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UNITED STATES
✓ NUCLEAR MERCHANT FLEET

PREPARED FOR THE USE OF THE
COMMITTEE ON COMMERCE
UNITED STATES SENATE

AT THE REQUEST OF
Hon. WARREN G. MAGNUSON, *Chairman*

BY THE
DEPARTMENT OF COMMERCE
DEPARTMENT OF DEFENSE
ATOMIC ENERGY COMMISSION



NOVEMBER 1967

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FOREWORD

In similar letters dated February 10, 1966, Senator Warren G. Magnuson, chairman of the Senate Committee on Commerce, requested the Atomic Energy Commission, the Department of Defense, and the Maritime Administration of the Department of Commerce to collaborate and prepare a document concerning a nuclear merchant fleet. These letters read as follows:

The Committee on Commerce intends to schedule hearings to develop a recommendation on a national policy toward a nuclear merchant fleet. These hearings will probably begin in late June.

As a background for these hearings, I request that the Atomic Energy Commission, the Department of Defense, and the Maritime Administration collaborate and prepare a document concerning a nuclear merchant fleet. I would like to have you collectively consider existing and proposed power plants, the experience with the NS *Savannah*, the manning and porting questions, the best uses of a nuclear vessel, what your recommendations are, and such other information as you feel will be useful.

I would like to have your report on or before June 14, 1966. I would appreciate your keeping me informed of your progress on this matter. Please contact Donald Brodie, staff counsel, telephone number 225-5115, room 5202, New Senate Office Building.

This report has been developed in response to Senator Magnuson's request.

REPORT

The report has been developed in accordance with the instructions of the Board of Directors, and is intended to provide a comprehensive overview of the company's performance during the year ended December 31, 1954. The report is divided into several sections, each dealing with a different aspect of the company's operations. The first section, "General Information," provides a brief history of the company and a summary of its current status. The second section, "Financial Statement," presents a detailed account of the company's financial performance, including a balance sheet, income statement, and statement of cash flows. The third section, "Management Discussion," offers an analysis of the company's operations and a discussion of the factors that have influenced its performance. The fourth section, "Future Outlook," provides a forecast of the company's future performance and a discussion of the risks and opportunities that it faces. The report is intended to provide a comprehensive overview of the company's performance during the year ended December 31, 1954, and to provide a basis for the Board of Directors' decision-making.

Respectfully,
[Signature]

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U.S. NUCLEAR MERCHANT FLEET

INTRODUCTION

The U.S. Government through the activities of the U.S. Atomic Energy Commission has taken the lead in the research and development of applications for the peaceful use of nuclear energy. The generation of heat and power for industry, transportation and communication promises to be a major peacetime use of nuclear energy. The Atomic Energy Commission has already made much progress in stationary powerplant and in naval ship powerplant design. There has been only one application of nuclear power to merchant ships. Therefore, progress toward solution of the engineering, economic, and institutional problems associated with the application of nuclear power to merchant ships has not kept pace with other applications.

The Maritime Administration, the Atomic Energy Commission and the marine industry in the United States have been engaged in study and research efforts to determine the most suitable "next generation" shipboard application of nuclear power to follow the completion of the *Savannah* project. The question has been complicated because features other than the simple substitution of a nuclear powerplant in a conventional type hull with burtoning gear seemed to be needed to make use of nuclear power economically promising.

The U.S. merchant fleet consists of 949 privately owned ships in active service as of April 1, 1966, 68 percent of which were constructed during World War II. The Government owned reserve fleet numbers 1,496 ships, all of which are of World War II vintage. Thus only a very limited number of the U.S. merchant ships can be considered modern and competitive. The privately owned ships are categorized as:

Subsidized passenger or combination passenger-cargo ships-----	27
Subsidized cargo ships-----	279
Unsubsidized cargo ships-----	368
Unsubsidized tankers-----	275
Total-----	949

The subsidized cargo ships are being replaced with ships which are among the finest in the world at a rate of 12 to 14 ships per year. Up to the present time, only one-third of the small subsidized fleet represents modern tonnage. Of 275 unsubsidized tankers, only 27 percent are 10 years old or less.

On the other hand, there are few ship replacements planned by our unsubsidized cargo-ship owners operating in foreign trades or by our domestic ship operators. The U.S. maritime industry is faced with an obsolescence problem of substantial proportion.

Stating this another way, the average age of the active and reserve U.S.-flag fleet is now almost 20 years, whereas the corresponding average age of our major competitors' fleets such as the United Kingdom is

10 years; Sweden, 10.3 years; Norway, 8.8 years; Japan, 8.5 years; West Germany, 9.5 years; and the Netherlands, 9.5 years.

In 1964 less than 9 percent of a total of about 340 million tons of import and export cargo was carried in U.S.-flag ships. By type of service, the U.S. fleet carried approximately 30 percent of our break bulk cargo, less than 4 percent of our liquid bulk and approximately 6 percent of our dry bulk cargo.

During the past several years, there has been a continuing reduction in the total percentage of export-import cargo carried by U.S.-flag ships. This trend will inevitably continue, unless the United States can develop more efficient and productive ships as part of integrated transportation systems.

Reference is made to the President's March 2, 1966, message on transportation, which places special emphasis on the importance of research and development for transportation in competition for international trade. While private enterprise bears the primary responsibility for such research, the message stated that the Government can help in areas beyond the responsibility or capability of private industry. In addition, the President has requested a study of advanced vessel concepts, to include:

Research, development and planning of high-speed, large-capacity ships, devoted primarily to transporting preloaded containers of varying types between the major ports in the world.

Research on an oceangoing surface effects vessel capable of skimming over the water at speeds more than 100 knots.

Continued exploration of the application of nuclear propulsion to merchant marine ships.

With the increasing size, speed and hence power requirements of all types of ships, the advent of containerization or prepackaging concepts in the general cargo trade, and the apparent reduction in nuclear powerplant costs since the *Savannah*, it is appropriate that the Maritime Administration and the Atomic Energy Commission continue to explore the feasibility of both long- and short-term use of nuclear power in the U.S.-flag merchant marine.

RECOMMENDATIONS

1. The Federal Government should take an active role in a development program leading to economically competitive nuclear-powered merchant ships.

2. The Department of Commerce and the Atomic Energy Commission assisted by the Department of Defense and the President's scientific adviser, should cooperate in the establishment of a construction and research and development program to implement the following policy:

(a) The Department of Commerce and industry, with Atomic Energy Commission support, should proceed immediately with the construction of two to four large, high-speed (27 to 30 knots) fast turnaround nuclear-powered ships utilizing commercially available nuclear powerplant technology in an integrated transportation system to be privately owned and in operation by 1972.

(b) The Department of Commerce and the Atomic Energy Commission should proceed in an orderly fashion with a research and development program including a Government-owned, land-based test

facility for an advanced reactor for nuclear-powered merchant ships.

3. For the recommended nuclear fleet, legislation should be provided to permit the Federal Government to pay the excess design, development, construction, and operating costs due to this initial application of nuclear reactor propulsion plants.

CONCLUSIONS

1. NS *Savannah* has proved the technical feasibility of nuclear power for merchant ships.

2. The NS *Savannah* has made a beginning but has not lead to the solution of a number of economic and other important problems, such as indemnity and labor.

3. The trends in ocean commerce and in ship design point to larger and more powerful ships in the future.

4. The best light water reactor plant designs currently available for merchant ships is not likely to prove economically competitive with oil-fired boilers. Industry estimates are somewhat more favorable than Government estimates.

5. There is good reason to believe that a reactor for merchant ships can be developed which will be equal to or superior to any oil-fired plant.

6. An economically competitive reactor will require an extensive research and development program by the Atomic Energy Commission, utilizing a land-based reactor test facility to minimize the costs and maximize the results achieved.

