FINAL REPORT

DEVELOPMENT OF METHODOLOGY TO REDUCE THE DISPOSAL OF NON-DEGRADABLE REFUSE INTO THE MARINE ENVIRONMENT

PREPARED FOR:
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
SEATTLE, WASHINGTON

CONTRACT 85-ABC-00203

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INTRODUCTION

1.1 BACKGROUND

The vastness of the sea has contributed to the belief that it is an ideal repository for waste from man's activities. Studies of deposition of waste in open sea waters have indicated a continuing accumulation of pollution of the sea itself, its beaches and the seabed. A portion of this pollution results from the discharge of nondegradable material from seagoing vessels, including those engaged in fishing, shipping and transportation, and research and military activities. In an attempt to quantify this problem, the National Academy of Sciences (1975) estimated that an annual rate of 6.4 million tons of nondegradable material was discharged into the ocean from such vessels. This debris, consisting of plastics, rubber, metal, glass and fishing gear, is (except for fishing gear) similar to the solid wastes generated by human activities onshore. As a first step in identifying economical and feasible alternative means of managing these wastes, the National Oceanic and Atmospheric Administration (NOAA) has sponsored this study to assess and evaluate current and potential disposal methods and to investigate optimum disposal strategies.

Figure 1-1 illustrates the steps taken in this study. It should be noted that the lack of certain data made the systematic completion of all parts of the study impossible. In certain areas, data were so sparse as to necessitate rather crude estimates (fishing gear disposal quantities, onboard storage space for wastes on all vessel types) leaving doubt as to both total annual tonnages of wastes currently disposed of overboard (particularly for fishing vessels) and the applicability of some disposal methods for certain ship sizes (particularly onshore disposal and recycling).

1.2 OBJECTIVES

The program objectives as initially stated were:

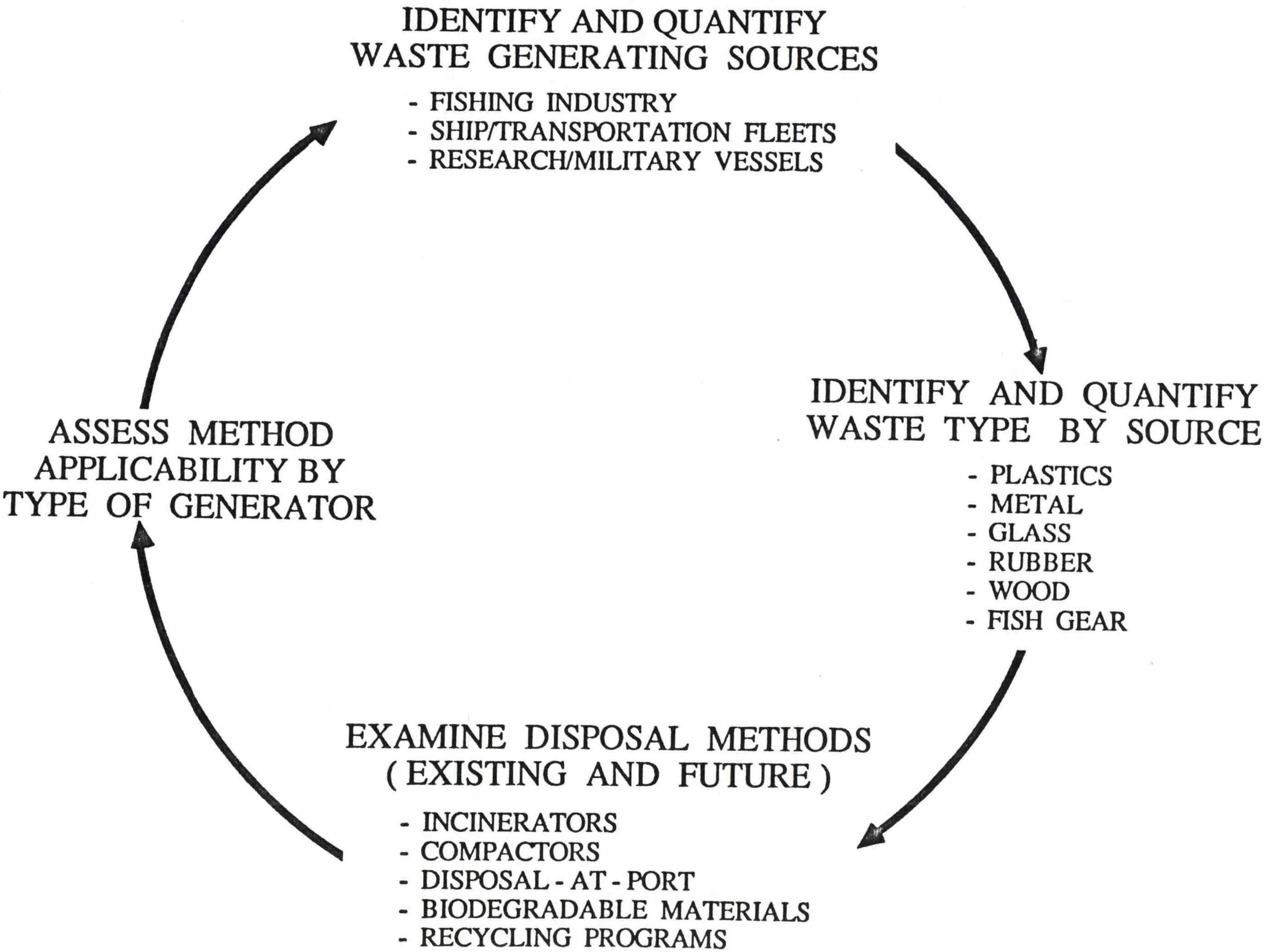


Figure 1-1. Program Components.

1. To synthesize and evaluate existing information concerning the nature, cost, and utility of equipment and procedures that have been or are being used to compact and store or incinerate non-degradable refuse at sea.

2. To assess the feasibility of developing and encouraging or requiring use of biodegradable materials, including preferential use of supplies and equipment from companies that minimize the use of non-degradable materials.

3. To evaluate the possibility of developing economically feasible recycling programs for certain non-degradable materials.

4. To conduct such field tests as may be necessary or desirable to evaluate the practical and economic feasibility of potentially promising mitigation measures involving compaction, incineration, recycling or other means.

As the program progressed, and for reasons discussed in the report, alternate objectives were established:

1. To quantitatively characterize the waste generation for all categories of sea activities.

2. To examine and analyze disposal methods, and identify optimum disposal methods for each sea activity.

3. To document the actual operation of existing disposal methods.

1.3 PROGRAM APPROACH

To develop information that would allow assessment of the nature, cost and utility of equipment and procedures for disposal of refuse generated at sea, the initial phase of the program involved extensive literature searches, and collection and review of the pertinent literature. A panel of experts on marine technology and informed environmentalists was assembled to provide advice on sources of information, information from their experience, and guidance on various aspects of the study. Contact was attempted with all the major suppliers of equipment relevant to the study to obtain information on design, size, rating and cost of the equipment. Contacts were made with many personnel in the marine industry and with the U.S. Navy.

Initial information collected indicated large gaps in the understanding of amounts and type of waste generated. This information was, of course, critical to the successful evaluation of the applicability of various disposal methods. Accordingly, the approach was modified to place a greater emphasis on refining and expanding the information on sources of waste generation, types of waste, and quantities generated in various activities. In view of the need to expand these activities, the objective of conducting field tests of a single optimum disposal method was abandoned and more emphasis was placed on examining the operation of existing disposal methods. The revised scope included field trips to inspect several types of ships, interview the crews, and document the current practices of waste disposal.

The assembled information was used to estimate rates of waste generation by vessel type, size, age, crew size, waste type, and sector of the marine activity environment. Onboard populations of various vessel types were defined, the type and quantity of various materials used onboard were determined, and factors were defined to convert material used to waste generation. This information was related to the characteristics of various possible disposal methods to assess the applicability of each method and to attempt to define optimum disposal strategies for each sea activity.

1.4 PROGRAM CONCLUSIONS

The objectives of the program were only partially met, due to the complexity and variety of activities at sea. It was necessary to group many activities into a single category and to treat many broad categories on a rather general basis. Examination of disposal methods was hampered by the fact that most new equipment manufacture occurs overseas and program resources did not provide for on-site foreign information gathering.

Regarding the loss of fishing gear, reported to be a major environmental problem for marine life, very little progress was made in clearly identifying the amount of fishing gear that is lost, and more importantly, the amount that actually could be recovered if that were mandated. If it is assumed that all gear that can be recovered is recovered, then gear reported lost at sea, and causing environmental damage, could not be considered as recoverable waste subject to waste disposal methods. Some gear is probably thrown overboard, but there was no information on the amount as a percentage of total losses.

In spite of these deficiencies, it was possible to determine the types of disposal equipment available, establish information on sizes, cost and capacity of incinerators and compactors and to relate this equipment to estimated waste generation rates for various types of vessels.

Information regarding the composition of various plastic materials used at sea was very limited and the current availability of degradable plastics as substitutes could not be clearly quantified relative to actual use. A basic problem is that substantial effort has been expended by the plastics industry over many years to respond to consumer demand for more durable products. In meeting this demand, technology for degradability has not received the attention that will no doubt be required as the full effect of environmental damage is more accurately assessed. It is clear that degradable products can be produced, but further study will be necessary to assess the rate at which these materials can be phased into marine use.

With regard to recycling, a fundamental limitation is lack of storage space on vessels. Most recycleable items of plastic, metal, or glass are used to package food provisions. Restorage of empty containers, possibly contaminated, back into the original space is questionable because of potential contamination of remaining unused food supplies.

The most promising disposal methods are incineration and compaction, both of which are in active use in the U.S. Navy and on passenger ships. Examination of ships with this equipment installed, did, however, reveal instances where, although equipment was installed, it was not used and overboard disposal was substituted. Problems with odor and pre-processing storage were cited as the main reasons that the equipment was not used.

The results of the study indicate that incineration is the method most applicable to ships with crew sizes of 30 or more, and at sea for voyage durations of the order of seven days and longer, although 30 days or longer may be a more practical duration. Categories of vessels of this type include vessels in Shipping and Transport (oil tankers, carriers, and general cargo), most varieties of military vessels, and larger research vessels over 400 grt (gross registered tonnage). Incineration is not deemed applicable to fishing vessels due to small crews (<30 people). These smaller vessels do not have sufficient space for onboard processing other than use of compaction on the larger fishing vessels.

Compaction was judged to an applicable disposal method for ships with waste generation rates such that the compacted waste could be stored within a cubical space of about 10x10x10 feet. Vessels of this type tend to have crews of less than 400. Vessels of this type include most large fishing vessels, shipping and transport vessels, about half of the military vessel types, all research vessels with voyages less than about 30-60 days. It was noted that there is currently extensive use of compaction in the U.S. Navy and on passenger ships, mainly where crew size exceeds 300 people. However, the purpose of this use is to compact waste to produce negative buoyancy so that disposal overboard will ensure that the compacted bales will sink. Restriction to no overboard disposal of any waste will make this method inapplicable for many vessels that currently have compactors simply due to the lack of space required to store the compacted bales. Conversion to incineration may be necessary should the overboard disposal restrictions be adopted.

Neither incineration nor compaction is judged applicable to the smallest ships with crew sizes less than 30 and voyage durations of only a few days. These smaller vessels are primarily in the fishing industry.

Comparison of the current practices of incineration at sea with current land-based incineration shows a wide gap in technology. Land based incineration is currently undergoing considerable upgrade of the technology because of the need to terminate land filling and incinerate all hazardous wastes. It is clear that these requirements have not yet impacted the marine incineration industry beyond those vessels, such as, the Vulcanus, which have been purposely outfitted to handle hazardous waste. Widespread implementation of incineration in ships will have to come to terms with the resultant atmospheric emissions, and their effect on nearby land, the ship's crew and on wild life at sea. Storage of incinerator ash and noncombustible glass and metal will have to be considered.

SECTION 2.0

WASTE GENERATION

2.1 CHARACTERIZATION OF WASTE GENERATING SOURCES

The three broad categories of vessels considered in this study were fishing vessels, shipping/transportation fleets and research/military vessels. Of these three sea activities, fishing vessels are the most numerous of all commercial vessels at sea. Used in practically every body of water in all ports of the world, these vessels range in size from oar-propelled dories to large mother ships with a wide variety of forms, arrangements and deck gear. Shipping and transportation fleets consist of passenger liners, tankers (oil and miscellaneous cargo), carriers (liquified gas, chemical bulk and ore cargo), container ships (cellular and lighter) and cargo ships (vehicle, livestock and sundry). For research and military sea activities, vessels types range from trawlers to submersible craft for ocean research, and over 60 different types of water craft for military activities. Early efforts in this study in assessing disposal methods operating onboard these vessels showed that while available information was extensive on current disposal systems used by the U.S. Navy and passenger liners, data on shipboard waste disposal methods for other sea activities were quite insufficient. To supplement the existing base of information, it was necessary to characterize additional waste sources before assessing waste disposal methods. The approach taken was to: (1) define the waste generation from representative vessel populations based on operating parameters such as size, complement onboard, duration at-sea, etc., for each vessel category; and (2) estimate, based on extrapolation of available naval and passenger liner information, the potential types and amounts of waste material that would be discharged from other categories of vessels.

Vessel and Onboard Populations

The initial task for characterizing the waste generating sources was to estimate the number of people onboard different vessel categories and the time spent at sea in a given activity. The large number and diversity of vessels within each type of sea activity, made classification and consolidation of vessel types into relatively broad categories necessary. For fishing vessels, the most numerous vessel type, available data did not warrant a breakdown beyond three categories: coastal, long distance and deep sea. Shipping and transportation vessels were categorized by passenger liners, oil tankers, ore and dry bulk and general cargo. Research and military vessels are considered two separate types of vessels with a further breakdown within the military activity of 35 vessel types representing combat ships, service and repair ships, and replenishment ships.

Realizing that the number of people onboard can vary depending on size of craft and type of sea activity, the complement for each vessel's classification was based on: (1) ship size capacity in gross registered tonnage (grt) for fishing vessels; (2) crew lists and vessel age for shipping and transportation fleets; and (3) averaged crew count for research and military vessels.

Population data for vessels in the fishing industry and shipping/transportation fleets were obtained from documents published by the Organization for Economic Cooperative Development (OECD, 1985a,b). OECD is an international agency established in 1960 to promote economic development throughout the OECD countries (Australia, Austria, Belgium, Canada, Denmark, Germany, Greece, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States). OECD (1985a) data provides on-vessel population and capacity size, number of fishermen, type and tonnage of marine harvest by country. For example, Table 2-1 lists the number of registered fishing vessels sailing under the flags of 13 counties and the number of fishermen employed in the industry. Of the thirteen countries indicating population data, nine countries provide the number of vessels by gross registered tonnage (grt) as shown in Table 2-2. Over 90 percent of the vessels fall in the range of 0-49.9 grt, six percent in the 50-99.9 grt, with the remaining three percent in the combined range of 100->1,000 grt.

OECD (1985b) presented developments of interest in the field of shipping, complemented by a statistical annex on the essential elements of

TABLE 2-1. VESSEL AND CREW POPULATION ENGAGED IN THE FISHING INDUSTRY

Country	Number of Registered Vessels	Number of Fishermen*
Belgium	202	1,282
Canada	37,992	77,277
Denmark	3,303	14,500
Finland	208	7,000
Germany	966	4,238
Greece	12,650	27,700
Iceland	929	6,207
Italy	22,981	34,000
Japan	401,000	447,000
New Zealand	2,314	7,053
Sweden	4,162	6,199
United Kingdom	6,967	22,883
United States	125,700	223,000
TOTAL	619,374	878,339

*Number of fishermen per vessel varies from 1 to over 25 depending on vessel size.

TABLE 2-2. FISHING INDUSTRY VESSEL POPULATION BY CAPACITY RANGE (1984)

Country	0-49.9 grt	50-99.9 grt	100-149.9 grt	150-499.9 grt	500-999.9 grt	>1000 grt	Total
Canada	37,190	415	114	273	0	0	37,992
Denmark	2,816	202	128	151	5	1	3,303
Finland	121	70	15	2	0	0	208
Germany	810	80	45	12	7	12	966
Iceland	409	130	98	166	13	13	829
Sweden	3,869	226	30	37	0	0	4,162
United Kingdom	6,346	376	97	135	8	5	6,967
United States*	12,324	2,509	855	387	87	20	16,182
TOTAL	63,885	4,008	1,382	1,163	120	51	70,609

*1976 statistics

seaborne activities gathered from a large number of sources. The vessel population in this document is categorized by capacity and type of vessel with additional information on sizes of crew. In 1984, Lloyd's Register of Ships listed over 76,000 ships at sea, categorized into four principal types:

- Oil tankers
- Ore & dry bulk carriers (including combination carriers)
- General cargo (including container ships)
- Miscellaneous (including fishing vessels, fish factory and carrier ships, chemical and other non-liquid tankers, liquefied gas carriers, transporter of barges, passenger ships and ferries, research ships and other non-trading vessels.

Data on these vessel groupings included number of vessels by age distribution and size of vessel types based on gross registered tons. The combined tonnage of the principal types of vessels was 418,000,000 grt with oil tankers and bulk carriers representing over half the tonnage. Figure 2-1 illustrates the percentage of total grt's by vessel group. The number of ships by size group is shown in Figure 2-2. The size groups range from 100 to over 140,000 grt. The largest number of vessels fall into the 100-499 range indicating 50 percent of the world fleet. The age distribution of the vessels range from under five years to over 30 years. Figure 2-3 shows the number of vessels in each yearly interval.

The primary source of characterization data for research vessels was Jane's Ocean Technology (Trillo, 1978) and for military vessels, data was obtained from the U.S. Navy (Alig, 1986). The Navy has been researching onboard disposal methods for naval ships for a number of years and their data include the population characteristics of over 500 military vessels in their fleet.

