and Davisville, Rhode Island, should be explored for handling of such waste. The availability of these activities would probably depend on the effect of such work on their primary mission.

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