7. Based upon commercially available nuclear plant technology, an interim program for limited nuclear ship construction (two-four) should be undertaken promptly for three basic reasons: (a) to provide operating ship experience which will provide an incentive for clearing the legal, institutional, and labor problems which stand in the way of large-scale routine use of economically competitive nuclear powered ships in worldwide international trade, (b) to provide further concrete experience in nuclear powered ship construction and operation; now limited to the NS *Savannah*, and (c) to create industry interest in the development of more economical nuclear reactors.

8. A parallel interim shipbuilding program and advanced light water reactor research program could provide the United States with an optimum nuclear ship program providing maximum benefits and maximum assurance of continued U.S. lead in nuclear merchant ship development.

9. In combination with other nonnuclear innovations, long-range benefits which may accrue to the United States are:

(a) a restructuring of economic factor inputs (increasing capital and management inputs and decreasing labor inputs) into the merchant marine to favor U.S. operators at the expense of their foreign competitors;

(b) a restructuring of the whole transocean shipping system to favor U.S. operators and U.S. exporters in foreign competitive markets, thus strengthening the foreign trade and hence the balance-of-payments position of the United States;

(c) improvement in military value of merchant ships;

(d) development of economical medium powered nuclear reactors.

10. The experience since the NS *Savannah* project shows clearly the unwillingness of private industry to proceed with further nuclear ship construction without Government help. The developments since the NS *Savannah* in trade and ocean shipping technology show clearly that trends are moving in the direction which promise to make nuclear power economically attractive. The Federal Government must take a leading role in the further development of nuclear power for merchant ships.

11. This report has developed a projection into the future which portends nuclear powered civilian maritime ships economically equal to or superior to oil-fired ships. These projections have been based on many assumptions as to vessel size and characteristics, reactor cost, nuclear fuel cost, and operating cost, which are reasonably foreseeable today.

The value of the relative operating cost estimates in this report is to establish a point of departure into a future which may promise progressively greater economical advantage of nuclear power over fossil fuel as time and science advance.

If the past can be used as a barometer for the future, today's predictions of future scientific accomplishments will in all probability be exceeded. With the proposed research and development program nuclear power, as applied to merchant ships, has the potential for becoming equal or superior to fossil fueled powerplants. Favorable accomplishment or technological breakthrough will enhance its economic advantage.

SUMMARY

I. TRENDS IN OCEANBORNE TRADE

1. World oceanborne trade more than doubled in volume between 1952 and 1964 and is expected to continue to grow rapidly. The large volume growth will require more or larger (or both) ships in the future than exist at present.

2. There has been a spectacular increase in the size of tanker and dry bulk carriers and an increase in both the size and speed of general cargo vessels since World War II. The increase in size and/or speed of vessels since World War II has required an increase in the size of powerplants from 6,000 shaft horsepower to about 30,000 shaft horsepower, with current shipbuilding proposals up to 105,000 shaft horsepower.

3. The high costs of loading and unloading ships in the United States (three to 10 times foreign costs) and the progress in container technology are causing a revolution in handling of general cargo. This revolution in cargo handling will permit faster turnaround of ships and permit an increase in ship time at sea from less than 50 percent currently to 80 percent or more in the future.

4. These trends in world trade, ship size and speed, and general cargo handling developments indicate that in the 1970-90 period a large share of general cargo can be expected to move in an integrated land-ocean transportation system with the ocean portion moving in large high-speed container or unit loading ships on fast turnaround schedules.

II. TRENDS ARE IMPORTANT TO UNITED STATES

1. A fast turnaround transportation system employing large high-speed container ships will change the economic input factor structure by requiring relatively higher inputs of capital, management, and fuel and relatively less labor input.

2. This restructuring of economic input factors will reduce or eliminate the disadvantages now suffered by the U.S.-flag merchant marine in international competition because economic factors in which the United States has an advantage or equality with competitive nations are substituted for labor where the U.S. factor cost is four to five times that of competitive nations.

III. NUCLEAR POWER HAS POTENTIAL APPLICATIONS

1. From 25 to 64 large (1,500,000 cubic feet) and giant (3 million cubic feet) container ships requiring powerplants of 50,000 shaft horsepower and above can easily be accommodated in the U.S. foreign trade fleet from 1970 to 1990. A large fast turnaround container ship will require high horsepower output, at a high percentage of utilization of plant potential (50,000 to 140,000 shaft horsepower). Such factors resulting in increased power requirements can make nuclear power more attractive.

A. NS "SAVANNAH" EXPERIENCE

1. The NS *Savannah* total program costs through August 20, 1965, were about \$97 million. These include costs of design development, construction of the ship and servicing facilities, and a 3-year testing and demonstration program. The NS *Savannah* has accomplished its objectives.

2. The NS *Savannah* propulsion plant has proved to be extremely reliable in commercial service.

3. The NS *Savannah* gained public acceptance in 28 domestic and 18 foreign ports during its demonstration program.

B. PRESENT NUCLEAR CAPABILITIES

1. This report includes brief descriptions of the NS *Savannah* nuclear plant and other concepts offered by reactor plant manufacturers.

2. American Export Isbrandsten Lines, Inc. has prepared and submitted an application for a construction differential subsidy to be applied to three large (813 feet), high-speed (29 to 30 knots) container ships. This proposal reflects estimated prices for 105,000-shaft-horsepower marine reactor powerplants.

3. The AEC estimates that a commercially available nuclear powerplant for three ships of the same characteristics as the AEIL proposal could be provided by an experienced reactor plant contractor-shipbuilder team for about \$82 million. Based on this estimate and economically satisfactory resolution of certain labor, licensing, indemnification, and safety problems, the Maritime Administration estimates the capital entry cost of three nuclear ships—that is, the difference in cost between nuclear power and conventional power container ships of the same characteristics as the AEIL proposal—will be approximately \$54 million. The corresponding AEIL estimate is approxi-

mately \$32 million. Government estimates for a two- and four-ship fleet are approximately \$34 and \$72 million, respectively.

4. Based on MARAD estimates of present technology, the annual cost of operating three nuclear ships proposed by AEIL over a 25-year period will be approximately \$1 million per year greater than operating three similar conventionally powered ships. The corresponding AEIL estimate is \$1,500,000 per year less than the operating cost of equivalent oil-fired ships. Regular operating differential subsidy payments are not included in developing these estimates.

5. There are questions of third-party liability coverage and the degree of Government and industry participation. The prospects of such coverage should be further explored and an examination should be made of possible continuing need for some form of complete Government third-party liability coverage.

C. FUTURE PWR MARITIME PROJECTIONS

1. There is a likelihood that a second-generation fleet of large, high-powered nuclear ships, beginning operations 10 to 15 years hence and using advanced reactors developed through the proposed R. & D. program will be economic provided nuclear third-party liability to the vessel operator is not excessive or is provided by the Government.

2. This prediction is sensitive to many factors such as small variations in capital costs, fuel costs, M. & R. costs, et cetera, and cannot be accurately predicted over a 25-year period beginning 10 to 15 years from now. For example, a 10-percent reduction in estimated nuclear fuel costs would save \$100,000 a year in operating costs for each ship.

3. The trends in world trade and technology indicate a reasonable chance for the recovery of the total Government nuclear investment provided the reduced fuel, construction, and operating costs can be realized, and future ship power requirements and world trade trends follow present predictions. Any other cost reduction breakthroughs that the advanced reactor test program or integrated transportation system might develop would materially enhance the benefits to the Government of a nuclear program beyond present estimates.

V. U.S. GOVERNMENT ROLE

1. The research and development interest by the maritime industry since the *Savannah* project has been largely limited to exploratory studies except for a proposal by American Export Isbrandtsen Lines to build and operate a three-ship nuclear-powered container ship fleet on trade route 12. A Maritime Administration letter of solicitation of interest to shipping operators in April 1966 evoked interest in nuclear power only after it had proved economically competitive.

2. The Federal Government must take a leading role in the further development of nuclear power for merchant ships because significant advances in the technology are required and financial risks in nuclear powerplant and ship construction are too large and uncertain to be undertaken by the private sector alone.