Realizing that data are not complete on all countries of the world, the OECD documents summarized above and the U.S. Navy data were used as the basis for the overall characteristics of the World Fleet and provided a representative cross-section of the total world vessel population. The following sections describe how the data were used and the methods employed to characterize the waste generating sources, followed by waste material factors

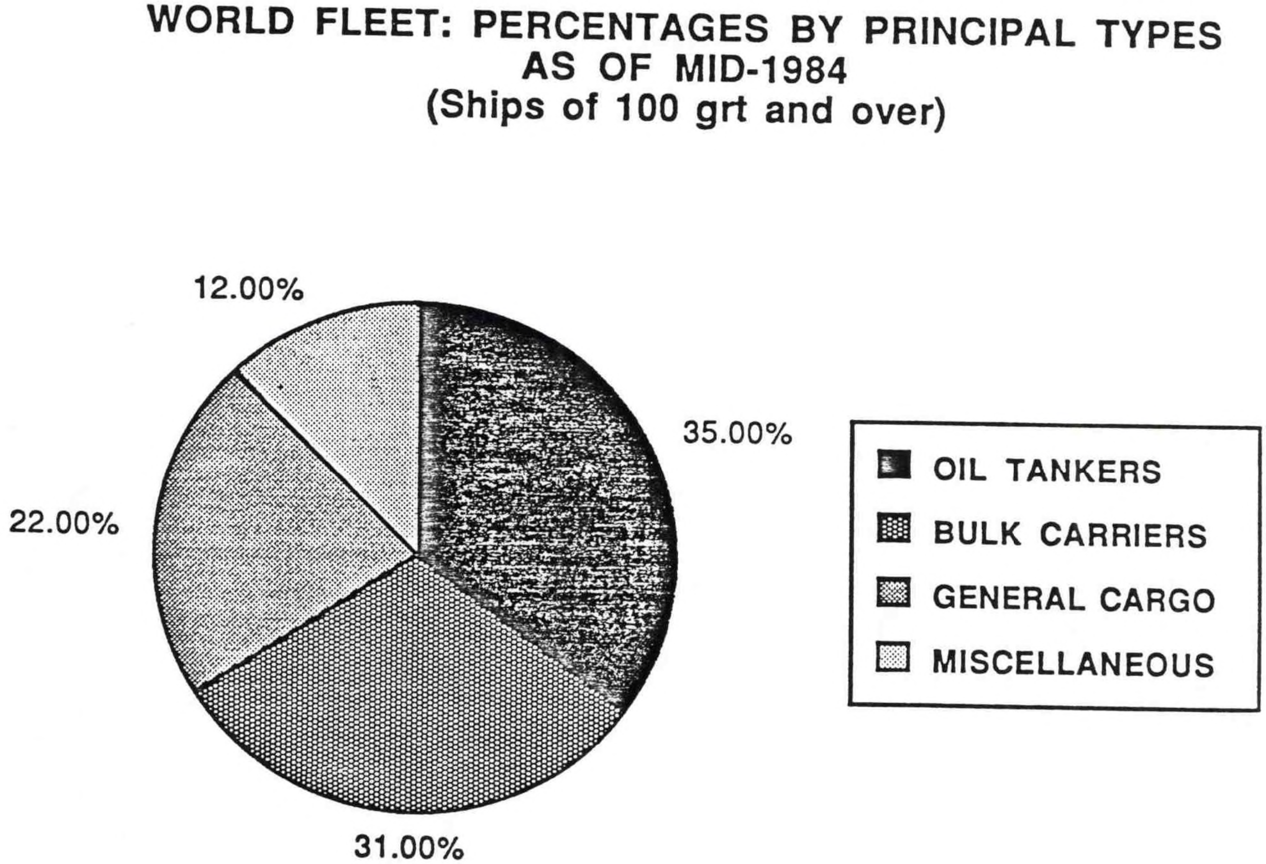


Figure 2-1. Principal Types of Vessels in the World Fleet.

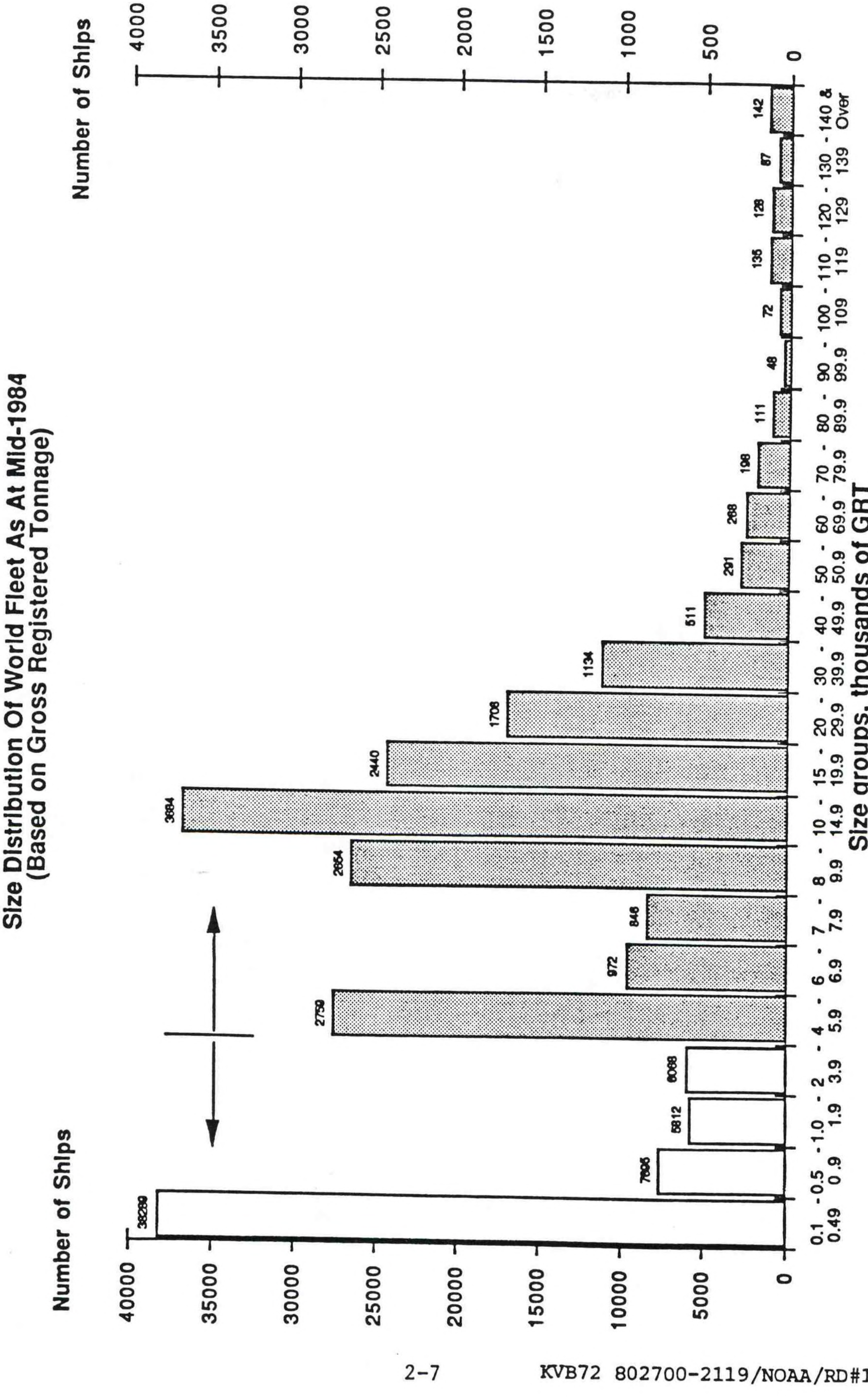


Figure 2-2. Size Distribution of World Fleet.

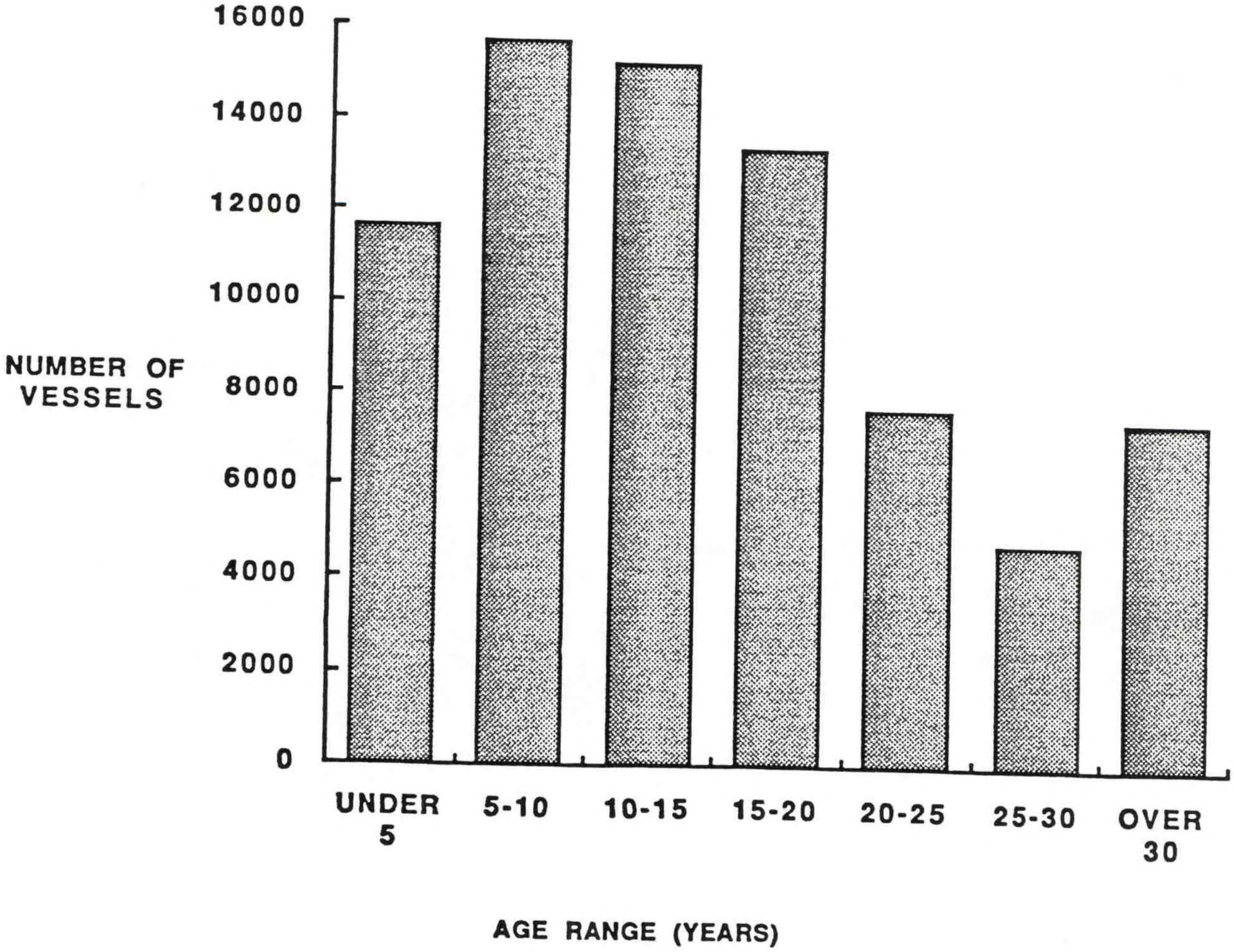


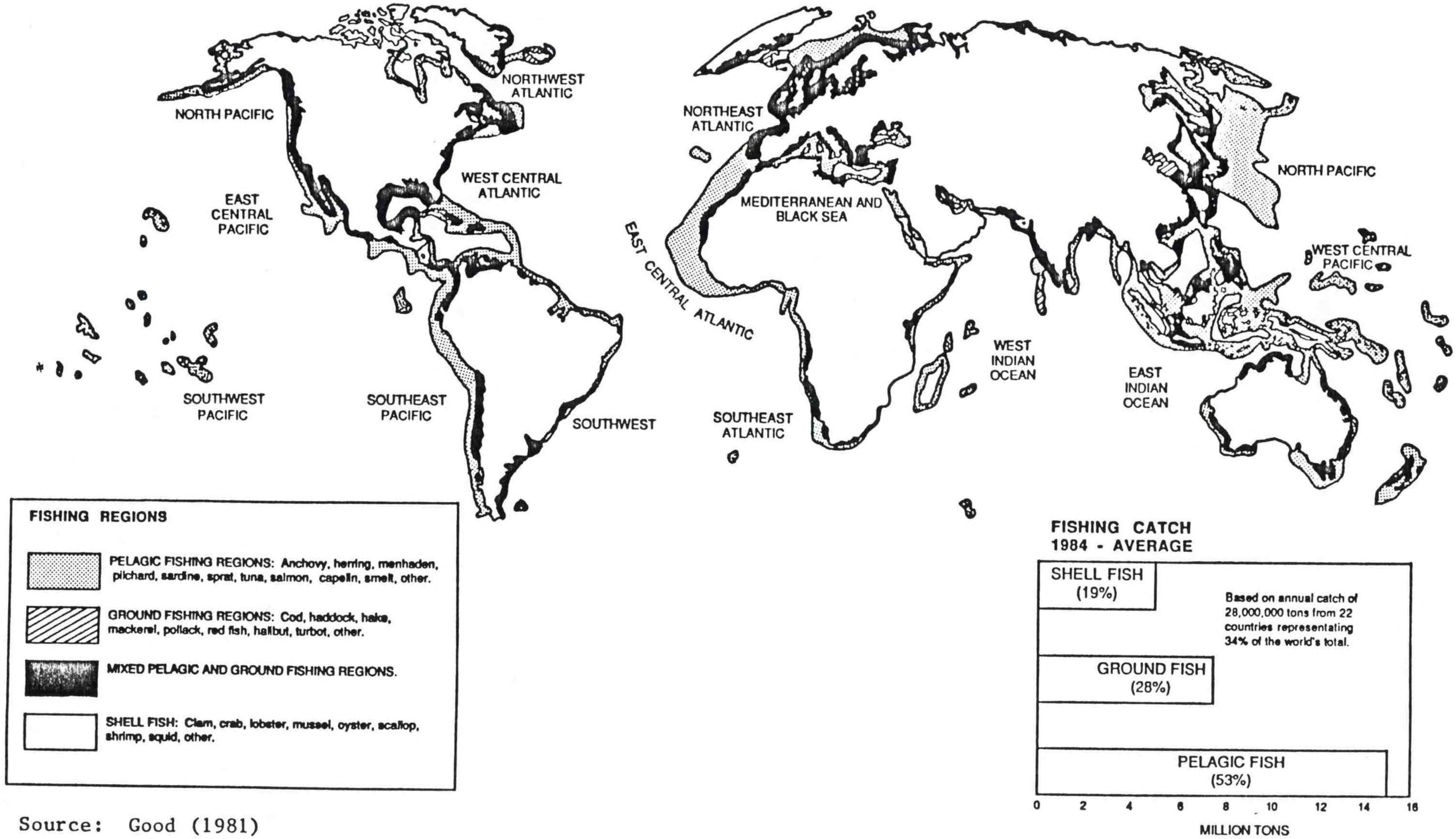
Figure 2-3. Age Distribution of World Fleet as of Mid-1984.

resulting in the type and quantity of waste generated by vessel classification.

2.1.1 Fishing Industry

Fishing vessels are the most numerous ships at sea and additionally have the most variable operations. In order to reflect a general pattern of characteristics, fish species landed were treated in an overall manner to indicate the potential vessel operations, complement aboard and duration at-sea. Figure 2-4 illustrates the fishing regions of the world by major fisheries: pelagic fish, groundfish and shellfish. In 1984, the world's total fish catch was estimated at 82 million tons (OECD,1985a). Of this catch, 34 percent of the world's total was identified by species and tonnage. This percent represents 22 countries from a systematic count of each country's total catch by placing fish species into three major fish categories. The culmination of this count indicated over half of the fish caught fell in the pelagic fishery, followed by ground fish at 28 percent, and 19 percent for shellfish. Table 2-3 shows the country, the total annual catch tonnage and the percentage of fish species landed in each major fishery. These data were utilized to provide an estimate of the capacity of vessels for the categories noted earlier. Seven OECD countries listed the number of vessels by capacity range in their fishing fleet (OECD,1985a). Understanding that vessel size and gear employed overlap for any given fish species, the percentage factor based on the country's major fishery was proportioned by the total vessel population and further proportioned within each capacity range. Table 2-4 shows of the 54,000 vessels represented, over 95 percent are in the 0-49.9 grt range, and the distribution of number of vessels by fishing operation are groundfish at 59 percent, pelagic at 29 percent, and 12 percent for shellfish.

The major factors in identifying potential waste generated aboard fishing vessels were derived from estimating population onboard and the time spent at sea. Data for 13 countries discussed above, listed a total vessel population of 619,374 and a crew of 878,339 to man these vessels. As the number of fishermen per vessel can vary from 1 to over 25, depending on vessel size, the capacity ranges were separated into three categories: Coastal, Long Distance and Deep Sea. Within those categories, an average crew for each



Source: Good (1981)

Figure 2-4. Fishing Regions of the World.

TABLE 2-3. FISH CATCH AND PERCENT BY FISH TYPE

Country	Total Annual Catch (Tonnage)	% Caught by Major Fisheries		
		Pelagic	Ground	Shell
Australia	160,000	50	—	50
Belgium	48,000	11	83	6
Canada	1,300,000	24	64	12
Denmark	1,800,000	30	40	30
Finland	103,600	94	5	1
France	410,600	46	37	17
Germany	319,600	29	47	24
Greece	118,000	81	16	3
Greenland	71,000	4	63	33
Iceland	840,000	27	68	5
Ireland	205,000	9	78	13
Italy	430,000	36	33	31
Japan	12,800,000	57	18	25
Netherlands	372,000	47	32	21
New Zealand	151,000	14	56	30
Norway	2,400,000	62	34	4
Portugal	282,000	81	12	7
Spain	1,123,000	45	31	24
Sweden	250,000	60	38	2
Turkey	542,600	46	53	1
United Kingdom	732,000	36	54	10
United States	2,290,200	67	18	15
TOTAL	28,000,000			

TABLE 2-4. ESTIMATED SIZES OF FISHING VESSELS BY FISH TYPE

Country	Total Fish Caught (Tons)	No. of Vessels in Fleet	Percent of Species Caught by Major Fisheries	Number of Vessels in grt Range					
				0-49.9	50-99.9	100-149.9	150-499.9	500-999.9	>1000
Canada	1,300,000	37,992	Pelagic - 24	8,926	100	27	65	-	-
			Ground - 64	23,801	265	73	175	-	-
			Shell - 12	4,463	50	14	33	-	-
Denmark	1,800,000	3,303	Pelagic - 30	845	61	38	45	2	1
			Ground - 40	1,126	80	52	61	2	-
			Shell - 30	845	61	38	45	1	-
Finland	103,600	208	Pelagic - 94	114	66	13	2	-	-
			Ground - 5	6	3	1	-	-	-
			Shell - 1	1	1	-	-	-	-
Germany	319,600	966	Pelagic - 29	236	23	13	3	2	3
			Ground - 47	380	38	21	6	3	6
			Shell - 24	194	19	11	3	2	3
Iceland	840,000	929	Pelagic - 27	110	35	27	44	3	3
			Ground - 68	279	88	69	110	9	9
			Shell - 5	21	7	5	8	1	1
Sweden	250,000	4,162	Pelagic - 60	2,322	136	18	22	-	-
			Ground - 38	1,470	86	11	14	-	-
			Shell - 2	77	4	1	1	-	-
United Kingdom	732,000	6,967	Pelagic - 36	2,284	135	35	49	3	2
			Ground - 54	3,427	203	52	73	4	3
			Shell - 10	635	38	10	13	1	-
TOTALS		54,527	Pelagic - 29	14,837	556	172	230	10	9
			Ground - 59	30,489	763	279	439	19	18
			Shell - 12	6,236	180	79	103	4	4

vessel size range was estimated. The mid range of this average was used as indicated below:

Population of Fishermen by Vessel Capacity

	Coastal grt Range 0.49 to 50-99.9	Long Distance grt Range 100-149.9 to 150-499.9	Deep Sea grt Range 500-999.9	>1000
Avg. Crew/ Vessel	3-5	6-14	15-20	21-30
Mid Range	4	10	17	25

To support this procedure, the number of fishermen by country was calculated based on the estimated number of vessels within the capacity ranges multiplied by the average number of crew for the vessel size. Table 2-5 shows this comparison. The results demonstrate a reasonable agreement between the method of estimating the crew on board by Coastal, Long Distance and Deep Sea, and the published data on population.