3. The Atomic Energy Commission and Maritime Administration must work closely together and in cooperation with interested segments of industry to attempt to achieve the most commercially competitive nuclear merchant marine. Encouragement of cooperative ar-

rangements between Government and industry is based upon the expectation that such arrangements will eventually reduce Government expenditures and provide maximum incentives for effectiveness in cost reduction in a program whose basic objective is strongly economics oriented.

(a) A fleet of large nuclear-powered ships is needed in operation in the near term in order to help bring about resolution of problems of insurance, indemnification, port clearance, shore staff, and so forth, to provide new marine reactor cost parameters, and to evolve economically competitive manning requirements for the next generation of nuclear ships. This operating experience is a prerequisite to a freely operating, economically competitive nuclear-powered fleet in the longer term future.

(b) The technical feasibility of light water reactors for ship propulsion has been successfully demonstrated. The Government should assist in funding commercially available nuclear plants guaranteed by industry and the Atomic Energy Commission would encourage the Maritime Administration to utilize those reactors which show reasonable promise for specific applications in a civilian shipbuilding program.

(c) In view of the potential which a reliable, safe, and economic nuclear reactor powerplant would afford the civilian U.S. merchant marine, a base technical program should be pursued. The focal point of this program would be a land-based test facility, which is not considered to be a prerequisite to ship construction. The objective of this technical program would be to resolve whether improved designs of light water reactors specifically for the civilian maritime application could be achieved within the required performance, cost, reliability, and safety envelopes; and whether, if attained, these characteristics, plus potential improvements, would be sufficient to assure reasonable economics for widespread merchant marine applications. To achieve the objective of an economically competitive reactor will require an extensive research and development program by the Atomic Energy Commission, preferably at a land-based reactor test facility to minimize the cost and maximize the results achieved. This program is estimated to cost approximately \$100 million (which includes \$35 million for the construction of the test facility) over a 10-year period.

4. The Federal Government should proceed with a near-term nuclear powered fleet program since this will also act as an additional incentive to the nuclear power industry in developing civilian maritime reactors for a wider scope of application in the 50,000 to 140,000 shaft horsepower range. Simultaneously an intensive research and development program should be undertaken by industry and the Government to ultimately make nuclear reactor units competitive. These developments may lead to additional and more widespread uses at a later time.

VI. DEFENSE VIEWPOINT

1. The United States needs a merchant marine of sufficient size to meet the national defense sealift requirements.

2. Nuclear propulsion will improve the military value of cargo ships; however, cargo ships equipped with currently proposed nuclear propulsion plants will be considerably more expensive to build and operate than conventionally powered ships.

3. The improved military value is not great enough to be the sole justification for the large added subsidy that would be required for a large shipbuilding program based on today's technology.

4. Major reductions in ship loading and unloading times are needed.

5. A development program leading to economical nuclear powered cargo ships is justified. Improvement of cargo handling capabilities should be a part of this program.

VII. REMAINING PROBLEMS

1. The NS *Savannah* program has left partially unsolved the problems of indemnification and future labor relations between engineers and deck officers.

A. MANNING

A training program of about 24 weeks' duration is required to develop a licensed marine engineer into a suitable nuclear ship engineering department officer. Deck officers require 4 to 6 weeks of special training before assignment to a nuclear ship.

Manning requirements and billets for future nuclear-powered ships should not be predicated on the precedents that have been established by the NS *Savannah*. The present complement of licensed reactor operators is in excess of an economically acceptable number. However, NS *Savannah* engine department manning has been reduced from an original level of 39 down to a present level of 26 men.

The concurrent development of highly mechanized fossil fueled ships has resulted in a reduction in the number of watch-standing personnel required for safe and effective ship operation. Advances on conventional ships may result in an improved manning system on the next generation nuclear ships. The extent of automation of the nuclear plant and the degree of acceptance of these concepts will have an effect of the comparable economics.

Labor problems have beset both automated merchant ships and the NS *Savannah* in the past few years and an equitable solution to these problems must be provided for. It may be advisable to recommend specific legislation to deal with this issue at the same time that the next group of nuclear ships is authorized.

B. SAFETY, LICENSING, AND INDEMNIFICATION

The NS *Savannah* has demonstrated that nuclear ships can be operated safely and that the required licenses can be obtained.

Advances in engineered safeguards technology are expected to keep abreast of expanding safety requirements engendered by higher horsepower ratings and increased number of nuclear ships.

Essential to any program for construction and operation of nuclear ships will be adequate financial protection against nuclear incidents in the form of insurance or governmental protection. New legislation would be requested to provide governmental indemnification. In considering new legislation, it would be important to give thought to the terms and conditions which might be imposed by ports outside the United States for the entry of foreign nuclear ships.

VIII. FOREIGN PROGRAMS

1. The United States is the first nation to build and operate a commercial nuclear-powered merchant vessel; however, there have been gains achieved by other maritime nations in this type of power application.

2. The Soviet Union has successfully operated the nuclear-powered icebreaker *Lenin* for six winter seasons in the Arctic Ocean and has recently announced its intention to build two more of an advanced design. The Soviet Union has further stated that the "creation of a nuclear surface fleet is very promising."

3. The Federal Republic of Germany is entering the final stages of production on a 10,000 shaft horsepower nuclear-powered ore carrier that will employ a reactor system regarded as an antecedent to the present design offering of the Babcock & Wilcox Co. It is anticipated that this vessel will be in initial operation by 1967.

4. The Chinese Peoples Republic is reported to have entered into the design stage of development of a nuclear-powered merchant ship in 1962 with construction initiated in 1964 for a 20,000-ton vessel.

5. The Japanese have reactivated their interests and efforts in the construction of a nuclear-powered hydrographic vessel, and it has also been reported that Great Britain has renewed its interest in this propulsion concept as a result of the sudden entry of the United States into the North European container trade market.

6. Other maritime powers have established joint research programs to develop new concepts in nuclear ship propulsion; however, to date these have been limited to research efforts and proposed land-based test facilities.

7. The efforts of the United States to initiate international commerce using nuclear-powered merchant vessels have met with favorable results in the field of foreign acceptance. The sudden renewed interests by foreign competitors in this application of nuclear energy on the eve of the first transatlantic high-speed container service can lead one to believe that others have envisioned some economically favorable applications for high-speed nuclear-powered vessels.

CHAPTER I.—TRENDS IN OCEAN TRADE AND TRANSPORTATION SYSTEMS

Since the end of World War II, the character of the world's transportation has changed rapidly. It is expected to continue to change. These changes have been based on a number of fundamental conditions which are accepted almost universally by analysis of ocean transportation trends. The most important of these conditions which will dictate the future trend of ocean transportation are:

1. As industrialization continues and national incomes grow, the volume of international trade will increase. The vast majority of goods in intercontinental trade will continue to be carried in ships.

2. The pressures of cost and competition will continue to force the maritime nations to adopt those techniques and devices which result in the lowest unit production cost of transportation. Increasing emphasis will be placed upon minimizing the time required for transfer of cargo between various modes of transportation for both packaged and bulk cargo.

3. This cost reduction process will result in truly integrated transportation systems in which every component will be rationally designed to minimize the total cost of capital and labor.

4. Ships of the future will be designed as part of such integrated systems and are expected to be specialized by cargo type, large and extensively automated.

These conditions and their resulting trends are of advantage to the United States, and also produce the most advantageous application of nuclear power. They lay the framework for this study.

A. TRENDS IN OCEANBORNE TRADE

WORLD OCEANBORNE TRADE TRENDS

There has been a persistent upward trend in both world exports and seaborne trade since the end of World War II in 1945. Table 1 gives figures for the years 1952-64 of dollar value of world exports and tonnage volume of world seaborne trade. The export values include trade crossing international land boundaries as well as that shipped in transocean commerce. As is shown, the volume of oceanborne trade more than doubled between 1952 and 1964, while dollar export value of world trade increased by 75 percent from \$90 billion to \$141 billion.

TABLE 1.—TOTAL WORLD SEABORNE TRADE

[Million metric tons]

Year	Bulk and general dry cargo	Oil	Total	Value, all exports (billions)
1952	365	295	660	\$90
1956	490	390	880	104
1960	540	530	1,070	128
1964	680	800	1,480	141

The table shows clearly the big increase in the tanker trade. The largest increase in the dry cargo trade probably has been in dry bulk rather than in general cargo trade. United Nations statistics do not provide this breakdown but we can infer this result from the U.S. statistics because the United States accounts for about 15 percent of world dry bulk trade. There has also been a large increase in general cargo trade, however, as indicated by the rapid increase in the value of total trade.

The outlook for continued growth in world trade is good.¹ Trade between developed countries will expand due to population and income growth. Trade with developing countries will increase as a result of population growth, and as a consequence of industrialization processes. A continuation of these trends is indicated at least until the year 2000 or well beyond the life of any ships built between now and 1975.

If current trends do continue, world trade (export value) will increase from its current (1966) rate of less than \$200 billion annually to somewhere between \$1,000 and \$2,000 billion by year 2000. The tonnage of oceanborne world trade, now about 1,500 million metric tons, can be expected to increase to somewhere between 10,000 and 20,000 million metric tons by 2000.

U.S. OCEANBORNE TRADE TRENDS

The U.S. trade since 1952 is given in table 2. The largest growth has been in the bulk trades but there is also steady growth in the liner general cargo trades.

TABLE 2.—U.S. TRADE, 1952-64

[Million long tons]

Year	Liner	Irregular	Tanker	Total
1952 Exports	23.2	38.5	10.9	72.6
Imports	15.4	22.4	50.8	88.6
1956 Exports	29.4	66.3	15.5	111.2
Imports	17.6	43.3	79.6	140.5
1960 Exports	31.1	86.4	16.0	133.5
Imports	17.7	72.9	117.4	208.1
1964 Exports	31.1	86.4	16.0	133.5
Imports	17.7	72.9	117.4	208.1

The United States and other highly industrialized countries trade growth may be at a slightly lower rate from 1970-2000 than that for the less-developed nations of the world because of the advanced state of industrialization. Projection of current trends to year 2000 indicate liner exports of 48 million long tons and imports of 32 million long tons. There will be an estimated 350 million long tons of oil imports but only negligible exports.

MARITIME IMPACTS OF THESE TRADE TRENDS

The prospective growth in world trade and in seaborne tonnage should permit the development of many more trade route exchanges with larger trade volumes than exist today. A large number of high-

¹ Haberler, Gottfried: "Growth of World Trade," American Economic Review, March 1964. Haberler sees continued growth assuming high levels of growth in the industrialized countries and no serious restrictions on trade for balance-of-payments reasons. He is optimistic about the first, cautious on the second.

volume trades will be to or from the United States because the United States accounts for 13 to 15 percent of total world trade.

The prospective trade growth will also affect vessels, as the later section in this chapter shows it has in years past. Increase in volume alone will require either more ships of current size configuration or a constant number of progressively larger ships, or some combination.

SUMMARY

World trade has grown rapidly since World War II in both value and tonnage. Barring worldwide depression or serious international exchange difficulties, this growth is expected to continue. These trends and their maritime impacts provide the context for this study of nuclear-powered vessels.

B. EMERGENCE OF INTEGRATED TRANSPORTATION SYSTEMS

The field of transportation is going through changes similar to the emergence of mass production techniques in manufacturing. The basic economic forces are the same in both fields.

From the viewpoint of the manufacturer, these techniques improve the profit picture by reducing the total unit cost. The increased investment in highly complex equipment is justified by intense utilization at high volume of both men and machines.

Rational design of such equipment leads to specialization. The assembly line and the unit train are both designed to handle one product at high volume. To maximize utilization, the support equipment is also specialized. Cargo handling gear, terminals and storage areas, and personnel are integrated into a single system which is controlled by management to produce the product or service at a lower more competitive cost.

The shipper must consider not only the charges for transport, but also his own related costs. Important among the costs is the value of time in transit, and it has led to an emphasis on speed and fast inter-mode cargo transfer. Inventory is a capital investment. Whether in a warehouse or in transit, the shipper bears interest on its value as long as the inventory remains in his ownership. In the case of production equipment such as computers and machine tools potential earning time is also important. Proper selection of means of transportation must consider the total time in transit as a relevant cost item. In the case of higher valued cargo and production equipment, transit time is an item as significant as packing charges and insurance.

As shippers have become more sophisticated in their calculations of total distribution costs, they exert further market pressure which leads to integrated systems in transportation. Although ships are an important component of such systems, equally important in the reduction of transportation cost and transit time are innovations in cargo handling, port configurations, and the rolling stock and facilities of inland transportation.

As a result of the economic forces discussed above, we would expect increased use of specialized transport equipment and the appearance

of complex equipment aimed at high-volume production. Because the focus of this report is the nuclear merchant fleet, the discussion following relates to these changes in the ship itself. Equally as important, however, to the continued development of the merchant marine are changes occurring in inland transportation and the coordination of specialized integrated transportation systems.

C. TRENDS IN GENERAL CARGO HANDLING AND CONTAINERIZATION

Improvements in cargo handling designed to move general cargo into and out of ships more rapidly and economically have taken two basic directions: (1) Substitution of portable preloaded containers, lighters, pallets, and so forth, handled by shipboard or dockside cranes for conventional break bulk stowage with boom and winch gear, and (2) capital investment in ships' cargo gear and stevedoring equipment to improve total cargo-handling productivity.

DEVELOPMENT OF CONTAINERIZATION

Proposals for various types of containerization of ocean freight date back to sailing ship days while proposals for piggybacking of road vehicles on U.S. railroads go back to the early 1900's.

Rapid loading and unloading of ships by means of prestowed containers improves the shipping system productivity in at least three ways:

1. It reduces the handling costs and congestion, pilferage, and damage by moving the handling of individual pieces away from the pier side and reducing the number of times individual pieces away must be handled.

2. It increases the productivity of the longshore gang at the ship from 15 tons per gang-hour to 300 to 600 tons per gang-hour.

3. It reduces port costs by cutting down on the unproductive time a ship has to spend in port and will ultimately cut down on pier and wharf costs by permitting a much larger volume of goods to be handled per berth space provided.

So long as transportation equipment remained relatively expensive compared to shipping, draying, and stevedoring labor, it was uneconomic to use expensive containers in or on railroad cars and steamships to save the labor costs. The failure to adopt unitized handling techniques on either the oceans or the railroads until quite recently can be attributed in part to the relative costs of labor and transportation equipment. Since the end of World War II, the relative costs of labor and equipment have changed enough to make containerization and piggybacking concepts increasingly attractive under cost factor conditions in the United States and other developed nations.

The development of container traffic on ocean vessels and piggyback trailer and container traffic on railroads has been done almost entirely with private capital. There was no significant Government help until the authorization of subsidy to American Export Isbrandtsen Lines for the conversion of two former ore carriers to full containerships for subsidized operation from the east coast of the United States to Europe.

The only readily available figures on the trends in the movement of container type traffic are those for the railroads' piggyback traffic (table 3):

TABLE 3.— <i>Trailer on flatcar traffic 1955-65</i>		<i>Thousand cars¹</i>
Year:		
1955	-----	168
1956	-----	208
1957	-----	249
1958	-----	278
1959	-----	417
1960	-----	554
1961	-----	591
1962	-----	706
1963	-----	797
1964	-----	890
1965	-----	1, 031

¹ Each car averaged about 1.6 trailers in 1964 and 1965.

The Sea-Land Co. has operated domestically in the coastal, inter-coastal and noncontiguous trade from 1957 to 1966. On April 23, 1966, the company started service with three ships to northern European ports. The Sea-Land container pool has grown from about 4,000 in 1958 to a planned level of about 20,000 with the beginning of European service.