The annual days at sea by vessel capacity ranges were estimated at 240 days for long distance and deep sea waters (Nat. Acad. Sciences, 1975) and at 160 days for coastal waters (Pruter, 1986). As this sea time is not continuous, average days per voyage were estimated, then divided into the total annual time spent at sea. The results, indicated below, yielded the number of voyages taken per year within each vessel capacity range.

Duration at Sea, Number of Voyages per Year

	Coastal	Long Distance	Deep Sea	
grt range	0-99.9	100-499.9	500-999.9	>1000
Annual Days at Sea	160	240	240	240
Avg. Voyage Duration (Days)	2.5	15	35	120
Voyages/Year	64	16	7	2

TABLE 2-5. COMPARISON OF REPORTED AND CALCULATED CREW POPULATION BY VESSEL CAPACITY RANGE

Country	Total Number of Fishermen		Coastal	Long Distance	Deep Sea	
	Reported	Calculated	Avg. Crew 4/Vessel	Avg. Crew 10/Vessel	Avg. Crew 17/Vessel	Avg. Crew 25/Vessel
Belgium	1,282	1,355	558	890	17	--
Canada	77,277	154,277	150,124	4,610	N/A	N/A
Denmark	14,500	15,032	12,072	2,790	85	25
Finland	7,000	934	764	170	N/A	N/A
Germany	4,238	4,549	3,560	570	119	300
Iceland	6,207	5,348	2,172	2,630	221	325
Italy	34,000	95,899	90,264	3,160	N/A	2,475
Sweden	6,199	16,576	15,916	660	N/A	N/A
Unit. Kingdom	22,883	29,469	26,888	2,320	136	125

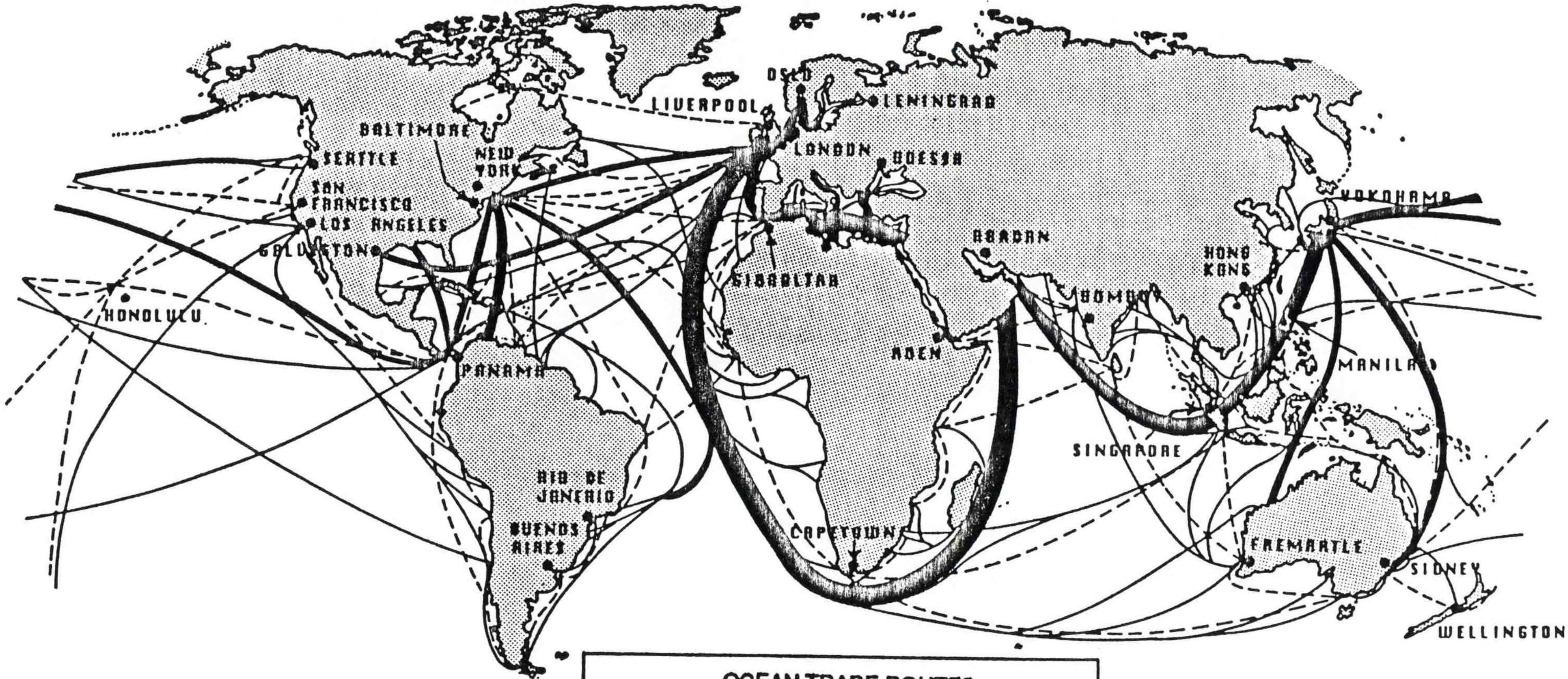
2.1.2 Shipping and Transportation Fleets

Vessels included in the shipping and transportation category are oil tankers, bulk carriers, general cargo and passenger liners. They were classified by type of cargo transported and specific vessel operation. Oil tankers are normally designed to carry petroleum products from crude oil to gasoline and their field of operation includes transporting crude oil from source to refinery and from refinery to market. Vessel size ranges from ultra large crude carrier (ULCC) and very large crude carrier (VLCC) to small crude and product tankers. Bulk carriers include combination carriers and refers to the ship's design to carry ore, grain or similar cargo from source to market.

General cargo vessels are engaged in international trade and pick up and deliver a wide variety of commodities at a number of ports. Vessels in this category also include container ships which applies to the ship's design to carry almost all of its cargo in containers.

Data on estimated population on-board and time spent at sea were extrapolated from the general analysis of the World Fleet, specifically for tankers, carriers, and general cargo vessels. Figure 2-5 illustrates the ocean trade routes for shipping and transportation and indicates the amount of cargo carried and vessel traffic in the ocean. Table 2-6 shows days at sea correlated with the size distribution by grt for groupings for oil tankers, ore and dry bulk carriers and general cargo vessels, and lists the total tonnage and the share of grt's within each size group.

Of the three vessel types, oil tankers are represented in each size grouping ranging from 100 to over 140,000 grt's, indicating coastal and open seas travel. To differentiate the vessel size and time spent at sea, the larger vessels were identified as crude oil tankers with a size range of 80,000 grt and upward, with a duration at sea of 20 to 30 days. The 30,000 to 70,000 grt range represents medium size tankers carrying refined petroleum or smaller amounts of crude products. Time spent at sea was estimated at 15 days, while the smaller vessels, under 30,000 grt, were estimated at seven days.



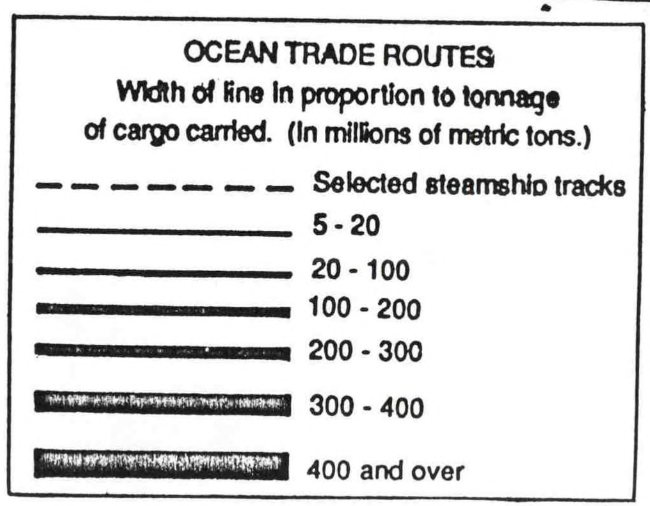


Figure 2-5. Ocean Trade Routes for Shipping and Transportation Fleets

Source: Rand McNally 1980

TABLE 2-6. SIZE DISTRIBUTION OF WORLD FLEET AS AT MID-1984

(In Terms of Gross Register Tonnage)

Size Groups (Grt)	Oil Tankers		Ore & Bulk Carriers		General Cargo	
	1000 Grt	%	1000 Grt	%	1000 Grt	%
100 - 499	491	0.3	-	-	2 267	3.0
500 - 999	765	0.5	-	-	1 658	2.2
1 000 - 1 999	924	0.6	-	-	4 982	5.3
2 000 - 3 999	1 663	1.1	-	-	9 361	12.3
4 000 - 5 999	871	0.6	-	-	8 411	11.0
6 000 - 6 999	302	0.2	375	0.3	4 136	5.4
7 000 - 7 999	456	0.3	653	0.5	4 031	5.3
8 000 - 9 999	728	0.5	2 873	2.3	18 177	23.9
10 000 - 14 999	4 971	3.4	14 780	11.5	18 208	23.9
15 000 - 19 999	8 900	6.1	23 072	18.0	4 007	5.3
20 000 - 29 999	8 732	5.9	22 889	17.8	1 430	1.9
30 000 - 39 999	10 055	6.8	22 457	17.5	342	0.5
40 000 - 49 999	11 221	7.6	7 584	5.9	-	-
50 000 - 50 999	7 178	4.9	6 349	5.0	-	-
60 000 - 69 999	8 309	5.6	8 001	6.2	-	-
70 000 - 79 999	5 804	4.0	8 368	6.5	-	-
80 000 - 89 999	3 694	2.5	4 713	3.7	-	-
90 000 - 99 999	1 443	1.0	2 063	1.6	-	-
100 000 - 109 999	6 894	4.7	309	0.2	-	-
110 000 - 119 999	14 045	9.5	1 614	1.3	-	-
120 000 - 129 999	15 009	10.2	997	0.8	-	-
130 000 - 139 999	10 943	7.4	806	0.6	-	-
140 000 and over	24 064	16.3	429	0.3	-	-
Total	147 462	100.0	128 334	100.0	76 109	100.0

Oil and Bulk carriers size distribution ranges from 6000 to over 140,000 grt and as they are generally engaged in long international trade, estimates for days at sea for all vessel size groupings were 20 to 30 days.

There are two types of vessel within the general cargo category: tramp cargo ships and container ships. Tramp vessels move from port to port rapidly handling cargo with the main function of picking up or discharging cargo from the ship directly into the next carrier. The time spent at sea between ports was estimated at seven days and the vessel size grouping falls into the 100-5,999 grt range. Container ships are represented as the larger vessels (6000 to 39,999 grt grouping) with duration at sea estimated at 10-12 days on the open sea and an additional seven days sail between ports.

The factors which determine the size of a crew for a ship of American Registry are:

- U.S. Coast Guard Requirements & Rulings
- Owner's requirement for maintenance and steward's duties
- Union requirements resulting from negotiations with the owner.

The Coast Guard is responsible for specifying the minimum manning of U.S. ships, on the basis of numerous statutes, and is primarily concerned with the safety of life at sea, i.e. that the ship has sufficient qualified personnel to be capable of safely coping with the normal hazards of the sea. The actual crew list is determined by the owner and the maritime unions with which he has contracts, considering mainly the maintenance and service provided beyond the safety of the ship.

The final crew is generally the result of negotiations and compromise and is influenced largely by precedent (Taggart,1980). Table 2-7 shows examples of crew lists by vessel type. In determining crew size within the World Fleet, the age of the vessels was also considered.

A distinction was made in estimating crew size for newer ships. Generally ships constructed in the last ten years have a higher level of automation and crew size can be reduced by up to 40 percent (DeBoer,1986). Table 2-8 shows the age versus vessel range of the World Fleet. The figure

TABLE 2-7. EXAMPLES OF CREW LISTS FOR SHIPPING AND TRANSPORTATION FLEETS

Type of Ship	Cargo Ship	Container Ship	Ore & Bulk Carrier	Oil Tankers	Passenger Liners	
Passengers					900 to 1200	
Deck Dept.						
Master	1	1	1	1	1	Captain
Chief Mate	1	1	1	1	1	Staff Capt.
Second Mate	1	1	1	1	3	First Off.
Third Mate	2	2	1	2	1	Second Off.
Boatswain	1	1	1	1	1	Cadet
Seaman, A.B.	6	6	6	6		
Seaman, O.S.	–	3	–	3		
Deck Maintenance	–	1	–	–		
Deck Storekeeper	–		1	–		
Total Deck Dept.	12	16	12	15	7	
Staff						
Radio Operator	1	1	1	1	1	Chief Purser
Purser	1	–	–	–	1	Dept. Purser
					2	Staff Purser
Total Staff	2	1	1	1	4	
Engrg. Dept.						
Chief Engineer	1	1	1	1	1	Chief Engr.
First Asst. Engr.	1	1	1	1	1	Staff Engr.
Second Asst. Engr.	1	1	1	1	4	First Eng.
Third Asst. Engr.	1	3	1	2	3	Sec. Eng.
Ch. Electrician	1	–	–	–	3	Third Eng.
Electrician	–	1	1	–	1	Refrig. Eng.
Second Electrician	1	–	–	–	1	Eng. Cadet
Dec, Engine Mech.	–	3	–	–		
Deck Eng. Mech. (Day)	–	1	–	–		
Oiler	–	–	2	–		
Wiper	–	2	2	–		
Ch. Refer. Eng.	–	–	–	1		
Refer. Maint.	1	–	–	–		
Eng. Storekeeper	–	–	1	–		
OMED	–	–	–	3		
Oiler/Maint.	–	–	–	3		
Jr. 3rd Eng.	1	–	–	–		
Eng. Utility	3	–	–	–		
Total Eng. Dept.	11	13	10	13	14	

Table 2-7. Continued

Type of Ship	Cargo Ship	Container Ship	Ore & Bulk Carrier	Oil Tankers	Passenger Liners	
<u>Stewards Dept.</u>						
Chief Steward	1	1	-	1	1	Chief Stew.
Chief Cook	1	1	1	1	1	Asst. Stew.
Cook/Steward	-	-	-	1	200	Cooks, Waiters, Room Stew., etc.
Sec. Cook	1	1	1	-		
Cook/Baker	1	-	-	-		
Messman	1	3	4	-		
Utility Man	2	-	-	-		
Galley Man	-	3	-	-		
Pantry Man	1	-	-	1		
Room Stewards	-	-	-	3		
Passengers, B.R.	1	-	-	-		
Officers B.R.	1	-	-	-		
Waiters	2	-	-	-		
Total Stewards Dept.	12	9	6	7	202	
	==	==	==	==	===	
GRAND TOTAL	37	39	29	36	227	

TABLE. 2-8. AGE DISTRIBUTION OF WORLD FLEET AS AT MID-1984.

Age Range (Years)	Oil Tankers		Ore & Bulk Carriers		General Cargo	
	1000 Grt	%	1000 Grt	%	1000 Grt	%
Under 5	16,623	11.3	29,968	23.4	10,548	13.9
5 - 10	60,568	41.1	31,840	24.8	18,475	24.3
10 - 15	46,753	31.7	38,217	29.8	15,024	19.7
15 - 20	13,149	8.9	20,981	16.3	13,284	17.4
20 - 25	5,828	3.9	4,968	3.9	9,726	12.8
25 - 30	2,766	1.9	915	0.7	5,009	6.6
Over 30	1,776	1.2	1,445	1.1	4,043	5.3
Total	147,463	100.0	128,334	100.0	76,109	100.0

indicates that oil tankers and bulk carriers ten years old or less account for about half of the total tonnage in these categories. The general cargo fleet is somewhat older, with 38 percent of tonnage included in the ten-year or newer group.

2.1.3 Research and Military Vessels

The general characteristics of vessel type and population onboard for military vessels was derived from data obtained from the United States Navy. They provided information for over 500 commissioned vessels by listing each ship by type and by the population onboard. The grouping of like vessels types yielded 35 different ships with varying numbers of crews based on vessel operation. The duration of tour duties and specific deployment is generally classified for security reasons, however, averages of 90 to 180 days per voyage were estimated by vessel type. The ship type, average crew and duration at sea are presented in Table 2-9.

Research and survey vessels have markedly different characteristics resulting from the type of ocean research operations performed and the wide variety of vessel configurations. Vessel types include those which were designed and constructed for oceanic research as well as converted vessels including crew boats, stern and beam trawlers, purse seiners, and ocean-going yachts. Additionally, the characteristics of any of these vessels are directly dictated by the mission that they are called on to perform such as fish research, oceanographic and hydrographic surveys, ocean mining and seismic exploration.

To identify any similar traits which would be germane to this study, a review of the World's Fleet of Research and Survey vessels was conducted in Jane's Ocean Technology (Trillo,1980). In this document, approximately 600 vessels are listed by country, with varying degrees of information on vessel size, field of research and acommodations for complement onboard. The results of this review included 100 vessels for which data were available. The information is summarized in Table 2-10.

Duration at sea, in most citations, was not listed and the limited data of vessel's time at sea did not allow for adequate consistency in determining voyage duration. Therefore, unlike the other vessel

TABLE 2-9. MILITARY VESSELS

Major Category	Ship Type	Avg. Crew	Duration at Sea (Days)	Waste Material generated ton/voyage/vessel
Tenders	Destroyer Tender	1600	90	131
	Repair Ship	715	90	59
	Salvage Ship	125	90	10
	Submarine Tender	1912	90	157
	Submarine Rescue Ship	160	90	13
	Salvage & Rescue Ship	100	90	8
	Aux. Deep Submerge Supt. Ship	160	90	13
	Amphibious Transport Dock	1380	90	113
Ammunition	Ammunition Ship	365	90	30
Stores	Combat Store Ship	365	90	30
	Amphibious Cargo Ship	556	90	46
Nuclear Submarines	Auxiliary Submarine	24	180	4
	Submarine	100	180	16
Destroyer Escort	Misc. Command Ship	880	90	72
	Amphibious Command Ship	813	90	66
	Patrol Combatant Ship	120	180	20
Oiler	Oiler	180	90	15
	Replinishment Oiler	390	90	32
Destroyer	Fast combat Ship	600	180	98
	Guided Missile Ship	100	180	16
	Battleship	1600	180	262
	Guided Missile Cruiser	405	180	66
	Guided Miss. Cruiser Nuclear	595	180	97
	Destroyer	295	180	48
	Guided Missile Destroyer	360	180	59
	Frigate	210	180	34
	Guided Missile Frigate	170	180	28
	Fleet Ballistic Missile Sub.	165	180	27
Aircraft Carrier	Training Aircraft	1440	90	118
	Aircraft Carrier	5000	180	819
	Aircraft Carrier Nuclear	6100	180	999
Landing Ship Tank	Amphibious Assault Ship	2800	90	229
	Dock Landing Ship	750	90	61
	Tank Landing Ship	560	90	46
Minesweeper	Ocean Mine Sweeper	85	90	7
	Fleet Ocean Tug	80	90	6

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TABLE 2-10. RESEARCH VESSELS

Number of Vessels Surveyed	Ocean Research Operations	grt Range	Avg. Complement	
			Crew	Scientists
12	Geographical, hydrography fishing patrol	20-50	6	2
10	Hydrography, fishing exploratory, geographical biological, meterology	51-100	5	4
11	Fisheries, multi-hydro ocean, electronic, meterology, hydrography	101-200	13	6
22	Exploratory, hydrography, geographical meterology, underwater acoustics & solar	201-400	16	10
17	Multi-discipline surveys, ocean sea bottom geology, fisheries, research seismiographic surveys	401-600	22	8
8	Fisheries, exploration, geological & geophysical research, ice braker	601-1000	25	8
11	Multiple discipline & oceanographic surveys, soil investigation and coring	1001-1500	27	13
10	Coring, geology exploratory fisheries, field parties & research , hydrography, biological, chemical	>1500	60	26

classifications in this study, waste generated aboard research and survey vessels was based on a daily average.

2.2 WASTE GENERATED AT SEA

To identify the potential waste generated onboard the various vessels, the material used as related to a ship's general operation was identified. The material used onboard was defined as solid material of human origin and is separated into two classifications: domestic and commercial. The domestic material represents a vessel's complement and is mostly packaging material including plastics, glass, rubber and metal. Figure 2-6 illustrates an example of the domestic material used onboard through a systematic count of items in the stores for a merchant ship and the daily usage per person (Horsman, 1982). Commercial material are of two types: cargo related bulk (shipping crates, dunnage, pallets, wires and plastic covers) and fishing equipment. The use of domestic material was extended to all vessel categories, while commercial material usage was related to shipping and transportation fleets (excluding passenger liners) and the fishing vessels.

2.2.1 Potential Domestic Waste Discharge

The type and quantity of waste resulting from the usage of domestic and commercial material was provided from two different sources. For domestic material, a composite description of solid waste generated onboard was derived by the U.S. Navy. The total amount of waste generated was 3.04 pound/day/man developed from a survey of over 60 different naval vessels by weighing each article used onboard and reweighing the material as waste after usage. (Typical examples are paper food and beverage containers, fiber and paper board, plastic films and containers, natural and synthetic ropes, cloth, cushioning, metal food and beverage containers, metallic straping and wire, wood cratings and glass food and beverage containers.) The result of this survey by material type is shown in Figure 2-7, indicating the fraction of waste generated. These factors were computed for the complement on all vessel types and by days spent at sea.

The primary data (days at sea and complement onboard) from the characterization of domestic waste generating sources combined with the

- METAL
  - NUMBER OF CONTAINERS: 8339
    FOOD: 580
    DRINK: 7680
    AEROSOLS: 79
  - DAILY USAGE PER PERSON: 5
- GLASS
  - NUMBER OF CONTAINERS: 820
    FOOD: 160
    DRINK: 660
  - DAILY USAGE PER PERSON: 0.5
- PLASTIC
  - NUMBER OF CONTAINERS: 696
    FOOD: 96
    GARBAGE BAGS: 600
  - DAILY USAGE PER PERSON: 0.4

Figure 2-6. Provisions for a Merchant Ship
(Crew=30; Voyage Duration=60 Days)
(Source: Horsman, 1982)

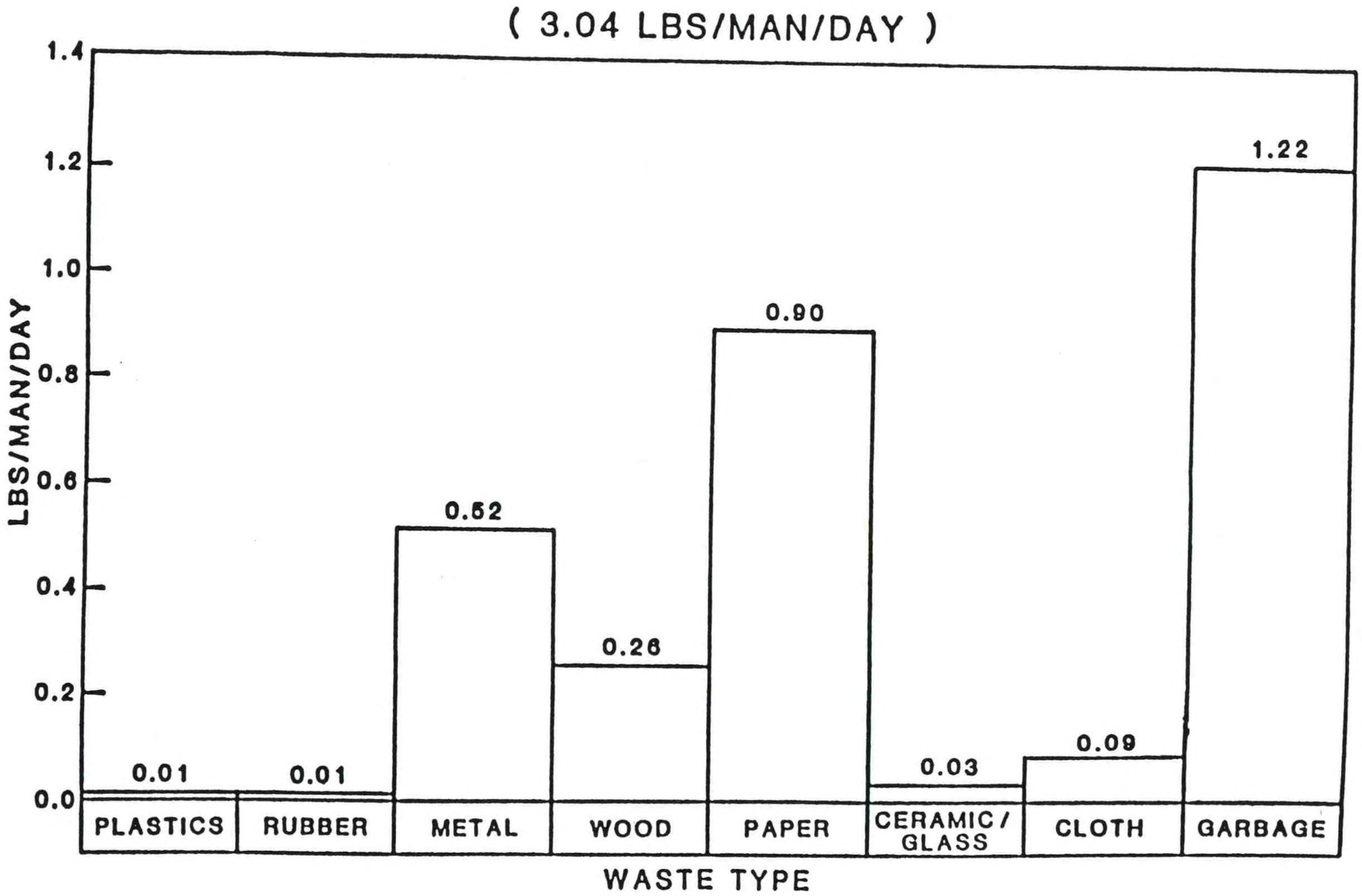

Figure 2-7. Solid Waste Generated At-Sea (Alig, 1986)

composite waste factors yield the potential generated waste material by vessel classification. The objective of this project was to identify and evaluate disposal strategies based on the type and volume of waste material so the results for each vessel classification are presented in a form which relates to the disposal methods most applicable.

Table 2-11 shows the estimates of potential waste generated by fishing activities. Vessels are separated into coastal, long distance and deep sea types. The amounts of waste are listed by type of material and the daily, voyage and yearly generation rates are shown.

Potential waste estimated for the shipping and transportation category is shown on Table 2-12. The volume of waste by type is listed as pounds per voyage per vessel. For oil tankers, ore and dry bulk carriers and general cargo vessels, a forty percent reduction of waste is also shown as would be expected for vessels under 10 years old since these vessels employ a smaller crew (DeBoer, 1985).

The waste materials generated by research and military vessel classifications are presented on Tables 2-13 and 2-14. Waste estimated for research vessels is listed in pounds/day for grt ranges. For military vessels, Table 2-9, above, showed the total estimated waste for each type of military vessel. Table 2-14 provides a distribution by waste type.

2.2.2 Potential Commercial Waste Discharge

Commercial cargo-related debris was estimated at 285 ton/ship/year for Shipping and Transportation fleets and fishing debris was estimated to be 13 ton/ship/year of fishing gear in the fishing industry (Nat. Acad. Sciences, 1975). The source of these measures did not allow for a waste composition factor by material, however, based on the material defined as cargo related, the main constituent waste types include metal, wood and plastic. For fishing equipment, two approaches were used in attempting to estimate the fraction of waste discharged into the ocean as fishing gear.

The first approach was to relate the type of fish landed, by vessel type and associated gear. This was based on the premise that the mission of catching certain species of fish would dictate the net gear employed. However, vessels and net gear overlap for any given species and there is no

TABLE 2-11. ESTIMATED DOMESTIC WASTE FROM FISHING VESSELS

	DOMESTIC WASTE MATERIAL GENERATED lb/Day/Vessel (lb/Voyage/Vessel) **(lb/Year/Vessel)**							
FISHING VESSEL	Plastics	Rubber	Metal	Wood	Paper	Glass	Cloth	Total
Coastal	0.04	0.04	2.1	1.0	3.6	0.12	0.4	7.3
	(0.1)	(0.1)	(4)	(3)	(9)	(0.4)	(0.9)	(18)
	(6)	**(6)**	**(333)**	**(166)**	**(576)**	**(19)**	**(158)**	**(1,264)**
Long Distance	0.1	0.1	5.2	2.6	9	0.3	0.9	18.2
	(1.5)	(1.5)	(78)	(39)	(135)	(4.5)	(13)	(273)
	(24)	**(24)**	**(1,248)**	**(624)**	**(2,160)**	**(72)**	**(216)**	**(4,368)**
Deep Sea	0.2	0.2	8.8	4.4	15.3	0.5	1.5	30.9
	(6)	(6)	(309)	(155)	(536)	(18)	(54)	(1084)
	(42)	**(42)**	**(2,166)**	**(1,083)**	**(3,749)**	**(125)**	**(375)**	**(7,582)**
	0.3	0.3	13	6.5	22.5	0.8	2.2	45.6
	(30)	(30)	(1,560)	(780)	(2,700)	(90)	(270)	(5,460)
	(60)	**(60)**	**(3,120)**	**(1,560)**	**(5,400)**	**(180)**	**(540)**	**(10,920)**
ALL VESSELS	0.6	0.6	29.1	14.5	50.4	1.7	5	102
	(38)	(38)	(1,951)	(977)	(3,380)	(113)	(338)	(6,835)
	(132)	**(132)**	**(6,867)**	**(3,433)**	**(11,885)**	**(396)**	**(1,289)**	**(24,134)**

TABLE 2-12. ESTIMATED DOMESTIC WASTE FROM SHIPPING AND TRANSPORTATION VESSELS

	DOMESTIC WASTE MATERIAL GENERATED lb/voyage/vessel (lb/voyage/vessel)*							
SHIPPING AND TRANSPORTATION FLEET	Plastics	Rubber	Metal	Wood	Paper	Glass	Cloth	Total
Oil Tankers								
Crude	11	11	562	281	972	32	97	1,966
Medium	5	5	281	140	486	16	49	982
Small	2	2	131	65	226	8	23	457
	18	18	974	486	1,684	56	169	3,405
	(11)	(11)	(584)	(292)	(1,010)	(34)	(101)	(2,043)
Ore & Dry Bulk Carriers	9	9	452	226	783	26	78	1,583
	(5)	(5)	(271)	(136)	(470)	(16)	(47)	(950)
General Cargo								
Containerships	7	7	365	182	632	20	60	1,273
Tramp Cargo	3	3	135	67	233	8	23	472
	10	10	500	249	865	28	83	1,745
	(6)	(6)	(300)	(149)	(519)	(17)	(50)	(1,047)
Passenger Liners	65	65	3,380	1,690	5,850	195	585	11,830
ALL VESSELS	102	102	5,306	2,651	9,182	305	915	18,563
	(22)	(22)	(1,155)	(577)	(1,999)	(67)	(198)	(4,040)

*Reduction of 40 percent generated waste for vessel age under 10 years.

TABLE 2-13. ESTIMATED DOMESTIC WASTE FROM RESEARCH VESSELS

Research Vessels grt Range	DOMESTIC WASTE MATERIAL GENERATED lb/day/grt Range							
	Plastics	Rubber	Metal	Wood	Paper	Glass	Cloth	Total
20-50	0.08	0.08	4.2	2.1	7.2	0.24	0.72	14.6
51-100	0.09	0.09	4.7	2.3	8.1	0.27	0.81	16.4
101-200	0.19	0.19	9.9	4.9	17.1	0.57	1.7	34.6
201-400	0.26	0.26	13.5	6.8	23.4	0.78	2.3	47.3
401-600	0.30	0.30	15.6	7.8	27.0	0.90	2.7	54.6
601-1000	0.33	0.33	17.2	8.6	29.7	0.99	3.0	60.1
1001-1500	0.40	0.40	20.8	10.4	36.0	1.2	3.6	72.8
>1500	0.86	0.86	44.7	22.4	77.4	2.6	7.7	156.5
	2.5	2.5	130.6	65.3	225.9	7.6	22.5	456.9

TABLE 2-14. ESTIMATED DOMESTIC WASTE FROM MILITARY VESSELS

Ship Type	DOMESTIC WASTE MATERIAL GENERATED Tons/Ship Type/Voyage							
	Plastics	Rubber	Metal	Wood	Paper	Glass	Cloth	Total
Ammunition	0.3	0.3	8	4	15	0.6	1.8	30
Stores	0.8	0.8	21	11	37	1.6	3.8	76
Oiler	0.5	0.5	13	7	23	1	2	47
Tender	5	5	141	71	247	10	35	504
Aircraft Carrier	19	19	542	271	949	39	97	1,936
Destroyer	7	7	206	103	360	15	37	735
Destroyer Escort	2	2	44	22	77	3	8	158
Landing Ship Tank	3	3	94	47	165	7	17	336
Minesweeper	0.1	0.1	4	2	6	0.3	0.5	13
Nuclear Submarines	0.2	0.2	6	3	10	0.4	1	20
All Ships	38	38	1,079	541	1,889	77	193	3,855

"typical gear". Fishing gear, like fishing methods, are different throughout the world. Differences in the gear used, even for catching the same species and in the same fisheries, exist because fisherman tend to adapt or modify gear based on their experience, knowledge of the fish's habitat and behavior practices and cultural practices (Uchida, 1984).

The second approach was to obtain data on fishing equipment available for use and the quantities sold. These data were unobtainable, and, as lost fish gear is not reported, the fate of the gear could not be identified. It eventually became evident there was no adequate measure for estimating the amount of fish gear lost or discarded, however, it is known that the main types of gear discharged into the ocean include nylon or synthetic netting, wood, wire, foam plastic, iron and ceramics. These waste material types constitute items largely identified by ship sightings and beach surveys representing various sizes of netting (trawl web, purse seines, gill nets, lift nets, etc.) floats and buoys, and fish and bait containers. A study of the net fisheries in the North Pacific (Uchida, 1984), revealed that gill nets are the most likely to become lost or damaged and discarded during fishing operations. These nets last only a few weeks and up to 400 nets can be used in a 4 month season. In addition to heavy fishing activity, bad weather and marine mammal damage also account for a proportion of the nets being lost or discarded. Nets in purse seine operations require that at least one end of the net be secured to a vessel at all times. High gear losses are not evident but portions of the netting can become damaged by entanglement on rocky bottoms or coral set in shallow waters and net damage also occurs if large predators, i.e., sharks, are caught together with small target species. Trawls, like gill nets, can be easily lost should they become hung on the bottom during trawling operations. Also, bottom trawls are highly susceptible to damage when being hauled over rough bottom. Loss and damage to trawl gear are probably highest during and immediately after the exploratory fishing phase when grounds are still unfamiliar to the trawl fishermen.

In spite of a considerable effort to secure detailed information on commercial waste discharge, the results were not fruitful. A major difficulty exists with, for example, estimating the loss of fishing gear and, more importantly, in considering what quantity of gear might be subject to reclamation and disposal. One estimate of 13 tons/ship/year (National Academy of Sciences, 1975) gives no information on the manner in which loss occurred. Loss could occur due to damaged nets being thrown overboard or it could occur by catching protuberances under the sea. In the former case, it would be possible for the vessel's crew to dispose of the waste by some process other than overboard discard. In the second case, it may not be possible to recover the netting at all.

In view of the paucity of data, the only conclusion drawn relative to fishing vessel commercial waste is that recoverable loss of fishing gear ranges from 4 to 40 tons/ship/year, based on a single source of data indicating 13 tons/ship/year, qualified with a 3:1 factor of uncertainty.

By similar reasoning, for cargo commercial debris, the single source of data, indicating 285 tons/ship/year, with application of a 3:1 uncertainty factor, results in 95 to 860 tons/ship/year.

In view of the major uncertainties in these loss rates, attempts to define waste discharge by specific vessel type, fishery type, etc., were abandoned as a subject requiring development of raw data not presently collected by commercial and fishing vessels.

SECTION 3.0

WASTE DISPOSAL TECHNOLOGY

This section discusses the methods for waste disposal currently available. Figure 3-1 is a flow chart depicting the various aspects of waste handling options.