Matson Navigation Co. followed with containers to Hawaii in 1958. Break bulk operations had required frequent upward adjustment of rates. Some reductions in freight rates were made after containers were introduced. Although Sea-Land and Matson had the only combinations of large shore or ship based cranes with specially designed shipboard cells for stacking containers by early 1966, United States Lines, Grace Line, States Marine Line, Moore-McCormack, American President Lines and Alaska Steamship Lines also carried containers. These lines did not have fully developed systems as of the beginning of 1966.

The rapid growth of trailer-on-flatcar domestic rail traffic and the success of Matson and Sea-Land in noncontiguous trades are the best indicators that container traffic will eventually be widespread in world ocean trade.

The movement to unitized freight handling on an intermodal basis (railroad piggybacking and container transport of all kinds) has been underway domestically since the early 1950's. The movement now appears to be expanding rapidly into the foreign trade as well. It is reasonable to expect the growth in foreign trade to equal that achieved in the domestic trade because the savings will be as great if not greater than in the domestic trades.

Besides the U.S. firms already cited, at least two combines of European lines have already announced plans to enter container ships in the North Atlantic. Matson Navigation Co. and Japanese shipping firms are exploring the possibilities of full container ship services between the United States and the Far East and American Export Isbrandtsen Lines has filed an application for three high-speed container ships to link the U.S. east coast and Japan.

AMOUNT OF CONTAINERIZABLE GENERAL CARGO

All liner cargo except pieces longer than 35 or 40 feet (depending on container size) and wider or higher than approximately 8 feet can be handled in box containers. Lighter aboard ship (Lash) systems would probably accommodate lengths to 50 feet, widths to 20 feet, and depths to 10 or 11 feet. Estimates of the percentage of total general cargo which can be accommodated in containers varies with the person making the estimate and the trade route considered, but usually ranges from 70 to 95 percent. The percentages are high enough that it can be assumed that all liner type cargo may be carried on container ships for long-term forecasting purposes, i.e., specialized containers such as double height, double width, half height, half width, etc., may be developed to handle most of current outsize cargo, and other means of prepackaging can be used.

IMPROVEMENT IN SHIPS CARGO GEAR

The post-World War II ships built for the U.S.-flag fleet have incorporated considerable improvements in standard cargo handling gear and hatch cover design when compared to the war-built fleet.

Most ships have 10 and 15 ton booms throughout, heavy duty winches, mechanically articulated boom positioning, power operated schooner guys, and power topping under load. Hydraulically operated hatch covers are installed at all levels and in some cases also a heavy duty, mechanically articulated, 50 to 60 ton boom serving two hatches.

These improvements do two things when compared to the war-built ship capabilities:

1. They reduce the time to rig out and stow cargo handling gear.
2. They provide a faster cycle time from hold to dock with the more extensive rigged gear.¹

These improvements have permitted the new U.S.-flag ships to show large enough cargo handling gains over their predecessor types to make the added capital expenditures worthwhile. The introduction of container ships promises to be a similar entirely new technology for ocean transportation.

STEVEDORING INNOVATIONS

Mechanization and modernization agreement for the west coast

The International Longshoremen's and Warehousemen's Union (ILWU) and the Pacific Maritime Administration entered into a mechanization and modernization agreement (M. & M.) about 5½ years ago. The longshore employers set up two funds to provide for early retirement and unemployment pay in return for the right to freely introduce laborsaving methods and equipment.

The introduction of the M. & M. agreement on the west coast resulted in a 40-percent increase in productivity per man hour during these 5½ years. This dramatic increase was obtained even though only Matson Navigation has gone to large-scale containerization.¹

¹ Dillon, Ebel, and Goobeck, "Ship Design for Improved Cargo Handling," SNAME, 1962, p. 677.

The M. & M. agreement is now up for renewal. The ILWU is not asking for renewal of the unemployment guarantee because there have been no technological layoffs. The union is instead asking for distribution of the existing \$12 million fund built up but never used under the old agreement. The union is in fact insisting that the employers provide effort-saving machinery wherever possible. The union is threatening to increase gang sizes in holds not provided with machinery in order to back up its demands for more mechanization.¹

East coast agreement

The settlement between the International Longshoremen's Association and the east and gulf coast employers in the spring of 1965 made a small beginning toward regularizing stevedore employment and increasing productivity on the east and gulf coasts. The agreement provided for some very modest annual wage guarantees for union members in three ports and for some reduction in gang sizes and flexibility in scheduling and assigning for the employers.

D. TRENDS IN SHIP SIZE, TYPE, AND SPEED

CARGO SHIPS

The trend toward the gradually diminishing importance of the all-purpose cargo vessel and the emergency of the large specialized carrier is illustrated by the trend in ship design since World War II in the United States. Table 4 shows the typical size and power requirements of the ships in the subsidized fleet starting with World War II cargo ships through the most recent ships being placed under contract and vessels proposed for the near future. The table indicates the trend toward high speed, large size, and high power requirements.

TABLE 4.—GENERAL CARGO SHIP TREND IN SIZE AND SPEED

Time	Length overall (feet)	Cargo (cubic feet 3)	Speed (knots)	Power (shaft horsepower)
1936-46.....	459	544,000	15½	6,000
1948.....	493	552,000	18½	13,000
1953-60.....	563	703,000	20	17,500
1965.....	572	810,000	23	24,000
1966.....	602	1,200,000	24	30,000
Proposed, 1967-68:				
Sea-Land (6).....	905	2,800,000	27	72,000
Sapphire (3).....	749	1,300,000	25	60,000
American export (3).....	813	1,690,000	30	105,000

It is a well known naval architecture axiom that increased speed is most economically achieved with longer ships. When larger (and longer) ships become economically feasible because larger volumes of trade are available, they can be designed for higher speeds more readily than the smaller ships they replace.

Cargo ships which best fit these characteristics are high-speed, fast turnaround ships carrying containers, barges or some other type of prepackaged freight to facilitate rapid loading and unloading. The container or barge carrying ship concepts offer several advantages over the conventional break bulk operations. These advantages result in

¹ The Wall Street Journal, May 2, 1966, p. 2.

high productivity which yields lower unit transportation system costs in spite of the high capital investment:

1. Loading and unloading time and expense is reduced dramatically.
2. Ships utilization in line-haul service is materially increased and unproductive port time reduced.
3. Crew costs per unit of ocean shipping are drastically reduced, because high-volume equipment increases their productivity.
4. Capital and fuel inputs are relatively larger and crew costs are relatively smaller per unit of ocean shipping.

The success of the Sea-Land and Matson domestic containership operations have demonstrated the technical feasibility and economic advantages of ocean container ship service under U.S. conditions. Container service by several lines or groups of lines will be underway in the United States to North Atlantic trade by the end of 1966.

Furthermore, the development of integrated transportation system is relatively new particularly for ocean foreign trade. The fact that two unsubsidized operators are seriously considering the construction of large container ships with high speed and power requirements, 60,000 shaft horsepower and over, is significant evidence to support predicted trends for greater use of large, fast, specialized ships.

FOREIGN TRADE POTENTIAL FOR CONTAINER SHIP OPERATIONS

It is always difficult to accurately forecast potentials of a revolutionary new development in transportation because new demand potentials are opened up for which no experience is available. The advent of railroads made possible the agricultural and industrial development of the U.S. Midwest not possible with existing water transport. The introduction of jet airplanes has made possible transcontinental 1-day business conferences and 2-week European vacations. Container ship operations may well make possible the exchange in foreign trade of a wide range of commodities not heretofore possible because of high freight costs.

Analyses of world trade indicates that at the present time, over 70 percent of the break bulk cargo carried is adaptable to containerization. It seems reasonable to assume that within 10 to 15 years containerization exceeding this magnitude will take place.