A survey was conducted to determine what waste management technologies are currently being used aboard ships. For instance, a spokesman for a passenger cruise line indicated garbage grinders, compactors and incinerators were installed in their fleet (Axcell, 1986). Vessels in the U.S. Navy primarily use commercial compactors for disposing of waste material (Alig, 1986). Data were collected on various technologies (such as unit cost, size, weight and capacity rate) to evaluate potential onboard disposal systems for vessels in other areas of sea activity. The survey yielded the following profiles for certain waste disposal methods:

- Incinerators

  -Cost: $25,000-$40,000
  -Size: 5 ft x 5 ft x 5 ft
  -Design Throughput: 125 lbs/hr-350 lbs/hr

- Compactors

  -Cost: $30,000-$90,000
  -Size: 3 ft x 6 ft x 2 ft
  -Design Pressure: 40 lbs/in^2-300 lbs/in^2

- Disposal At Port

  -Cost: $200/load (40 cubic yards) from dock to transfer area

- Recycling

  -Plastics: Based on composition
  -Bottles: $25/ton (Recovery Cost)
  -Metal (Aluminum Cans): $500/ton (Recovery Cost)

There are five major suppliers of marine incinerator units in the world: Volcano in Japan; Atlas Danmark in Denmark; Hamworthey Engineering in England; Golar Metal in Norway; and Vent-O-Matic Incinerator in the United

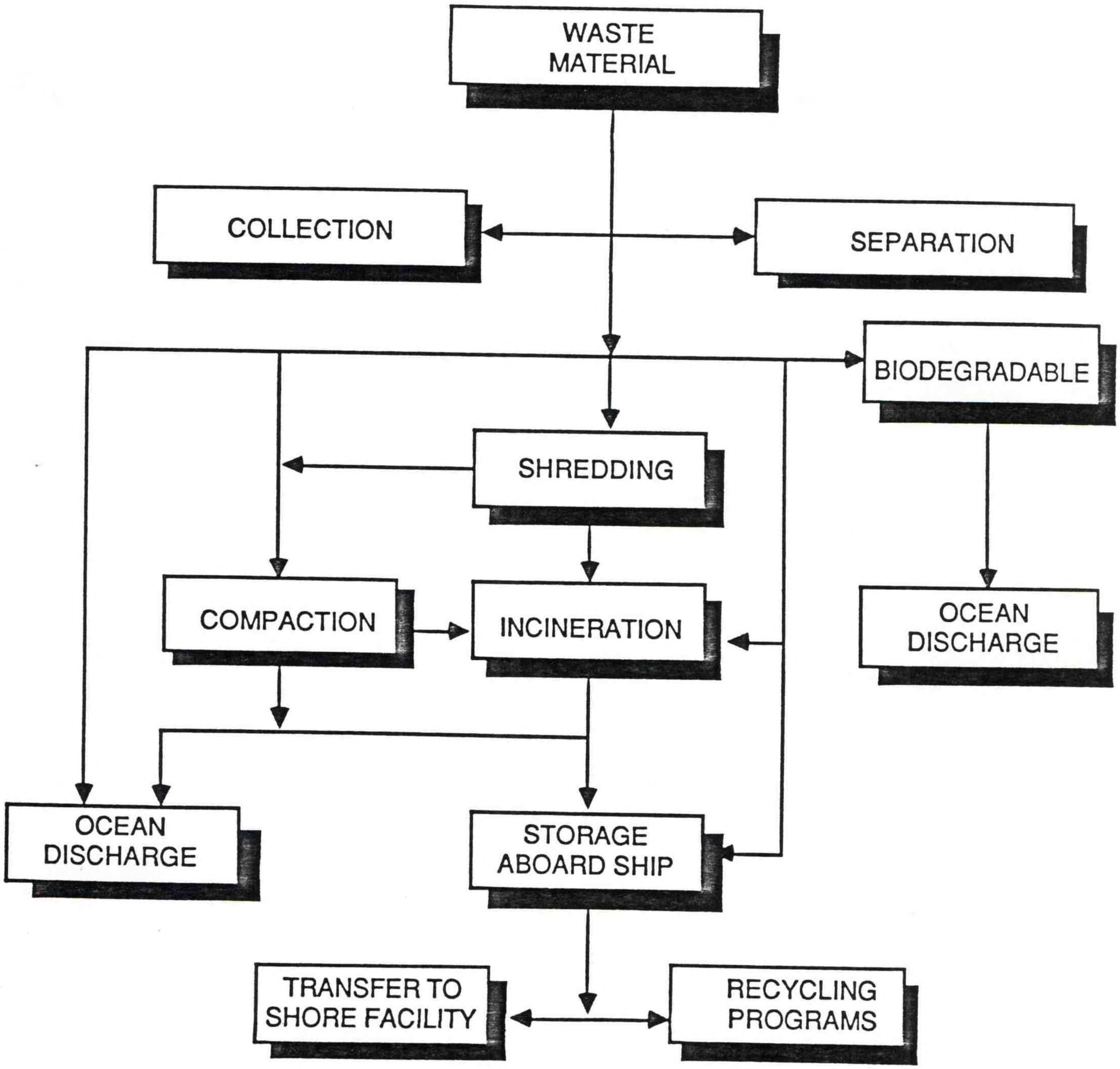

FIGURE 3-1 FLOW CHART OPTIONS FOR SHIPBOARD DISPOSAL OF WASTE MATERIAL

States (Hillery, 1986). The European suppliers primarily advertise their systems as multifunctional, capable of burning both liquid and solid waste simultaneously or mixed together. The majority of commercial marine incinerators are designed for the disposal of a vessel's primary problem, waste oil, with the capabilities of burning solid waste, but operational experience by the U.S. Navy demonstrated poor function, i.e., corrosion, excessive operator time and poor reliability (Alig, 1982). Vent-O-Matic has two lines: a Navy unit which is designed only for solid, combustible waste on vessels with large crews; and an industrial-type incinerator which has been modified for marine use for commercial ships with smaller crews (Hillery, 1986).

Technically, onboard space limitations are a primary factor when considering retrofitting equipment aboard a ship. Also, dedicating an area for waste material storage is difficult when the design of a vessel space is already highly utilized. For vessels with disposal systems, the reliability of the equipment is also of foremost importance. The following criteria for an optimum system were developed based on the comments obtained by interview and phone contacts:

1. Space and weight requirements should be minimized commensurate with the vessel function.

2. A high degree of reliability and a minimum of maintenance and operator attention.

3. Designed to handle waste discharge rate of vessel.

4. Durable and long-life construction material to resist corrosion and handle shipboard shock and vibration.

5. Designed to operate simply, safely and efficiently under all conditions.

The substitution of biodegradable material is technologically possible, specifically for plastic materials which are the major constituent of packaging (hence litter). Changes in types and uses of packaging have been proposed; however, the short- and long-term effects have not been fully explored. For instance, while use of plastics with enhanced degradability would reduce the persistence of these materials in the marine environment, the benefits might be offset by increases in the quantities disposed of at sea.

Patterns of waste disposal from ships are difficult to document because of the number of waste generating sources and variability due to crew size and voyage length. However, ocean vessels may be categorized according to characteristic traits to allow estimates of waste material generated from the vessels. In this study, shipboard waste disposal technologies have been reviewed and the potential of storing wastes onboard for subsequent land-based disposal technology was explored in order to assess the applicability by vessel size and type.

3.1 INCINERATOR DESIGN CONSIDERATIONS

This section discusses general incineration concepts, including land-based incineration. Specific applications for marine use are then discussed.

Because of recent increased attention to atmospheric emissions of hazardous chemicals and use of incineration to destroy liquid and solid hazardous wastes, the standards for design of land-based incinerators are currently undergoing significant development. These considerations may well accrue to marine incinerators and, thus, must be addressed in considering new or retrofit marine installations. Disposal of solids and liquids at sea should not be at the expense of unacceptable emissions of hazardous air pollutants.

An incinerator must be designed for the particular types of waste which it will be burning. This is a singular challenge because most incinerators will need to burn a variety of different wastes and the potential variety is enormous. Many waste streams are liquids which can be burned in excactly the same manner as fuel oils - and to some degree they can be substituted for commercial fuel oil. However, the simplicity ends here. Waste often includes solid bulk material as well as liquid/solid mixtures. The incinerator facility design must integrate the function of the incinerator with that of the waste preparation system. When a facility must handle a variety of wastes, there will be design tradeoffs between the cost of the incinerator and the cost of the preparation system. In this section, the features of different incinerator design and waste handling concepts are presented as a guide for the evaluation and selection of equipment for specific application.

3.1.1 Incinerator Burners

Incinerator burners have been designed to handle everything from gases to whole steel drums of semisolid material. We can divide these into two groups: burners for fluid wastes and burners for solids or semisolids. The first category is relatively straightforward.

Liquid Burners

Liquid fuels and liquid wastes differ only in certain chemical and thermal properties or in legal definition. The differences between burners for these two material categories tend to be minor unless the waste is a heavy slurry. Fluid (gas or liquid) fuel burners are composed of circular air directing hardware with fuel injectors to mix the fuel with the air. The differences between various burners are almost entirely in the fuel injectors; the air directing hardware can be invariant. Good combustion performance requires that the fuel be well mixed with the air and this requires that liquid fuels be finely atomized. Small fuel droplets in this spray can burn up completely before they leave the combustion zone with the flue gases. If the droplets are too large, they will not burn completely. Fuel droplets larger than 200 microns (0.2 millimeter) in diameter have been known to leave a large furnace in the form of small carbon particles. It is entirely conceivable that hazardous constituents could be carried out of an incinerator in the residues of large droplets from a waste stream spray. To prevent occurrence of this phenomenon, proper attention must be given to the properties of the waste liquid, spray quality of the injector, residence time, and temperature. This phenomenon is well documented on residual fuel fired boilers and it has the potential to cause the emission of incompletely burned wastes from liquid streams fed to incinerators.

Emission of this type can be prevented by using a fuel nozzle which produces a fine spray with no large droplets; such nozzles have been developed for heavy residual fuels. However, waste streams can include liquids or slurries which are thicker or otherwise different from residual oil and the existing fuel atomizing technology may be inadequate for some waste applications. An alternate approach is to design the incinerator so that large liquid droplets settle to the floor where they remain long enough to burn completely. This is a valid concept, but should be approached with caution: particles (or droplets) with diameters between 0.2 and 10 micron have relatively low settling velocities and can easily be blown out of the combustion zone if gas velocities are high enough.

Solid Burners

There are many types of equipment used to burn solid wastes and the discussion here will address them in the chronological order of their development.

Stokers

Stokers are the most common type of combustor utilized to burn either solid fuels or waste material. The fuel is spread on a grate and air is forced up through it to support the combustion. The stoker grate is installed below a boiler or an incinerator and air flow through the system is controlled. There is usually some automatic mechanism to feed the fuel onto the grate as well as to remove the residual ash from the grate. There are a variety of mechanisms used to automate the operation of the stokers from any manufacturers.

Stokers, in their simplest form, can be used to incinerate any waste with heating value and they are the basic combustor used for most municipal refuse incinerators. If the waste does not have sufficient heating value to support combustion, then the furnace must be heated with supplemental fuel; liquid or gas fired burners above the grate are common. Stoker operation may appear automatic, but in order to operate well a stoker needs continual adjustment and intervention by an experienced operator.

Stokers have fundamental drawbacks which impact directly on their use for waste incineration when there is the potential of hazardous emissions. Fuel air mixing tends to be poor which leads to large temperature variations and uneven combustion. If the bed of fuel (waste) on the grate is not uniform, combustion air tends to blow through the thinnest parts of the bed; thus most of the air goes where it is least needed to support combustion. As a result, stokers may require large amounts of excess air to avoid incomplete combustion. Another problem is that air blowing through the bed of fuel (waste) tends to carry pieces of fuel with it and these pieces do not burn completely before leaving the furnace. Emitted carbon is a chronic problem with coal and wood fired stokers: it wastes fuel and tends to cause fires in the dust collectors. Similar emissions from an incinerator could result in hazardous constituents in the dust collectors or in the flue gas. Chlorinated dibenzo-furans have been detected in emissions from municipal and woodwaste incinerators.

The emission of unburned gases from a stoker can be resolved by adding a secondary combustion chamber as discussed below. However, the emission of unburned solids is a concern which should be addressed in the design of the solid combustor.

Rotating Kiln

The rotating kiln has become the most accepted concept for land-based incineration of a variety of solid and liquid waste streams. The kiln is a steel tube, mounted on a vary slight incline and rotated slowly. Solids dumped in the upper end are tumbled by the rotation and gradually moved by the incline to the lower end. The kiln is lined with fire brick and the interior is maintained at a high temperature, approximately 2000°F. It takes an hour or two for most solids to work their way down the length, which is long enough to heat even very large pieces of material such as drums full of waste. Heating is with a burner directed down the length of the kiln and the burner can be fired with liquid waste or any standard fuel including pulverized coal. Probably the biggest advantage to the rotary kiln is the flexibility. The design has to handle almost any type of waste stream; in addition the emissions from incineration of solids can be minimized. The slow tumbling of solids in the kiln assures exposure to oxygen and high temperature, but there is no undue tendency for pieces of material to be carried out by the flue gases. A rotating kiln is a very simple device which is considered to be one of the least expensive incineration systems to construct. It does not require special cooling of the shell, and experience shows that it can be run continuously for months without significant need for maintenance work.

A waste disposal kiln can be run at temperatures up to at least 2500°F. When operated at low temperatures, the residues stay in solid form although some metals may be oxidized and glass may melt. At higher temperatures, the residue will melt and tend to form a liquid coating on the inside of the kiln. Kilns operated in this manner are said to be operating in a slagging mode. Depending on the chemistry of the slag residue, it may cool to a glass-like solid which is insoluble. One potential problem with slagging operation occurs when the slag has a very low viscosity. It is possible for a rivulet of slag to form which flows rapidly from the kiln and may carry unburned (or unheated) material with it. This thin slag formation can occur at relatively low temperatures depending upon the chemistry of the slag. There are ways to accommodate or prevent this problem. The chemistry of the waste can be altered by deliberate addition of certain materials, or the kiln can be built with dams or a controllable incline in order to accommodate a low viscosity slag.

There is no fundamental limit to the size of a kiln. Kilns can be built in a wide range of sizes depending on the amount of waste to be incinerated. Firing rates are typically in the range of 0.3 to 1.0 million Btu's per hour per square foot of cross section. The firing rate must be enough to heat the waste material to the destruction temperature and to accommodate heat loss through the kiln shell. Although the solid waste will provide some of the necessary heat release, supplementary firing is usually necessary. The auxiliary burner can be located at either end of the kiln and should be used to control the exit gas temperature.

The kiln length is usually 2 to 4 times the kiln diameter, but it can be built longer. Residence time of tumbling solids will be determined by the combination of length, slope, and rotation speed. The gas residence time will depend upon the kiln volume, but unburned species may enter the gas stream from solids on the bottom of the kiln. Since this entry can occur at any position along the length of the kiln, the kiln gas residence time is not usually counted in the incinerator system design.

Molten Bath Incineration

Incinerators have been built around baths of molten salt or molten glass. These units represent extensions of industrial manufacturing process units and tend to be special application devices. The molten baths maintain high uniform temperatures, which provide a level of certainty about thermal destruction of wastes processed in the bath. Salt baths are usually designed around specific chemical interactions between the bath and the waste feed and are thus intended to process a specific waste. Obviously this will produce a residue with a specific chemistry which might be recycled for industrial purposes.

The molten glass bath is not waste specific although it may be limited in the types of waste which it can accept. Some wastes will not melt in the glass bath and others might contaminate it. This review will not explore the feasibility of using the process for various wastes. An advantage of the glass bath approach is that the residue will be a glass which will not likely pose a disposal problem.

Fluidized Beds

Fluidized bed combustion systems have received substantial attention in recent years. The fluidized bed concept is not new, but the commercial application to combustion is recent. Refined versions of the basic concept including the circulating fluidized bed are currently under development.

The fluidized bed forces air through a bed of sand which contains the fuel. The thermal mass of the sand helps to hold steady temperature. By drawing heat from the bed as the fuel burns (as in a boiler), the bed temperature can be closely controlled at moderate levels. Fluidized beds can burn a wide variety of solids and sludges as well as any liquid or gas. Their application to the incineration of a variety of wastes has not been demonstrated and there are potential problems. One drawback of the simple fluidized bed is the combustion efficiency which can be as low as 90 to 95 percent. Unburned material tends to be carried out of the bed just as it is in a stoker; as ash accumulates in the bed, material must be removed. However, since the bed contains 2 to 5 percent fuel, some unburned fuel (wastes in this case) is removed with the excess bed material. Newer circulating bed designs may eliminate these problems, but this needs to be demonstrated.

Fluidized beds are constrained to operate at temperatures below that at which the bed material begins to melt or at which waste residues might become molten. Thus the fluid bed cannot produce the inert glass solids which may be possible from some other devices. It is possible that the maximum operating temperature might be below that necessary to oxidize a particular hazardous waste, but this would depend upon the waste stream and has not been explored.

Fluidized beds offer significant promise for incineration of certain waste streams, it is not clear that they can always achieve the high level of destruction efficiency necessary if they are used for a wide variety of waste streams.

3.1.2 Secondary Combustion Zones

Waste incinerators designed to handle solid wastes usually require a secondary combustion chamber in order to provide the residence time and temperature necessary to assure complete destruction. Combustion gases flow from the solid waste combustion system (which can be a kiln or stoker device) into the secondary combustion zone where sufficient secondary fuel is added to raise the exit temperature to the guaranteed destruction level. The secondary combustion chamber is only capable of burning gases or volatile liquids and is not used for solid wastes. It can be an incinerator which is capable of operating independently of the solids combustion unit.

Residence time is calculated from the average time it takes for the gas to travel from the chamber inlet to the exhaust. Frequently the average gas residence time in the solids combustion unit is adequate for complete destruction of wastes, but there is some uncertainty regarding the actual time temperature history of every element of the gas leaving this chamber. A drum of material in the kiln might be emitting material near the point where the gases enter the secondary chamber so that the additional residence time would be needed.

The secondary chamber can, and frequently does, serve as a liquid injection incinerator for hazardous wastes. Hazardous aqueous wastes with little or no heating value can also be fired into the secondary chamber. Thus the secondary chamber is fired both by the solids combustion unit and by a liquid combustion burner. The liquid (or gas) burner is used to control the temperature at the exit of the secondary chamber. Although the temperature at the exit of the solids combustion unit is usually measured and controlled, it is the temperature at the exit of the secondary combustion chamber which provides the assurance of destruction efficiency.

3.1.3 Incinerator Ancillary or Auxiliary Systems

The incinerator may need a waste feed system as well as devices to control air pollution and to handle solid residues. These ancillary systems are discussed in this section. The success of the facility operation will be determined in substantial part on how well these ancillary systems work and how well they are matched to the incinerator.

Waste Processing and Feed

Waste brought to an incineration system may need to be stored and possibly processed in some way before it can be introduced to the incinerator. The feed system must be able to supply a steady flow of material to the incinerator to help avoid operating upsets and downtime. The system must be designed and operated to avoid spills or fugitive emission of hazardous wastes. It is important that people in the vicinity are not unduly exposed to toxic substances which the incinerator may emit. These fairly obvious requirements can be difficult to achieve particularly if there are a wide variety of waste streams coming to the incinerator. Several items illustrate the problems:

1. Liquids frequently contain solids which tend to settle in tanks and may plug feed lines.

2. Waste solvents frequently contain corrosive chemicals which can damage pumps, meters, and plumbing.

3. Some solids need to be shredded before they are fed to the incinerator and this process should be vented into the incinerator. Handling shredded material can be difficult.

4. The opening and feeding of drums into storage tanks or directly into the incinerator is likely to be the major activity at the facility; this operation holds a high potential for spillage and/or worker exposure.

Liquid organic wastes provide a fuel at incineration facilities which usually displaces a premium fuel such as fuel oil or gas. In order to use this waste as fuel, it must be stored in permanent tanks and pumped under pressure to the burner. This means that there must be facilities to transfer these liquids from drums and/or bulk transporters to the facility tanks. The tanks may need agitators and possibly corrosion proof linings. The feed system to the kiln must include accurate meters to support firing rate control and to document the amount of waste liquid which is burned.

Systems to feed solid fuels to combustion systems are usually major sources of difficulty even when the fuel is as predictable and consistent as coal. The varied materials encountered in solid waste handling systems provide a challenge to the system designer. Shredded hardware will not flow through hoppers and is likely to jam up screw feeders. Potential plugging and jamming problems should be recognized and designers should arrange systems so that maintenance work on the hardware can be performed easily and with minimal worker exposure to toxic wastes. Material feed problems must be resolvable without the need to shut down and cool off the combustion system.

Air Pollution Control

Air pollution control should begin with the combustion system: it should emit no measurable amounts of toxic organic compounds. This is vitally important because most of the standard gas cleaning devices (scrubbers and dust collectors), to date, have not categorically demonstrated the ability to capture organic species. It is also a reasonable expectation because an incinerator is capable of completely destroying organic species if it is properly designed and operated.

The two pollutants of primary concern from incinerators are particulates and hydrochloric acid (HCl). Particulates come from the incombustible ash in the waste and HCl comes from chlorine in chlorinated organic wastes (which are a major constitutent in most hazardous waste incinerator feed streams). Chlorine gas (Cl_2) may also be emitted, particularly if excess air levels are very high. This emission should be controlled with by controlling the excess air because it cannot be effectively controlled with an acid gas scrubber.

The selection of pollution control hardware is determined in large part by the need to collect the HCl. This gas is highly soluble in water and is easily collected by a scrubber. This makes a scrubber an almost automatic part of the gas cleaning hardware on an incinerator. Usually lime or limestone is used to maintain the pH of the scrubber liquid.

Particulate emission levels at an incinerator outlet are usually relatively low, but not low enough to meet stack emission standards. Either a precipator or a bag house could be used to collect particulates. Both of these units have high collection efficiencies and in most instances exceed the removal requirements as established by the regulations. These units are also proportionately more expensive to build. Also, as we note below, there are potentially severe corrosion problems. A scrubber is generally not a high efficiency dust collector (for fundamental reasons), but it is adequate for most incinerators and may be put in series with the acid gas scrubber. Thus most land-based incinerator installations today utilize one or more types of wet scrubbers in series to control air pollutant emissions.

Hydrochloric acid is highly corrosive and it will rapdidly corrode most metals in certain temperatures and moisture ranges, and in particular, any temperature below about 300°F. As a result, the scrubber internals and all downstream ducting are usually made of plastic. The plastic will not withstand prolonged high temperatures (over 800°F), but it does not corrode.

Ash Handling and Wastewater Treatment

Ash quantities from a solid waste incinerator can be substantial. The ash handling system should be automated. The manner in which the system operates will depend upon the properties of the ash.

Ash which has not been melted, i.e., a nonslagging operation, is likely to be dusty. It usually makes sense to wet this ash and the handling system usually starts with a water tank or trough. This also accommodates the fact that ash may leave the incinerator in a red hot condition. The result is a calx to be disposed of. This sludge may be high in various metals or other elemental species; thus it must be disposed of in a secure landfill unless it can be processed for reclaimed material. The ash should not contain any organic constituents or even any significant amount of carbon. Water from the ash quench tank may contain some toxic compounds, but it is practical to treat with the rest of the facility wastewater.

Fused ash from a slagging combustor should be glass-like and more inert than most natural soils. It may be practical to add selected materials to the waste entering the combustor to promote the formation of an inert residue. An inert residue is highly desirable because there are few restrictions and related costs on its disposal. Most of the facility wastewater is associated with the scrubber effluent which usually contains substantial amounts of alkaline salts and is at high temperature. A water treatment system to control pH and to lower the temperature is a necessity. Other water treament may be required depending on the nature of material contributed by a particulate scrubber of the ash handling system.

3.1.4 Monitoring and Control

Good control of the incinerator operation is a key aspect of emissions control as well as of the economic viability of the incinerator. Unsteady operation results in interruptions in feed and in accelerated wear to many system components. All incinerators rely on refractory linings which deteriorate more rapidly when exposed to swings in temperature. Periods of unsteady operation, thermal and mechanical, are likely to be the primary cause of excessive emissions: these periods will be the primary cause of incomplete combustion and substandard destruction efficiency.

Steady operation of incinerators can be difficult to achieve; this is true of liquid waste as well as solid waste units. A primary cause of fluctuations is variation in thermal output. The heating value of liquid waste streams varies greatly and a steady input of liquid (gallons per minute) does not translate to a steady input of heat. The heating value of solids varies more than that of liquids. In addition the flow of solids into the combustion zone is seldom steady. It can be a common occurrence for feed systems to jam or hang up resulting in a complete stoppage of flow through this system until operators manually restore the system. Drum feeding is inherently unsteady: they are fed in at the rate of one every few minutes. In an incinerator, the use of most of these different material handling systems is inherently necessary due to the variability of the waste types received for incineration. A combination of screw augers, ship hoists, barrel chutes, ram chargers, and lances all in the same incinerator is necessary to effectively handle wastes.

In order to maintain steady operation, temperatures and excess air levels must be continuously measured and the controls adjusted as necessary to maintain these parameters. This section presents a discussion of the types of measurements which can be made and appropriate control concepts.

Emissions

The principal organic hazardous constituents (POHC), which are of primary concern, cannot be measured on a continuous basis. Specifically, there are no instruments with provision for continuous time telemetry that measure POHC, HCl, or waste destruction efficiency, to date. These measurements can only be made using grab sample approaches where the sample is returned to a laboratory for analysis. In the case of toxic organic constituents (undestroyed wastes), the lab work requires days or weeks to complete. Thus, continuous emission control can only be assured by secondary measurements which relate to the emission of the species of primary concern.

The approach used to assure waste destruction on a continuous basis is to monitor temperature and oxygen concentration at the combustion zone exit to be sure that these parameters do not fall below critical levels. This is probably an effective way to prevent air emission of organic wastes. This approach does not assure that solids leaving the incinerator (particulates and ash residue) are free of organic constituents. This emission can only be prevented by proper design of the system initially and steady operation of the system subsequently.

Gas pollutants species such as carbon monoxide (CO) and nitrogen oxide (NO) can be monitored continuously and they do provide information about the combustion performance. CO does represent incomplete combustion, but it is formed in a different manner than the organic species which are of concern in regard to destruction efficiency. CO is an indicator of insufficient temperature or oxygen at some point in the combustion process and so it can be used in somewhat the same way as direct temperature and oxygen measurements. There may be little or no relationship between CO and the carryover of organics in the ash or particulate matter. The manner in which CO can be related to incinerator destruction efficiency is currently the subject of debate in the technical community.

NO is a pollutant that is frequently regulated, but it is also an indicator of combustion zone temperature. This is especially true of refractory lined systems such as incinerators. It is used as a burning zone temperature indicator on cement kilns, but its applicability on incinerators has not been explored.

Particulate emission rates cannot be measured continuously at present but visual observation of the flue gas (opacity monitoring) is a measurement whch is related to particulate emissions. It is used on most stationary combustion sources although it has two drawbacks:

1. Particulate visibility is determined by the size distribution of the particles as well as by the amount of particulate. The relationship between opacity and particulate emissions is different for different combustion sources and it can change with time on an individual source. Thus opacity is an imperfect measurement of particulate emissions rate.

2. Incinerator flue gases carry a great deal of water vapor which condenses in the stack and can make an opacity measurement meaningless as a particulate emission indicator.

Process Monitoring

Since one of the main objectives of incinerator process control is to control emissions, the emission monitoring data are used as part of the incinerator control scheme. The objective is to maintain a steady flow of material through the incinerator and to maintain steady temperatures.

Gas temperatures at the exits of both the primary and secondary combustion chambers can be measured directly and should be used to control the rate at which supplemental fuel is fired into these two chambers. Variations in the heating value of this fuel (which is usually a waste) and in the amount of heat absorbed by the solid waste feed will require substantial adjustments in these firing rates. Automatic control of these burners is necessary.

The temperature of the residual ash leaving the incinerator is a valuable indicator of the operation, but there is no simple or automatic control response. If the temperature of this material drops, it is an indication of decreased residence time and corrective action by the operators is necessary. This is a site-specific item which is not discussed in detail here. Solids incineration is a type of solids thermal processing and experience can be drawn from existing industrial processes. That experience suggests extensive use of indirect measurements of actual process phenomena and the need for experience to properly interpret these indirect data.

Most of the required temperatures can be measured with direct contact thermocouples. However, optical pyrometers are useful for measuring surface temperatures (refractory, residual ash, shell, etc.). The pryometer will not work if the target is obscured by dust in suspension or by scale on the surface of the target.

Air flow rates should be determined from O_2 measurements of the flue gases leaving the primary and secondary combustion zones. Oxygen concentrations should be maintained constant at predetermined levels. The amount of air required to maintain a steady O_2 level will depend primarily on the thermal input to the incinerator rather than on the heating value (Btu per pound or gallon) of the fuel. Thus, a sudden increase in the O_2 level usually indicates a decrease in thermal input - insufficient fuel. The response of the O_2 indicator will probably be more rapid than the temperature indicators which are slowed by the thermal mass of the incinerator. This shows how an instrument which is normally used to indicate air flow, can actually be the leading indicator of fuel input: a simple example of the use of indirect instrumentation.

3.2 MARINE INCINERATORS

In comparison with the technology of land-based incineration, discussed in the previous section, the state-of-the-art in marine incinerators is at a much more primative level, primarily because the technology has not yet been subject to constraints on hazardous air emissions nor to the specific distribution of hazardous feed materials.

Marine incinerators in current use are predominantly designed for intermittent operation, hand feeding, and, as best as can be determined, do not include any provisions for air pollution control. Control of air pollution would normally be required in most harbors of the U.S. In particular, in the U.S. at the Port of Long Beach, Los Angeles, California, any ship entering the harbor is subject to all the permitting requirements of the South Coast Air Quality Management District that would be imposed on a land-based incinerator, including the use of Best Available Control Technology (BACT) for all criteria pollutants, modeling of near field impacts, and health effects risk assessment. The alternative to complying with these requirements would be simply to not operate the incinerator within the coastal boundaries of the harbor. However, it is obvious that efforts to control waste disposal on vessels will involve trade-off assessments of the atmospheric impact.

With these cautions in mind, not fully adressed in this study, the following discusses the current state of technology regarding marine incinerators.

Table 3-1 presents criteria for incineration of waste material, including considerations of special handling by vessel personnel, combustibility, reduction of volume, residual, exhaust and on-board storage space. Most wastes are ammenable to incineration with the exception of metal and glass packing materials.

Three primary suppliers of marine incinerators provided information for this study:

1. Golar Metal, Inc. Tvedestrand, Norway (USA: Lionville, PA)
2. Vent-O-Matic Incinerator, Corp., Hyde Park, MA
3. Aalborg Boilers, Aalborg, Denmark

TABLE 3-1. INCINERATION CRITERIA FOR SHIPBOARD GENERATED WASTE MATERIAL

TYPICAL EXAMPLES	SPECIAL HANDLING BY VESSEL PERSONNEL BEFORE INCINERATION	INCINERATION CHARACTERISTICS				ONBOARD STORAGE SPACE
		COMBUSTIBILITY	REDUCTION OF VOLUME	RESIDUAL	EXHAUST	
PAPER PACKAGING, FOOD & BEVERAGE CONTAINERS, ETC.	MINOR - PACKAGED TO FEED INTO HOPPER	HIGH	OVER 95%	POWDER ASH	CLEAN	MINIMUM
FIBER AND PAPER BOARD	MINOR - REDUCE MATERIAL TO SIZE FOR FEED. MINIMUM MANUAL LABOR	HIGH	OVER 95%	POWDER ASH	CLEAN	MINIMUM
PLASTIC PACKAGING, FOOD & BEVERAGE CONTAINERS, ETC.	MINOR - PACKAGED TO FEED INTO HOPPER	HIGH	OVER 95%	POWDER ASH	POSSIBLY SMOKEY & HAZARDOUS BASED ON INCINERATOR DESIGN	MINIMUM
PLASTIC SHEETING, NETTING, ROPE, BULK MATERIAL	MODERATE MANUAL LABOR TIME FOR SIZE REDUCTION	HIGH	OVER 95%	POWDER ASH	POSSIBLY SMOKEY & HAZARDOUS BASED ON INCINERATOR DESIGN	MINIMUM
RUBBER HOSES, BULK PIECES	MAJOR MANUAL LABOR TIME FOR SIZE REDUCTION	HIGH	OVER 95%	POWDER ASH	POSSIBLY SMOKEY & HAZARDOUS BASED ON INCINERATOR DESIGN	MINIMUM
METAL FOOD AND BEVERAGE CONTAINERS, ETC.	MINOR-PACKAGED TO FEED INTO HOPPER	LOW	LESS 10%	SLAG	CLEAN	MODERATE
METAL CARGO, BULKY CONTAINERS, THICK METAL ITEMS	NOT EASILY INCINERATED	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	MAXIMUM
GLASS FOOD & BEVERAGE CONTAINERS, ETC.	MINOR- PACKAGED OR CRUSHED	LOW	LESS 10%	SLAG	CLEAN	MODERATE
WOOD, CARGO CONTAINERS, LARGE AND BULKY PIECES	MODERATE-MANUAL LABOR TIME FOR SIZE REDUCTION	HIGH	OVER 95%	POWDER ASH	CLEAN	MINIMUM

The decline of shipbuilding in the U.S. tends to favor the non-U.S. manufacturers for new shipbuilding, but would not necessarily be so for retrofit of U.S.-based ships.

In contrast to land-based incinerators, shipboard incinerators must be as compact as practical, and availablity of operating personnel is at a premium so automatic operation is desired. Most shipboard incinerators are designed for intermittent operation; the waste is charged to the incinerator, firing is started, and combustion lasts for several hours, typically 3-6 hours. Some larger incinerators are designed for continuous operation with the advantage that a smaller incinerator is required to consume the daily waste, but the disadvantage of requiring 24 hour supervision by the operating staff.

Commercial marine incinerators currently available are typically capable of handling charges of 200 to 500 pounds of waste, have natural or induced draft, and are hand fired. It should be noted that incinerator ratings are usually quoted on the basis of heat input rate, rather than a weight charged basis, because of the variability of the heat content in the wastes. Some modern incinerators are designed for continuous firing, and can handle simultaneous disposal of all shipboard waste, including garbage, plastic, metal cans, and sludge. A typical configuration is shown in Figure 3-2.

These units have a number of advantages:

1. Operate under negative pressure, thus having no problem with puffing when being charged.

2. Highly reliable, since there are no moving parts except for the fan.

3. No auxiliary fuel is required.

4. Minimum operator skill is required.

5. Low external skin temperature, 10-30°C above ambient, inherently safe.

6. Low exhaust temperature, about 400°F.

7. Low weight - 4,000 to 10,000 lbs.

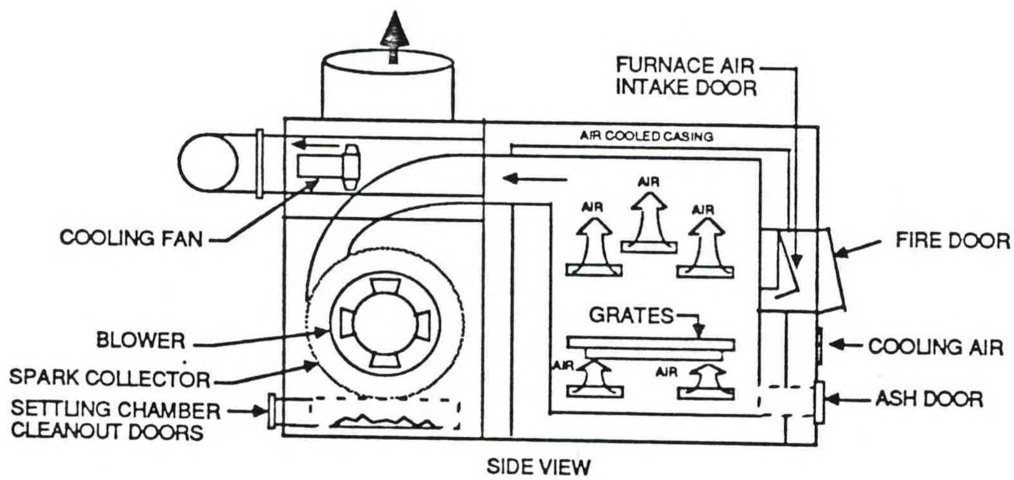

Figure 3-2 Typical shipboard incinerator

Some of the disadvantages of incinerators include dirty operation and excessive labor required for charging, stoking and ash removal, and they may not meet air pollution regulations imposed in harbors. Some of these disadvantages can be remedied by automatic equipment for charging, stoking, agitating, and ash removal can be performed automatically with sea-water-driven eductors. The additional equipment to perform these automatic functions will, of course, tend to take more installation space. For military ships, in particular, any device that contains a flame can be considered as a hazard to ship safety.

The cost for current typical marine incinerators ranges from $16,000 for smaller units holding a 7 cubic foot charge, up to $50,000 for larger units. Installation costs are quoted to range from $10,000-30,000 depending on vessel and incinerator (Bourgeault, 1986).

Currently, the Navy has in use only two types of shipboard incinerators. Incinerators meeting military specification MIL-I-15650 are installed in many of the large ships such as aircraft carriers and replenishment ships. These incinerators are physically large and amount to little more than a large firebox with a fan, but with no controls, burner, or agitator. Their simplicity makes them reliable, but also makes them of limited use due to minimal flexibility and no automation. There are also about 50 model SK-25 incinerators installed on Navy guided missle frigates. They are smaller than the MILSPEC incinerators but are automated and more flexible. For operational reasons, however, their use has been discontinued and they will be removed and replaced by vertical trash compactors (Singerman, 1986).

The Navy has recently tested a model OG-400 incinerator made by Golar Metal AS for possible use on small and medium sized ships. The unit has been modified to include a continuous-feed mode and to increase the throughput rate from 40 to 175 pound per hour. Another continuous-feed model made by Golar is the OG-500 with a throughput capacity of 300 pounds per hour. This unit could be used on the larger ships, replacing the older MILSPEC units. Cost of these incinerators is between $30,000 and $40,000 (Singerman, 1986).

All incinerators under consideration by the US Navy will be used to burn dry trash only. While many incinerator units are advertised and sold as also being able to burn wet garbage, waste oil, and sewage sludge, Navy experience in these areas has resulted in their elimination as candidate materials for incineration.

Incinerator Waste Heat Recovery

Since incineration tends to be viewed by ship operators as an unproductive burden, there are distinct advantages to incineration methods from which waste heat can be recovered to generate space heating, hot water or steam, thus serving to reduce fuel cost, offsetting the burden of incinerator operation. The ability of an incinerator to generate steam is of particular use when a ship is docked in a harbor.

Commercial boiler/incineration systems range in capacity from 2,400 to 19,000 lb steam/hour, and in size from 5' to 9' in diameter and 14' to 29' in height.

A disadvantage of heat recovery incinerators is that they are probably more suseptible to corrosion from clorine and sulfur present in the waste, compared to an incinerator that does not recover heat. Acids generated by these chemicals will aggrevate corrosion of the steam generating convection surfaces, and there may be more tendancy for plugging of the exhaust gas passages. This may require laboratory chemical analysis of typical waste materials before an installation design can be completed, requires more operator attention to the type of waste being burned, and requires routine inspection of all the boiler internal surfaces.

Some brief mention in the literature was observed regarding disposal of wastes in the main propulsion boilers or in exhaust gas streams from diesel powered ships. This method appears to be the most economical of both space and cost, and also may have particular advantage as a retrofit method since it uses existing equipment. However, no detailed information was found regarding the actual use of either of these methods.

A major disadvantage of firing waste in main propulsion boilers is that the variability of the waste heat content can result in boiler control problems, smoking, and corrosion; and can adversely affect the ability to properly follow load swings. It is unlikely that more than 5 to 10% of the boiler heat input could be tolerated as waste. It is believed that most ship propulsion is fired by diesel fuel. In the event that coal was the main fuel, the co-firing of waste would be more attractive since the waste properties regarding corrosion would be similar to that of the coal and the boiler equipment would be designed to protect against chlorine and sulfur corrosion.

A disadvantage of using diesel propulsion engine exhaust as a heat source for incineration is that, at low power, the heat would be insufficient to maintain the proper combustion temperature.

Since very little information was found on incineration in marine boilers or diesel engine exhaust, and since these methods seems to be a logical way to dispose of waste, particularly as potential retrofit methods, further investigation of these areas is warranted. Research has been conducted on co-firing waste in land-based boilers, but most of that work has concentrated on hazardous waste with the conclusion that these types of wastes are more appropriately burned in incinerators specifically designed to handle the problems unique to hazardous waste. The problem of permitting hazardous waste burning at land-based facilities is also a strong deterent. These same problems would accrue to marine installations, but only if disposal of hazardous waste were involved.