Number of fast turnaround container ships possible, 1970-90

It is possible to make a rough approximation of the minimum number of giant container ships (defined as 900 to 1,000 feet long, carrying about 3 million cubic feet of container space with a speed capability of 25 to 30 knots and requiring 50,000 to 140,000 shaft horsepower) needed in the period 1970-90 by making a few assumptions about U.S. liner trade and the carrying capacity of giant container ships.

TABLE 5.—U.S. LINER TRADE ESTIMATES, 1970-95

[Millions of long tons]

Year	Exports	Imports	Total
1970	33	22	55
1975	36	24	60
1980	38	26	64
1985	41	28	69
1990	45	30	75
1995	48	32	80

Current inputs for estimating merchant marine requirements give C-4 type break bulk ships in the liner trade about 50,000-long-ton annual capability. Averages assumed for U.S.-flag liner ships for 1970, 1985, and 1990 are:

Year	U.S.-flag liner ships, C- type (number)	U.S.-flag foreign trade produced (million long tons)	Ave./ship (long tons)
1970	425	16.4	39,000
1985	339	15.9	47,000
1990	350	17.5	50,000

If we assume that the giant container ship carrying 1,200 40-foot containers can do six times as much work as the C-4 average for 1990, the average annual productivity would be 300,000 long tons. If we assume that the giant or an even larger ship (or concentration on the short European run by large ships) can do eight times the work of a C-4, the average annual productivity would be about 400,000 long tons.

The increase in general cargo foreign trade between 1970 and 1990 is estimated at 20 million long tons (table 5). At current rates of U.S.-flag fleet development, only about 1 million long tons of the increase would be carried by conventional U.S.-flag ships. If only half the remaining estimated increase (9,500,000 long tons) were to be carried in U.S.-flag giant container vessels, it would require about 32 at 300,000 long tons capability or about 25 at 400,000 long tons capability, considering the imbalances in trade patterns.

The giant container ship assumes 3 million bale cubic capacity. The number of ships required would be doubled for large container ships with only about 1,500,000 bale cubic capacity.

The figures above assume no increase in trade because of lower real costs of ocean transportation, assume no decrease in conventional type U.S.-flag vessels, and assume that U.S.-flag ships (container ship and conventional liners) still have something less than 40 percent of total U.S. liner trade by 1990.

All the above estimates may be conservative:¹ (1) Total foreign trade may grow faster than the 3.5 percent per year postulated by the Maritime Administration for foreign trade projections; (2) lower real ocean transport costs may increase transoceanic trade; (3) giant container ships may displace a significant number of break bulk ships.

Thus the minimum number of giant container ships which could easily be accommodated in the U.S.-flag liner trade is 25 to 32. The number could conceivably be higher with expanding trade, fewer C-4 type ships, and lower real costs of ocean transport.

¹ It is assumed that the costs of operating large aircraft introduced in 1970 and beyond will remain too high to become a significant factor in transoceanic cargo weight lifted. The attraction of high value cargo to aircraft may affect ocean freight rates, however, by taking away high revenue cargo and forcing a restructuring of rates on medium and lower value cargo.

TANKERS

The most rapidly growing aspect of world trade since World War II has been the carriage of liquid petroleum. The evolution of the tanker trade is familiar to all who have been aware of ocean transportation trends. The growth and size of the ships in this trade has been dramatic. The war-built T-2 (about 16,000 deadweight tons capacity) marked the beginning of this trend by proving the advantage of the larger tanker. The increased reliance on the Middle East as a source of petroleum for Europe, Japan, and the United States, and the need for optimum vessel economy for this long movement has accelerated the development of large tankers. Thus, both the number and the size of vessels has grown since demand for oil from long-haul sources has increased more than demand for oil which can be moved overland or via shorter sea routes.

In 1954, about 61.2 percent of the world tanker fleet had a carrying capacity under 17,000 deadweight; 33.4 percent between 17,000 and 29,999 deadweight; 5.4 percent between 30,000 and 49,999 deadweight; and none were 50,000 deadweight and over.

The situation in the last decade has changed quite rapidly. In 1964, about 14.3 percent of the tanker fleet had a carrying capacity under 17,000 deadweight; 28.8 percent between 17,000 and 29,999 deadweight; 35.6 percent between 30,000 and 49,999 deadweight; and 21.3 percent 50,000 deadweight and over.

At the present time, there are 60 tankers over 100,000 tons deadweight in operation or under construction (16 in operation and 44 under construction). The largest of those now under construction is the *Idemitsu Maru*, with 205,000 deadweight. The Gulf Oil Co. has recently announced to the press¹ that they plan to operate six gigantic 300,000 ton oil tankers for the transportation of oil from the Middle East to Europe. These ships, though having the usual speed of only 16½ knots, will require 60,000 to 70,000 shaft horsepower plants. In a recent study, it was predicted that by 1980 a limited number of tankers of 500,000 deadweight would be built. This trend to large size tankers will necessitate the use of powerplants in the 60,000 and higher shaft horsepower range. Accurate predictions as to the number of vessels with power in excess of 60,000 to 70,000 shaft horsepower in various time periods is, of course, most speculative. However, if tankers such as those proposed by Gulf are built, it seems reasonable to believe that others will follow.

DRY BULK CARRIERS

Dry bulk carriers are those ships which customarily carry single types of bulk cargoes, excluding tankers. Most of the world's bulk trade consists of commodities such as grain, ore, coal, fertilizer, etc. As of January 1966, the world bulk fleet was composed of approximately 1,168 ships. The size distribution of these ships is shown in table 6:

¹ Business Week, May.

TABLE 6.—SIZE OF DRY BULK CARRIERS JAN. 1, 1966

Size of Vessels in deadweight tons	Ore carriers		Other bulk carriers		Total	
	Number	Thousand deadweight tons	Number	Thousand deadweight tons	Number	Thousand deadweight tons
10,000 to 14,000.....	32	383	91	1,043	123	1,426
14,000 to 18,000.....	84	1,313	229	3,639	313	4,952
18,000 to 25,000.....	83	1,751	311	6,723	394	8,474
25,000 to 30,000.....	27	739	74	1,993	101	2,732
30,000 to 40,000.....	36	1,242	103	3,471	139	4,713
40,000 to 50,000.....	19	896	17	764	36	1,660
50,000 to 60,000.....	33	1,780	14	756	47	2,536
60,000 to 80,000.....	11	756	2	141	13	897
Over 80,000.....	2	162	-----	-----	2	162
Total.....	327	9,022	841	18,530	1,168	27,552

Dry bulk ships are generally smaller than tankers with only two vessels in operation of 80,000 deadweight tons or over. The speed of these ships is also generally slower than tankers with 15 knots being the most common. Tankers are generally well below the 15 knot range. As of January 1, 1966, the size distribution of bulk carriers on order is shown in table 7:

TABLE 7.—SIZE OF BULK CARRIERS ON ORDER, JAN. 1, 1966

Size group (deadweight tons)	Ore carriers		Other bulk carriers		Total	
	Number	Thousands of deadweight tons	Number	Thousands of deadweight tons	Number	Thousands of deadweight tons
10,000 to 14,000.....	-----	-----	8	105	8	105
14,000 to 18,000.....	3	46	18	291	21	337
18,000 to 25,000.....	-----	-----	102	2,183	102	2,183
25,000 to 30,000.....	2	56	27	717	29	773
30,000 to 40,000.....	3	74	89	3,155	91	3,229
40,000 to 50,000.....	3	137	55	2,465	58	2,602
50,000 to 60,000.....	10	549	23	1,237	33	1,786
60,000 to 80,000.....	14	952	55	3,705	69	4,657
80,000.....	8	685	6	603	14	1,288
Total.....	42	2,499	383	14,461	425	16,960

The experience in dry bulk ships shows a trend toward larger ships but not to the extent indicated for general cargo ships and tankers. The largest bulk carrier now under construction is 144,000 deadweight tons with a speed of 15¼ knots. This ship will require an estimated 20,000 shaft horsepower to meet this speed requirement.

The size of bulk carriers is affected by the magnitude of cargo offerings as well as the limitation of port facilities. Off loading of bulk carriers is less efficient than off loading of tankers. The dramatic size growth of tankers has not been extended to the bulk carriers because of these limiting restraints.

Very little additional growth for the largest class of bulk carriers is predicted during the next 20 years.

SUMMARY

Since World War II there has been a continual increase in the size, speed, and power of all kinds of ships. The increase from 15,000 to

300,000 deadweight tons in tanker size has been the most dramatic. The increase in power requirements for ships handling general cargo will be equally dramatic if the increase from the 6,000 shaft horsepower of the war-built ships is carried up to the 105,000 shaft horsepower of the proposed American Export Isbrandtsen Lines 30-knot container ships.

E. POTENTIAL FOR NUCLEAR POWER IN THE MARITIME FIELD

Nuclear power compares most favorably to fossil fuel power in applications requiring high shaft-horsepower in trades where there can be high percentage utilization of the powerplant potential.

FAST TURNAROUND CONTAINER OR BARGE SHIPS

These ships most nearly satisfy the condition which favors nuclear power because of its high speed and fast turnaround. The estimated economic results of using nuclear power in this application are shown in chapter II.

LARGE TANKERS AND DRY BULK CARRIER APPLICATIONS OF NUCLEAR POWER

Large tankers and dry bulk carriers deliver low-value-per-ton commodities on an assembly line or pipeline basis. There is no substantial premium on speed of delivery since there is a very low interest cost on these commodities in transit. Powerplants for bulk carriers will therefore be built to give the most economical overall delivery cost. Larger, more costly powerplants will only be installed up to the point where the revenue from the added transportation capability made possible by higher speed is greater than the combined added costs of machinery amortization and fuel.

Nuclear power is most competitive in the range of high shaft horsepower output propulsion systems; that is, in excess of 50,000 shaft horsepower. The increase in the size of bulk carriers (soon to be 300,000 deadweight tons for tankers) is requiring larger and larger powerplants. The projected 300,000 deadweight tons tankers will require an estimated 60,000 to 70,000 shaft horsepower plant operating twin screws to attain the projected 16-knot speed. Dry bulk carriers are not likely to become as large as tankers because of loading and unloading and other restrictions and therefore will not require high shaft horsepower plants in the foreseeable future.

There are two serious limitations on the use of nuclear powerplants for tankers even after plants of 50,000 to 100,000 shaft horsepower are required: (1) the ballast legs of tankers require less than full power and therefore make poor use of the fixed charge component of nuclear fuel; (2) there is very little penalty for the fuel storage space and for oil companies some credit for using their own products at an intra-company price. Both these factors make it doubtful that nuclear power will be competitive in bulk ships with present nuclear technology.

POSSIBLE FUTURE APPLICATIONS

Experience indicates that radical new ship forms and systems will develop for many special purposes in the next 10 to 20 years. Rapidly

increasing knowledge of the sea, weather forecasting, lightweight structures, and high-powered, lightweight powerplants are giving the ship designers new flexibility to provide for future ocean shipping requirements. Among new ship concepts that are being studied are:

(a) Tractor ships, or large ships that would have a disconnecting feature that would permit the aft engine room propulsion section to be detached from the cargo section or sections of the ship, and immediately attached to waiting loaded cargo sections.

(b) Catamaran cargo carriers may possibly prove feasible in the handling of containerized cargo. The twin hull configuration lends itself to a large deck area and higher propulsion efficiencies.

(c) Surface effect ships are currently under study by Navy and MarAd to determine their role as a highspeed ocean cargo carrier. Studies to date indicate that speeds approaching 100 knots may be technically feasible. These crafts are relatively small, but if developed they would require power in the range of 200,000 to 500,000 shaft horsepower in commercial usable sizes.¹

(d) Submarine cargo vessels, or possibly submarine trains, utilizing a submarine tug and a series of cargo carriers may well provide a system for sea transport of the future.

All of these systems require compact, high-powered propulsion systems. Moreover, fuel requirements for fossil fuel propulsion systems account for large portions of the load on long voyages. In addition, the fueling problem at each end of the voyage would be time consuming and costly. A lightweight, high-powered nuclear propulsion unit obviously would benefit these applications.

NUMBER OF SMALL CONTAINER SHIPS, SPECIAL PURPOSE AND BREAK BULK SHIPS NEEDED 1970-90

The current merchant shipbuilding program for the U.S.-flag subsidized general cargo fleet is about 14-15 ships per year. The projections discussed in section D indicate that 2 or 3 per year will be large or giant containers ships (1,500,000-3,000,000 cubic feet). Current trends indicate the smaller ships will require powerplants in the 30,000-45,000 shaft horsepower range.

Thus the total number of merchant ship powerplants which can be projected for U.S. subsidized construction between 1970 and 1990 at this time are 25 to 64 in the range 50,000 to 140,000 shaft horsepower, depending upon the size and speed of large and giant container ships built and approximately 235 to 250 plants of 30,000 to 45,000 shaft horsepower.

F. THESE TRENDS IMPROVE THE COMPETITIVE ECONOMICS FOR U.S.-FLAG SHIPS AND U.S. INDUSTRY

The U.S. operator of merchant ships faces economic costs determined uniquely within the United States. The cost of ship construction domestically is over twice that of foreign competition based upon the lowest domestic bid as compared with the lowest foreign shipyard cost. U.S. shipboard wage costs are four to five times equivalent for-

¹ Surface Effect Ships for Ocean Commerce, U.S. Department of Commerce, Washington, D.C., 1966.

eign wage costs based upon our "parity" operating differential subsidy formula for measuring wage differentials.

However, U.S. costs of capital are lower. The U.S. operator can also assemble large amounts of capital and competent, sophisticated management groups more easily than elsewhere in the world. Fuel costs are about the same for oil-fired plants here and abroad.

The revenues from shipping service are determined by the forces of international competition. The amount of revenue is independent of internal production factor costs.

Under these economic conditions, the U.S. operator must assemble an economic package which will permit him to compete in terms of cost per unit of service or, failing that, depend on subsidy payments.

Other U.S. exporting industries face a similar problem and overcome it. These industries combine large amounts of capital, superior management, and highly productive labor to achieve internationally competitive unit cost outputs. An example in transportation is the success of aircraft manufacture and commercial air carrier service. The U.S. merchant marine must use similar techniques to achieve truly competitive cost output. Like other export industries, a merchant marine based on high capital investment, low unit labor cost, and highly complex integrated systems would minimize U.S. unit output costs, improve our competitive position, and minimize required Government subsidy.

The trends in world trade, ship technology, and cargo handling methods are opening the way for a more competitive U.S. merchant marine under U.S. cost conditions. The development of integrated ocean transportation systems require specialized high-speed, fast turnaround ships which carry containers or barges to facilitate rapid loading and unloading. These ships and shipping systems also change the structures of cost factor inputs to fit the criteria for most effective competition by U.S. operators.

In addition, nuclear power compares most favorably to fossil fuel power at high-shaft horsepower in trades where there can be a high utilization of the powerplant potential. High-speed ships sailing at full power on long runs with fast turnaround most nearly satisfy the conditions for most favorable use of nuclear power. (See ch. II and III.)

The changes in the structure of economic cost factors resulting from this type system are discussed below.

LOADING AND UNLOADING

A recent study of the components of ocean freight costs by loading, unloading, and vessel segments showed a wide variation depending upon port pair and commodity. In all cases, however, estimated U.S. loading and unloading costs were in excess of similar foreign costs. U.S. loading costs in some ports for some commodities were estimated at more than half the total freight bill. On the other hand, foreign loading costs for some commodities were less than 5 percent of the total freight bill.

(a) For all commodities studies in the report, cargo handling costs ranged from 25 to 67 percent of total unit ocean freight costs.

(b) Cargo handling costs ranged from 138 to 1,224 percent higher

for loading and 135 to 1,200 percent higher for unloading in United States as compared to foreign ports for the same commodity.