3.3 TRASH COMPACTORS

The US Navy was the primary source of information on trash compactors. Data provided by the Navy indicated about 15-20% of US Navy ships are equipped with compactors. Table 3-2 shows the criteria for compaction of various waste types. Most waste can be compacted; the exceptions include unshredded plastics, fiber and paper board, bulky cargo containers and thick metal items. These items are large in size, easing the process of separation.

The following information was obtained from reference SNAME, 1982. Compaction can reduce the volume of waste into bags, boxes, or briquettes. When these compacted slugs are equally formed and structurally strong, they can be piled up in building block form; this utilizes more of the overhead

TABLE 3-2. COMPACTION CRITERIA FOR SHIPBOARD GENERATED WASTE MATERIAL

TYPICAL EXAMPLES	SPECIAL HANDLING BY VESSEL PERSONNEL BEFORE COMPACTION	COMPACTION CHARACTERISTICS			ONBOARD STORAGE SPACE
		RATE OF ALTERATION	RETAINMENT OF COMPACTED FORM	DENSITY OF COMPACTED FORM	
METAL FOOD & BEVERAGE CONTAINERS, GLASS, WOOD	NONE	EXTREMELY READILY	ALMOST 100%	HIGH	MINIMUM
SHREDDED PLASTICS, FIBER & PAPER BOARD	MINOR- REDUCE MATERIAL TO SIDE FOR FEED. MINIMAL MANUAL LABOR	READILY	MINOR SPRING BACK	MEDIUM	MINIMUM
METAL DRUMS, UNSHREDDED CARGO PACKING, LARGE PIECES OF WOOD	MODERATE-LONGER MANUAL LABOR TIME REQUIRED TO SIZE MATERIAL FOR FEED	READILY	CONSIDERABLE SPRING BACK	RELATIVELY LOW	MODERATE
UNSHREDDED PLASTICS, FIBER & PAPER BOARD	MAJOR MANUAL LABOR TIME FOR MATERIAL; USUALLY IMPRACTICAL	INAPPLICABLE	INAPPLICABLE	INAPPLICABLE	MAXIMUM
BULKY METAL CARGO CONTAINERS, THICK METAL ITEMS	COMPLETELY IMPRACTICAL; SHIPBOARD COMPACTION NOT FEASIBLE	INAPPLICABLE	INAPPLICABLE	INAPPLICABLE	MAXIMUM

space in the storage compartments. The compaction ratio for normal mixed shipboard waste is about 4:1. The US Navy has tested many commercial compactors and has not found a suitable one. Accordingly, a development program was initiated for a compactor suitable for marine use on small ships. The Navy has developed a horizontal compactor approved for service use that is suitable for large ships. Some of the available compactors have options such as sanitizing, deodorizing, adjustable compaction ratios, bagging, in plastic or paper, boxing in cardboard (with or without plastic or wax paper lining), baling, etc. Paper or cardboard would tend to become soaked and weakened by moisture in the garbage during long voyage onboard storage; on the other hand, there have been problems due to the generation of gas and pressure exploding tight plastic bags. If fragmentation or shredding machines are used prior to compaction, the compaction ratio can be increased, and the storage space decreased. However, it should be noted that shredding equipment can be a very high maintenance item. A compactor should be installed in a compartment with adequate room for operating and maintaining the unit and storing trash to be processed. The compartment should be located adjacent to the areas of food processing and commissary storerooms; it should have washdown fresh water service, coamings, and deck drains; an adequate ventilation; and hand and automatic fixed fire extinguishing systems.

There are current seven different trash compactors on U.S. Navy ships, described below (Singerman, 1982), and are probably typical of compactors installed on other ships such as passenger liners.

Automated Power Systems Model 4630

This is a horizontally configured trash compactor that produces slugs of trash 14 inches in diameter in a compaction chamber by using a ram face pressue of approximately 300 pounds per square inch. This compactor is powered by a remote electro-hydraulic unit.

Auto-Pak VC-W164 (Flinchbaugh VC-W164)

This is a vertically configured trash compactor with height, width, and depth dimensions of 72x36x19 inches. It has a compaction container capacity of 2.5 cubic feet. This model's hexagon ram develops a ram face pressure of approximately 64 pounds per square inch.

Piezo Model E PH20

This model is a horizontally configured trash compactor with height, width, and depth dimensions of 45x70x20 inches. The compaction chamber has a capacity of 2.6 cubic feet. The model develops a ram face pressure of approximately 83 pounds per square inch.

Precision Metal Products Model PR-15-H

This model is a vertically configured trash compactor with height, width, and depth dimensions of 78x28x30 inches. The compaction chamber capacity is 4 cubic feet and the ram develops a face pressue of 60 pounds per square inch.

Todd/CEA Model 10T-1535-1A

This is a horizontally configured trash compactor with height, width, and depth dimensions of 50x92x27 inches. It produces a trash slug 15 inches in diameter under a ram face pressure of approximately 118 pounds per square inch.

Tony Team Model 1800

This model is a vertically configured trash compactor with height, width, and depth dimensions of 70x25x25 inches. The trash bag or bale size is 18x18x20 inches developed by a compaction ram face pressure of approximately 40 pounds per square inch.

Wyott Model 74 -3000

This model is a horizontally configured trash compactor with height, width, and depth dimensions of 68x120x30 inches. It has a compaction chamber capacity of 2.8 cubic feet and a ram face pressure of approximately 88 pounds per square inch.

The compactors listed above will all be replaced following successful development of the Navy vertical trash compactor. This compactor is currently under development and was designed for all surface ships greater than or equal in size to a fast frigate. One unit can handle the trash generated by a crew of 350, so ships with more than 350 crew members will require more than one unit. The unit is designed to process shipboard solid waste, exclusive of garbage and industrial waste, at a rate of 150 pounds per hour creating high density slugs which are negatively bouyant. The trash slug is approximately 50 pounds, and is discharged in a trash bag that can be hand carried. The unit will be fully automated and cost approximately $125,000.

There are currently only four aircraft carriers that have solid waste pulpers installed. These units are the SOMAT SPC-250S Solid Waste Pulpers which were installed as original equipment when the ships were built. The pulpers process solid wast consisting of paper, food and galley wastes, and classified documents at an average rate of 1100 pounds per hour. The cost of this unit is $40,000.

The Navy is currently developing a smaller version of the SOMAT SPC-250S, the SP-150S which will have a minimum throughput rate of 375 pounds per hour. The final design of the SP-150S will be versatile enough to be adapted and scaled to different types and sizes of ships.

A trash disposal unit (TDU) and a trash compactor are installed on nuclear submarines. Solid waste is compacted into disposable metal containers and discharged from the vessel through a vertical tube (TDU) extending through the pressure hull. Solid waste disposed by the compactor/TDU consists of paper, cardboard, rags, metal, plastic, dirt and dust, discarded tools, etc. In cases where garbage grinders are not available, wet material such as scullery wastes which cannot be compacted are placed in plastic and then mesh bags and disposed of through the TDU. The submarine compactor/TDU system is capable of handling approximately 300 pounds of solid wastes in two hours.

Submarine solid waste disposal is a very slow, labor intensive, and odorous operation. Additionally, equipment and operating costs are very high. Consequently, the Navy has begun development of a new submarine solid waste disposal system with more desirable operational capabilities.

3.4 RECYCLING OF WASTE

Manufactured products made of plastic, glass, metal and paper are suitable for recycling. Active land-based programs are ongoing in the U.S., and other parts of the world, to recycle these product materials.

Table 3-3 specifies the recycling criteria by waste type and indicates typical recovery values.

A fundamental problem in recycling waste generated on shipboard is storage space. Based on waste generation rates for various vessel types, calculations indicate that space to store waste would, in only a few days at sea, exceed the space required for incinerators or compactors. There is also a penalty in ship fuel consumption incrementally imposed by carrying waste materials throughout a voyage, although this penalty is probably relatively small.

An additional problem is that to be effective, a recycling program requires separation of waste to extract the recycleable materials. This is best done at the initial point of disposal where separate waste containers can be used for disposal and for recycle storage of certain types of waste. This method requires that all aboard ship be informed regarding the items to be placed in the recycle containers. It has the advantage of avoiding post-separation which is a noxious task if waste has begun to deteriorate and is odorous, leading to a shipboard task that has a high probability of being postponed or avoided altogether.

The general problem of waste storage has been addressed by SNAME, 1982. If the ship has a small complement or short runs, and available space, the accumulated solid waste can be stored in its original bulk form. It can be placed in trash type containers or special storage bins for retention until it can be removed at pierside or to a support ship. Storage of dry bulk waste is usually no problem provided safety measures are enforced to prevent fire, and detection alarm systems are in place. Storage of food waste garbage is a more difficult problem involving a sloppy, noxious smelling mixture with possibility of contamination. The handling and odor problem can be reduced by use of a dewatering device. Attached to the output of a garbage grinder, a dewater device reduces the weight and volume of the garbage tremendously because this garbage is more than 90 percent water. With the organic solids removed, the water can be discharged overboard. However, an effective means of removing the organic solids is yet to be demonstrated. The separated solids can then be stored with less space and odor problems. On some ships where adequate holding tanks are available, the entire discharge from the

TABLE 3-3. RECYCLING CRITERIA FOR SHIPBOARD GENERATED WASTE MATERIAL

WASTE MATERIAL	EXAMPLES OF RECOVERED MATERIAL	SPECIAL HANDLING BY VESSEL PERSONNEL BEFORE RECYCLING	ONBOARD STORAGE SPACE RATING	RECOVERY VALUE $/TON
GLASS	BOTTLES, JARS, CULLET	SEPARATION OF CLEAR GLASS FROM COLORED GLASS	HIGH - ITEMS REMAIN INTACT FOR RECYCLING PROCESS	$40 - CLEAR GLASS $30 - COLOR GLASS
METALS	FERROUS - METAL CANS IRON SCRAP, STEEL SCRAP	NONE	HIGH	
	ALUMINUM - CANS, FOIL TRAYS, PANS, ALUMINUM WIRE & SCRAP	COMPACTED - NOT CONTAMINATED WITH EXTRANEOUS MATERIALS	MODERATE	$800-UNPAINTED $600-PAINTED
	OTHER - LEAD SCRAP AND ALLOYS, COPPER WIRE, BRASS, BRONZE AND ZINC SCRAP	NONE	HIGH	
PAPER	CORRUGATED, NEWSPAPER, PAPER BAGS, BOOKS, MIXED WHITE PAPER, KRAFT	PACKAGED OR BALED - NOT CONTAMINATED WITH EXTRANEOUS MATERIALS	HIGH	$50 -$55
PLASTICS	THERMOPLASTICS - POLYETHYLENE, POLYPROPOLENE, POLYVINYL CHLORIDE, NYLON (PACKAGING BANDS, PACKING ROPES, CUPS, CONTAINERS, ETC.) THERMOSETS - FIBERGLAS, SYNTHETIC RUBBER, HOSES, RIGID RE-ENFORCED PIPES AND PRODUCTS	BUNDLED	HIGH	$60-$100

garbage grinders can be directed to the sewage system when in coastal waters and overboard in authorized dumping zones. Problems relating to general storage of solid waste are not quite as severe with recycleable materials, but food waste present on the materials would be expected to aggrevate odors and contamination potential.

Consideration of the storage space requirements indicate that recycling is primarily applicable to only those ships with relatively short voyages, of the order of one week or less, assessment of ship size and voyage duration, discussed elsewhere in this report, indicates a fairly large number of ships, primarily small fishing vessels which have sufficently short voyage duration such that recycling may be practical. A mitigating factor is that waste originates as items stored on board at initiation of the voyage. Space required for restorage of recycleable waste materials is very likely to be less than that required for the original items. This, of course, only applies to items that do not involve crew subsistence, for instance, unused packaged foods could not be safely stored in conjunction with potentially contaminated wastes. Since many of the items subject to recycling involve food packaging materials, this is a fundamental limitation to restoring waste in the original space.

3.5 ENVIRONMENTALLY DEGRADABLE PLASTICS

Titus, 1973, presents a discussion of plastic degradability. Although the work is somewhat outdated, it summarizes the basic concepts. Degradable plastics are plastics which will predictably decompose to a powder or liquid form and eventually be encompassed in the natural environment. Plastics can be degraded by three basic mechanisms: biodegradation, solubility and photodegradation. This technology is based on over 20 years research and experience in making plastics more durable - an area in which plastic manufacturers were highly criticized in the past, mainly for poor weatherability.

The first class of materials, the biodegradables, are those plastics which, because of their chemical structure, are susceptible to being assimilated by microorganisms such as fungi and bacteria through enzyme action. This mechanism requires heat, oxygen and moisture. Most naturally occurring polymers such as cellulose and natural rubber are attacked by a variety of fungi and bacteria. However, minor modification of these polymers such as acetylation of cellulose or vulcanization of rubber produce biodegradation resistant materials.

Laboratory and field investigations on synthetic polymer deterioration have shown that some plastics have been attacked by microorganisms. The time span, however, for such deterioration is lengthy and can cover more than a decade. Actually, the filler and additives incorporated in plastics have much to do with the rate of degradation. These chemicals are of lower molecular weight and can act as a source of food for the microorganisms. When they have been consumed, their loss will result in the loss of the material's elongation, flexibility, and there may be accompanying discoloration and staining.

The almost total resistance of potential waste plastics such as polyethylene, polypropylene, polyvinyl chloride, and polystyrene to biodegradation has led to the modification of their basic structure by specific functional groups to the monomer stage during polymerization. However, this copolymerization approach has been unsuccessful to date in producing completely degradable materials.

In addition to modifying plastics materials via additives and copolymerization, experimental work has been conducted to obtain selected mutants and microorganisms to better degrade plastics. For example, Enzymes Inc. has prepared mutant microorganisms by Cobalt 60, Strontium 90 and 500,000 volt x-ray radiation. These new mutant strains of soil microorganisms show increased capability for degrading the resistant types of synthetic polymers. The use of these specialized bacteria and fungi as inoculants in waste disposal areas may do much to help the problem of degrading waste polymers.

A study was conducted under the sponsorship of the Environmental Protection Agency which covered the biodegradation of all thermoplastic plastics. It indicated that plastics themselves are pretty immune to enzyme attack. In fact, only the aliphatic polyesters and urethanes derived from aliphatic ester diols and low molecular weight (MW <500) unbranched polyethylene derivatives can be assimilated. The results showed a 95 percent weight loss of a 40,000 molecular weight polycaprolactone resin container after a 12 month soil burial test.

The Union Carbide Corporation has formulated polycaprolactone resins which give predictable degradable rates. This material is not attacked by airborne spores. It must be in contact with a nutrient soil environment to be assimilated. Degradation is thickness sensitive and influenced by environment. For example, it would not degrade in an arctic environment. This material is available in all forms and can be pigmented and fabricated by normal processing techniques. Although no data were found regarding its behavior in the marine environment, it is unlikely that the necessary nutrient conditions exist for degradation in sea water.

The next phenomenon is solubility. The solubility of plastic materials varies considerably with plastic formulation, temperature, solvent. concentration, and solvent. However, for environmentally degradable plastics, the only solvent to be considered is water. Therefore by solubility we mean completely soluble in water forming nontoxic homogenous solutions.

There are several plastics that are completely water soluble and thermoplastic. Examples are polyvinyl alcohol (PVA), hydroxypropyl cellulose (HPC), and polyethylene oxide (PEO). Normally small amounts of plasticizers, internal lubricants, and antioxidants are added to improve processing and utility. These plastics can be pigmented and coated. They have been extruded, injection molded, thermoformed and blow molded.

As to the solubility, when an item of hydroxypropyl cellulose, for example, is immersed in water, it quickly forms a slippery gel on the outer surface. This gel layer must dissolve and wash away before the water can penetrate progressively deeper to dissolve the complete item. Thus additives such as fillers, plasticizers and lubricants which tend to wick or absorb water through the outer gel/layer will speed up the overall rate of solution. Increasing the molecular weight or thickness, raising the water temperature, or adding hydrophobic modifiers such as waxes and oils increase the dissolving times.

The solubility of water soluble plastics varies with formulations, molecular weight and temperature. Hydroxypropyl cellulose is insoluble in water above 45°C; polyethylene oxide at 65°C. Reversing these trends achieves faster solution times except, of course, when you reach freezing temperatures. However, heat promotes the solubility of polyvinyl alcohol. Its solubility depends on degree of alcoholization. For example, completely alcoholized grades are hot water soluble and cold water insoluble, whereas, 85 percent of partially alcoholized types are soluble in both hot and cold water.

Water soluble plastics are non-toxic, edible, non-caloric, non-nutritive and wash through plumbing without damage or clogging. They have low biological oxygen demand and do not support mold or bacterial growth. In an incinerator, they readily burn and eventually decompose to carbon dioxide, water and residual carbon. They are resistant to grease, oil, and petroleum hydrocarbons and therefore lend themselves to the packaging industry.

The last and most promising technique is photodegradation. Some plastic materials, depending on their molecular structure or additives, are ultraviolet light sensitive. They absorb ultraviolet energy below 320 microns from the sun. When enough energy in a form of photons is absorbed, the bonds between carbon and hydrogen are broken and oxidize to produce peroxides and hydroperoxides. These decompose further to produce carbonyl groups, hydroxyl groups, water and carbon dioxide.

These reactions cause a breakdown of a long chain backbone and reduce molecular weight. Once initiated, this reaction continues even in the dark. Thus, the plastic loses its strength, becomes brittled, and can be easily broken up by natural erosion forces such as rain and wind into small particles. These may become part of the soil or be attacked by microorganisms. As previously stated, low molecular weight alone will not constitute a biodegradable material. Photodegradation is time and temperature dependent and will vary with the polymer structure material thickness, and concentration and content of additives such as pigments, ultraviolet accelerators and promoters, ultraviolet absorbers and antioxidants. Such additives do not significantly affect the materials processing but would influence storage, coloration and physical properties. The following materials are those which have been successfully degraded by this technique:

polyethylene, polystyrene, polypropylene, polybutene, polybutadiene, acrylonitrile-butadiene-styrene, and polyvinyl chloride.

The most successful materials are the linear, non-aromatic, molecular structured plastics. For example, unvulcanized syndiotactic polybutadiene is inherently degradable by ultraviolet light without sensitizers. The degree of crystallinity (normally between 15 and 30 percent) midway between an elastomer and a thermoplastic is the key to its degradability. Under direct sunlight it has disintegrated in periods ranging from one week to more than one year.

Several companies and universities are developing ultraviolet accelerators and promoters for initiating and controlling the photodegradation process. Since most of this work is proprietary, few of them have been chemically identified. However, some of these additives mentioned in the literature are: paraffin, oleic acid, iron compounds, benzophenones, coal tar dyes, cobalt, zinc, copper and copper oxides. Most additives are unaffected by the usual fabricating methods and have little effect on plastic properties. They are inexpensive, usually non-toxic, increasing compound costs as little as 1/2 cent a lb. Table 3-4 lists the materials which have been successfully degraded to date (as of 1973). These, more or less, constitute the lower strength, lower modulus, inexpensive, easily fabricated, tough materials. They can be made in all their usually forms such as foams, sheets, films, reinforced moldings and composites that constitute a high ton usage plastic. They can be processed by all standard mass fabrication techniques and equipment.

Some problems faced by the military in the use of degradable plastics include the following:

- They must function in very broad temperature and environmental ranges such as -40 to +120°F - desert, tropic, and arctic temperature zones. This poses serious problems in determining degradation rates. For example, water soluble items would be out of the question in a desert and parts of the arctic on any meaningful timetable.

- There is a limitation in effectiveness of some systems with pigmentation and coatings. Olive drab or other dark colors would screen out desired ultraviolet energy.

TABLE 3-4. DEGRADABLE PLASTICS

PE, low density (branched)
PE, high density (linear)
PE, glass filled high density (10-40%)
PS, general purpose
PS, high impact
PS, glass filled (20-30%)
PP, general purpose
PP, glass filled (20-40%)
PP, general purpose
PP, glass filled (20-40%)
Polybutene-1
1,2 Polybutadiene
ABS, high impact
ABS, glass filled (20-40%)
PVC, rigid
PVC, flexible
PVB, glass filled
Polycaprolactone
PVA (unplasticized)
PVA film (plasticized)
HPC
Polyethylene oxide film

- There are to date limitations on the plastic materials suitable for degradation. The very high temperature, high strength composites now being used would not be suitable. Therefore military engineering uses are limited.

- There would be storage problems. Items would have to be protected from ultraviolet source and moisture.

- All degradation mechanisms are sensitive to part thickness.

- To date almost all materials technology is concerned with proprietary materials involving licensing and royalties.

In conclusion, degradable plastics are still undergoing development. Although the techniques are generally understood, there are few off-the-shelf resin compounds or products. The range of known plastics suitable for controlled degradation is quite limited. Because of the very limited materials involved, the biodegradable approach is restricted.

The selection of soluble material is also limited to a rather few materials. These items would be dependent on both environment, rainfall and temperature, as well as part thickness. There would also be dimensional stability problems because of their sensitivity to high relative humidity.

Photodegradable materials present the best candidates for all environments. These materials have the following advantages and disadvantages:

Advantages

- The best physical properties
- The widest range of resin formulations
- A variety of processing techniques
- The best degradation prediction rates
- The ability to initiate degradation via artifical ultraviolet sources
- The ability to continually degrade without continuing ultraviolet exposure

Disadvantages

- The rate of degradation is sensitive to pigmentation, coatings, ultraviolet intensity, formulation, and part thickness.

- In a marine environment, negatively buoyant materials disposed overboard would sink and therefore not be subject to photodegradation.

The future outlook for degradable systems is very promising, especially in the commercial packaging industry. Although these formulations are proprietary, licenses are being signed and commercial supplies should be available at attractive prices. In addition, much effort is being conducted to broaden the range of photodegradable materials. It is expected that the thermoplastic polyesters, polyamides, and polyurethanes will be next. In the military, engineering development personnel are becoming increasingly conscious of ecosystem impacts of disposable items and more consideration will be given to degradable plastics.

3.6 WASTE TRANSFER TO SHORE

Storing waste on board ship and then transferring it to shore at the dock incurs all of the problems discussed above in regard to recycling; storage space, fuel cost, odor, and potential for contamination. In contrast to recycling, waste with no recovery value incurs a cost for pick up and disposal at the dock. A brief survey of the situation did not reveal any companies currently in business to collect waste from ship docks, although there was some indication this was being considered.

Since every harbor, at least in the U.S., has an associated waste collection company for land-based waste collection and disposal, there appears to be no fundamental difficulty in implementing this disposal method, at least from the land-based side of the operation. The difficulties all occur on the ship side of the problem. In addition to storage space requirements, once the vessel has returned to shore, the waste has to be unloaded. Job description for seamen and longshoremen would require clarification and negotiation to delineate responsibilities.

A contact with a local waste collection company serving the Port of Long Beach in Los Angeles, California indicated that disposal pick up charges from a dock area incur a transfer cost of $125.00 per 40 cubic yards of material with an additional charge of $20.00 per load by weight density, wet or dry. An average cost would be about $200 per load. The waste would be transported from local points to a slab area for separation and subsequent recycling and disposal. The contact indicated this procedure was not currently used at this time.

SECTION 4.0

RESULTS AND CONCLUSIONS

In order to compare the available methods of disposal with the waste generation rates for vessel categories and assess the onboard space considerations, it was first necessary to condense the information on those methods into representative capacity and cost ranges. As will be discussed later, the need for onboard storage space is the leading determinant of applicability of all approaches except incineration which appears to be applicable to all vessels except for the smaller categories. The capacity and cost information developed for disposal methods or equipment is summarized below:

- Incineration

  Capacity - 40 to 300 lbs per hr (continuous feed)
  - 200 to 500 lbs per batch (batch-type)

  Cost - $10,000 to $40,000

- Compaction

  Capacity - 150 to 1,100 lbs per hour
  Cost - $30,000 to $125,000

- Recycling

  Recovery Value - Plastic $60 to $100 per ton
  Metal $600 per ton
  Glass $35 per ton
  Paper $50 per ton

- Port Disposal

  $200 per 40 cubic yard load

As noted above, all methods are sensitive to the space available for shipboard storage of wastes, either in uncompacted or compacted form. In attempting to match the disposal methods with the various vessel categories and sizes, it was first necessary to estimate the waste generation rates by man-day and multiply this figure by crew size and voyage duration. These results are summarized as follows:

- Generated Waste Material (1.8 lb/Man/Day)

Type	% of Total
Plastics	1
Rubber	1
Metal	28
Wood	14
Paper	49
Glass	2
Cloth	5
	100%

- Generating Sources

Vessel Classification	Domestic Waste Material Generated lb/day	lb/Voyage
Fishing Industry		
Coastal Vessels	7	18
Long Distance Vessels	18	270
Deep Sea Vessels	30-46	916
Shipping & Transportation Fleet		
Oil Tankers	40-65	460-1970
Ore & Dry Bulk Carriers	30-50	950-1580
General Cargo Vessels	40-70	280-1270
Passenger Liners	2370	11,830
Research Ships	15-156	---
Military Vessels	40-11,000	8,000-2,000,000

The conversion of the summarized information, provided above, into more detailed breakout by ship size requires that some assumptions be applied. These are:

- Uncompacted waste, whether stored for onshore disposal or recycling, was assumed to have a density of 10 lbs/cu.ft. This assumes that no special treatment such as "breakdown" of cartons or crushing of bottles and cans is performed.

- Compacted density of 80 lbs/cu.ft. has been assumed.

- Given the low recovery value of recycled material, it has been assumed that recycling would not be carried out where quantities of any recycleable material were less than one ton per voyage. This assumption may not hold true for certain research vessels or military ships where motivations other than economics may prevail.

- It was assumed that, regardless of the method chosen, one percent of the vessel's total volume was available for waste storage. This assumption is, at best, tenuous, but it does provide some "feel" for the space involved. It can be seen, in the tables which follow, that sufficient onboard space is available (under this assumption) to store wastes on all vessels except passenger liners and military vessels, where crews (and passengers) involve large numbers.

Tables 4-1, 4-2 and 4-3 provided detailed results for commercial, military and research vessels. Some general results are presented below:

- Incineration could be applied to all but the smaller vessels. Passenger liners and large military vessels would require large, continuous-feed incinerators or multiple batch-type units.

- With compaction, only the largest military vessels could not store the wastes from an entire voyage. Compaction with onboard storage can be broadly applied.

- Storage of uncompacted wastes onboard is limited to fishing vessels and research vessels, where crew sizes are small relative to the total vessel size.

- Waste generation rates are too small on most vessels to make recyling an economically attractive approach. Large complement, long voyage military vessels generate significant amounts of recycleable materials (mainly paper and metal). Compaction would have to be applied to the recycle and non-recycle material because of space limitations.

TABLE 4-1 APPLICABILITY OF VARIOUS WASTE DISPOSAL METHODS TO FISHING, SHIPPING & TRANSPORT, AND PASSENGER VESSELS

Major Category	Ship Type	Size grt rating	Avg. Crew	Duration days	Waste lb/day	Waste lb/Voyage	Incineration: Small 50- -300 lb/d	Incineration: Med. 300- -1050 lb/d	Incineration: Multiple >1050 lb/d	Compaction: Storage Space cubic feet	Compaction: Cubical Space ft x ft x ft	Store On Board: On Board cubic feet	Store On Board: Cubical Space ft x ft x ft	Recycle Tons/voyage (NA=<1 ton): Plas	Recycle: Metal	Recycle: Paper
Fishing	Coastal	0-99.9	4	2.5	7	18	NA	NA	NA	0	1	2	1	NA	NA	NA
	Long Dist.	100-499.9	10	15	18	273	NA	NA	NA	3	2	27	3	NA	NA	NA
	Deep Sea	500-999	17	35	31	1083	NA	NA	NA	14	2	108	5	NA	NA	NA
	Deep Sea	>1000	25	120	46	5460	NA	NA	NA	68	4	546	8	NA	NA	1.3
Shipping & Transport																
Oil Tankers	Small	100-30,000	36	7	66	459	A	NA	NA	6	2	46	4	NA	NA	NA
	Medium	30,000-70,000	36	15	66	983	A	NA	NA	12	2	98	5	NA	NA	NA
	Crude	80,000->140,000	36	30	66	1966	A	NA	NA	25	3	197	6	NA	NA	NA
Carriers		6,000->140,000	29	30	53	1583	A	NA	NA	20	3	158	5	NA	NA	NA
General Cargo	Containers	6,000-39,999	39	18	71	1278	A	NA	NA	16	3	128	5	NA	NA	NA
	Tramp	100-5,999	37	7	67	471	A	NA	NA	6	2	47	4	NA	NA	NA
Passenger Liners			1300	5	2366	11830	NA	NA	3	148	5	1183	NA	NA	1.7	2.9

NA - Not Applicable
A - Applicable

TABLE 4-2 APPLICABILITY OF VARIOUS WASTE DISPOSAL METHODS TO MILITARY VESSELS

						Incineration			Compaction		Store On Board		Recycle Tons/voyage (NA=<1 ton)		
Major Category	Ship Type	Avg. Crew	Duration days	Waste lb/day	Waste lb/Voyage	Small 50- -300 lb/d	Med. 300- -1050 lb/d	Multiple >1050 lb/d	Storage Space cubic feet	Cubical Space ft x ft x ft	On Board cubic feet	Cubical Space ft x ft x ft	Plas	Metal	Paper
Tenders	Destroyer Tender	1600	90	2912	262080	NA	NA	3	3276	NA	26208	NA	1.3	36.7	64.2
	Repair Ship	715	90	1301	117117	NA	NA	2	1464	NA	11712	NA	NA	16.4	28.7
	Salvage Ship	125	90	228	20475	A	NA	NA	256	6	2048	NA	NA	2.9	5.0
	Submarine Tender	1912	90	3480	313186	NA	NA	4	3915	NA	31319	NA	1.6	43.8	76.7
	Submarine Rescue Ship	160	90	291	26208	A	NA	NA	328	7	2621	NA	NA	3.7	6.4
	Salvage & Rescuew Ship	100	90	182	16380	A	NA	NA	205	6	1638	NA	NA	2.3	4.0
	Aux. Deep Submerge Supt. Ship	160	90	291	26208	A	NA	NA	328	7	2621	NA	NA	3.7	6.4
	Amphibious Transport Dock	1380	90	2512	226044	NA	NA	3	2826	NA	22604	NA	1.1	31.6	55.4
Ammunition	Ammunition Ship	365	90	664	59787	NA	A	NA	747	9	5979	NA	NA	8.4	14.6
Stores	Combat Store Ship	365	90	664	59787	NA	A	NA	747	9	5979	NA	NA	8.4	14.6
	Amphibious Cargo Ship	556	90	1012	91073	NA	A	NA	1138	NA	9107	NA	NA	12.8	22.3
Nuclear Submarines	Auxilliary Submarine	24	180	44	7862	NA	NA	NA	98	5	786	9	NA	1.1	1.9
	Submarine	100	180	182	32760	A	NA	NA	410	7	3276	NA	NA	4.6	8.0
Destroyer Escort	Misc. Command Ship	880	90	1602	144144	NA	NA	2	1802	NA	14414	NA	NA	20.2	35.3
	Amphibious Command Ship	813	90	1480	133169	NA	NA	2	1665	NA	13317	NA	NA	18.6	32.6
	Patrol Combatant Ship	120	180	218	39312	A	NA	NA	491	8	3931	NA	NA	5.5	9.6
Oiler	Oiler	180	90	328	29484	NA	A	NA	369	7	2948	NA	NA	4.1	7.2
	Replentishment Ship	390	90	710	63882	NA	A	NA	799	9	6388	NA	NA	8.9	15.7
Destroyer	Fast Combat Ship	600	180	1092	196560	NA	NA	2	2457	NA	19656	NA	NA	27.5	48.2
	Guided Missile Ship	100	180	182	32760	A	NA	NA	410	7	3276	NA	NA	4.6	8.0
	Battleship	1600	180	2912	524160	NA	NA	3	6552	NA	52416	NA	2.6	73.4	128.4
	Guided Missile Cruiser	405	180	737	132678	NA	A	NA	1658	NA	13268	NA	NA	18.6	32.5
	Guided Miss. Cruiser Nuclear	595	180	1083	194922	NA	NA	2	2437	NA	19492	NA	NA	27.3	47.8
	Destroyer	295	180	537	96642	NA	A	NA	1208	NA	9664	NA	NA	13.5	23.7
	Guded Missle Destroyer	360	180	655	117936	NA	A	NA	1474	NA	11794	NA	NA	16.5	28.9
	Frigate	210	180	382	68796	NA	A	NA	860	10	6880	NA	NA	9.6	16.9
	Guided Missle Frigate	170	180	309	55692	NA	A	NA	696	9	5569	NA	NA	7.8	13.6
	Fleet Ballistic Missle Sub.	165	180	300	54054	NA	A	NA	676	9	5405	NA	NA	7.6	13.2
Aircraft Carrier	Training Aircraft	1440	90	2621	235872	NA	NA	3	2948	NA	23587	NA	1.2	33.0	57.8
	Aircraft Carrier	5000	180	9100	1638000	NA	NA	9	20475	NA	163800	NA	8.2	229.3	401.3
	Aircraft Carrier Nuclear	6100	180	11102	1998360	NA	NA	11	24980	NA	199836	NA	10.0	279.8	489.6
Landing Ship Tank	Amphibius Assault Ship	2800	90	5096	458640	NA	NA	5	5733	NA	45864	NA	2.3	64.2	112.4
	Dock Landing Ship	750	90	1365	122850	NA	NA	2	1536	NA	12285	NA	NA	17.2	30.1
	Tank Landing Ship	560	90	1019	91728	NA	A	NA	1147	NA	9173	NA	NA	12.8	22.5
Minesweeper	Ocean Mine Sweeper	85	90	155	13923	A	NA	NA	174	6	1392	NA	NA	1.9	3.4
	Fleet Ocean Tug	80	90	146	13104	A	NA	NA	164	5	1310	NA	NA	1.8	3.2

NA - Not applicable A - Applicable

TABLE 4-3 APPLICABILITY OF VARIOUS WASTE DISPOSAL METHODS TO RESEARCH VESSELS

Major Category	Size grt rating	Avg. Crew	Duration days *	Waste lb/day	Waste lb/Voyage	Incineration Small 50--300 lb/d	Incineration Med. 300--1050 lb/d	Incineration Multiple >1050 lb/d	Compaction Storage Space cubic feet	Compaction Cubical Space ft x ft x ft	Store On Board On Board cubic feet	Store On Board Cubical Space ft x ft x ft	Recycle Tons/voyage (NA=<1 ton) Plas	Recycle Tons/voyage (NA=<1 ton) Metal	Recycle Tons/voyage (NA=<1 ton) Paper
Research	20-50	8	30	15	437	NA	NA	NA	5	2	44	4	NA	NA	NA
	51-100	9	30	16	491	NA	NA	NA	6	2	49	4	NA	NA	NA
	101-200	19	30	35	1037	NA	NA	NA	13	2	104	5	NA	NA	NA
	201-400	26	30	47	1420	NA	NA	NA	18	3	142	5	NA	NA	NA
	401-600	30	30	55	1638	A	NA	NA	20	3	164	5	NA	NA	NA
	601-1000	33	30	60	1802	A	NA	NA	23	3	180	6	NA	NA	NA
	1001-1500	40	30	73	2184	A	NA	NA	27	3	218	6	NA	NA	NA
	>1500	86	30	157	4696	A	NA	NA	59	4	470	8	NA	NA	1.2

* Average duration assumed as 30 days, actual durations are widely variable

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APPENDIX

VESSEL VISITATION

APPENDIX

Vessel Visitation

A review of disposal method programs which are currently being used was through visitations to vessels with operating waste disposal strategies. The vessels included a passenger liner, a research vessel and a container ship and the following discussion is a profile from available information on each vessel's operating variables and the type of waste disposal method employed.

Passenger Liner

Fairsky
Sitmar Cruises

The passenger liner's population on board ranged from 1,700 to 1,800 with an average cruise of 10 days. The liner was constructed in 1984 and the initial design of the vessel included a dedicated area for waste disposal equipment. The means of disposing of waste includes an incinerator, a compactor, a shredder and recycling of aluminum cans. The incinerator, a Golar model, runs continuously and its exhaust is expelled through the main mast of the ship. In conjunction with the incinerator, a shredder is used to fragment solid waste before being fed into the incinerator. The use of the shredder facilitated the handling of the material by the ship's personnel and assisted in attaining substantially complete combustion of waste material in the incinerator. The compactor's primary function is to reduce the cardboard boxes and aluminum cans from food and packaged items. The compressed material is stored on board and off loaded at port.

Research Vessel

Miller Freeman
NOAA

The research vessel is a 215-foot, 1,900 ton ocean research ship built in 1967, fully rigged in 1975 and rerigged in 1982. She is designed as a stern trawler; however, her primary mission is to provide an observation platform for the study of oceans' living resources. Equipped with a variety of biological and oceanographic sampling gear, the normal area of operations is the North Pacific Ocean with cruises of two to three weeks. The vessel's homeport is in Seattle, and the ship's work force is approximately 40 people plus as many as 11 scientist. Waste material generated from the ship's complement averages four 55-gallon drums/day and, originally, the method of disposing of this waste was a compactor. This method proved to be ineffective because the compressed material took up more space than the vessel could afford on board and because the removal of the material upon return to port created additional costs.

In 1983, an incinerator was purchased to replace the compactor, and its operation has been successful. The incinerator is a Swedish design, costing approximately $15,000 and capable of burning all types of solid waste. It is equipped with a door in front for loading of solid waste and removing ash. The door can be opened only while the incinerator is not burning. The high temperature in the combustion chamber is 2500°F. The incinerator is a self-contained unit and is located on the main deck enclosed in a weather shelter.

The unit is in operation every day and, for every hour of operation, it takes two hours to cool down for reloading. It is operated by the ship's engineer who also cleans out the ashes and maintains the unit. The time spent for collecting and separating the waste material for incineration is approximately 2-3 hours per day.

Container Ship

American California
United States Lines, Inc.

Launched in 1985, the container ship's overall length is 289.5 m with approximately 2,000 container spaces stacked 4 to 5 high. There is accommodations for 35 people, but at the time of visitation, there was 21 crew members. The vessel is based out of New York and has 13 ports of call; three in the United States, five in Asia, three in the Middle East and two in Europe, with an overall sea voyage including port side at approximately two months. The ship was designed to transfer waste material by placing trash in a chute near the galley, where it is transported to the boiler room and burned in the ship's boiler/incinerator system.

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