(c) Cargo loading costs generally exceeded unloading costs for a given commodity in a given port ranging from 14 to 36 percent higher for the commodities shown.

U.S. shippers and ship operators stand to gain more than their foreign counterparts from improvements in cargo handling. Dock wages are higher in the United States so there will be greater stevedoring savings in the United States than abroad and U.S. shipboard wages are 4 to 5 times foreign costs so there will be greater savings to United States than to foreign ships.

INCREASED SHIP UTILIZATION

The study estimated vessel costs at from 33 to 75 percent of unit ocean freight costs. In the latest year for which data are available to make estimates, U.S.-flag subsidized liners spent about 46 percent of total voyage-days in line haul service and about 54 percent of voyage-days in port or steaming between ports in the same geographic area.

The expense of maintaining and operating a ship while in port may be imputed to the port costs. Costs are higher at sea for fuel but there are no port charges. If we assume for approximation purposes that added costs in port balance added fuel costs at sea we may impute ship costs on the basis of voyage-days. Thus, for U.S. subsidized ships about half the vessel cost was incurred in port or 16 to 37 percent (33 to 75 percent over 2). When the imputed vessel costs are added to the direct loading and unloading costs total port costs range from 62 (25 plus 37) to 83 percent (67 plus 16) of the ocean unit costs for shipping commodities to and from the United States.

The rapid ship turnaround resulting from containerization will enable ship operators to increase the line haul portion of voyage-days from the current average of less than 50 percent to 70 or 80 percent depending on the length of voyage and progress in container handling techniques. The decrease in nonproductive time in port will be an incentive to increase ship speed because a 5-knot increase in sea speed will result in an average increase in effective speed of 4 knots at 80 percent sea time but only a 2.5-knot increase with 50 percent sea time.

The earning power of the investment capital in the ship is also increased by faster turnaround time. A vessel at sea 80 percent of the time has a 60 percent greater revenue potential than one at sea 50 percent of the time. Both these factors, better use of available speed and increased revenue capability from faster turnaround, will permit U.S.-flag owners to build and operate higher capital cost, higher speed ships than would be possible under conventional break bulk operating patterns.

The increase in potential utilization of capital invested in ships made possible by containerized handling techniques for cargo will make investments in high-speed more expensive ships feasible regardless of whether they use oil or nuclear energy. The increased potential utilization makes high-speed container ships a logical application for nuclear power because a part of the nuclear fuel is a fixed cost¹ and

¹ A substantial portion of the cost of nuclear fuel is represented by investment charges in the nuclear fuel. These are incurred whether or not the ship is underway.

only part is variable as contrasted to oil where the whole charge is variable.

The figures assembled for the recent study of ocean freight costs agree with two independent sources. The Office of Business Economics made a study of 1962 gross ocean freight payments and receipts which indicated about 34 percent were attributable to the flag of the ship and about 66 were attributable to stevedoring, port expenditures, and so forth.² A MarAd study, "Ship Design for Improved Cargo Handling," had figures showing that about 68 percent of total costs were due to the cargo handling function when both the direct stevedoring costs and the costs of the ship in port were attributed to the cargo handling function.³

The economic basis for the U.S.-flag move to containerized ships can thus be clearly laid.

About two-thirds of unit ocean shipping costs are associated with the cargo handling function and only about one-third with the line haul ship function. A disproportionate share of the cargo handling function costs is at the U.S. end because U.S. loading and unloading costs are three to 12 times those of foreign countries. If we assume, for example, that a hypothetical commodity moves between United States and Europe at \$100 per M/T, U.S. loading cost may be \$50, vessel cost \$40, and foreign unloading \$10. If we allocate the \$40 vessel cost into \$20 in port and \$20 at sea, and allocate the port time equally between the United States and Europe, the costs become: \$60 U.S. loading cost, \$20 vessel cost in line haul and \$20 foreign unloading cost. (Table 8.) A 40-percent increase in overall efficiency in the system would benefit the U.S. participants by \$32, the foreign participants by \$8 and the ship operator in line haul by \$8. This wide potential leverage for the U.S. operator explains the reason for the switch to containers and more efficient systems.

TABLE 8.—HYPOTHETICAL SHIPPING COSTS, UNITED STATES TO EUROPE

	Vessel cost in port unal- located	Vessel cost in port allocated to loading and unloading ¹
Loading, United States.....	\$50	\$60
Port.....	20	
Vessel cost:		
Line.....		20
Haul.....	20	
Unloading, Europe.....	10	20
Total cost.....	100	100

¹ Assumes vessel spends 50 percent of total voyage-days in port and spends equal time in U.S. and European ports.

CREW COST PER UNIT OF OCEAN SHIPPING

The United States is at an economic disadvantage with foreign competitors largely with labor costs in building and operating of U.S.-flag ships. It is not possible to predict the actual crew on future U.S.-flag ships, therefore, it is not possible to predict actual crew costs on future ships. (See ch. VI, on manning.) We can, however, approach

² "Survey of Current Business," August 1963.

³ "Ship Design for Improved Cargo Handling," SNAME, October 1961.

the answer by looking at the possible crew cost component of current versus proposed ship costs. If the largest container ship proposed so far is actually built, the six conventional ships it could displace are likely to have a combined crew of about 300 men. Even if automation reduced the crews on conventional ships to 35 billets per ship, it would still be 210 billets.

Under today's conditions the largest tankers are being automatically controlled and monitored to be operated by crews of about 30 men. It is reasonable to assume large, high-speed container ships can be built for approximately the same size crew. Even if we assumed a crew of 50 on the future large automated container ship and the low crew (35 per ship) for conventional ships, the crew cost component of the large ship would be reduced to less than a fourth of what it would be for equivalent shipping capacity in conventional break bulk ships. If it were possible to assume the most favorable conditions the large, high-speed container ship would have only one-sixth of the costs of equivalent conventional ships.

If the large, high-speed container ships were to be nuclear powered and nuclear power required either more men or higher priced men than were required on equivalent oil-fired ships, the effect on total costs would be minimized compared to conventional break bulk ships because of the smaller relative size of the crew cost component of total shipping system costs.

These advantages can accrue to U.S.-flag shipping firms and U.S. exporters in greater degree than to foreign-flag shipping firms and shippers because U.S. labor costs are two to five times¹ higher and capital costs are lower than in competing foreign nations.

CAPITAL

It is difficult to document the exact difference in capital costs between the United States and European and Japanese capital markets. Container ships systems will require not only highly capitalized ships but also a large container and bogie pool. Container cost varies with size and type from \$2,400 (20 foot) to \$3,600 (40 foot) per unit and \$10,000 for a 40-foot refrigerated unit. Future container ships may carry 1,000 or more large boxes including some specialized types, such as refrigerator boxes. The container equipment required to support such a ship could range from \$10 to \$12 million or more.

A container shipping system will require the ship operator to assemble, invest, and manage a much larger amount of capital than has been necessary in the past. The United States has had far more experience with large enterprises than any other country in the world. It should be easier to assemble the complex management group required in the United States than in any other competing maritime nation. The United States has the lowest capital costs in the world (for both borrowed and equity money)—so low, that it has been necessary to impose a 15-percent foreign investment tax on capital exports for balance-of-payments purposes.

It is usually possible to finance a larger share of the total capital costs of an enterprise on borrowed money in the United States than abroad. U.S. banks usually are willing to loan a larger share of total

¹ Monthly Labor Review, May 1963, p. 487.

capital, on longer terms, at lower rates of interest to ventures backed by a large stable U.S. corporation than comparable foreign banks can do for similar foreign ventures. Except for U.S.-flag shipping, transportation enterprises financed in the United States (e.g. airlines) have about 20 percent equity capital and about 80 percent borrowed capital. Many of the large tanker operators who have financed their foreign-flag tankers in the United States have been able to get 75-80 percent mortgages for up to 20 years when backed by whole life charters from large international oil companies. In contrast to these examples, U.S.-flag subsidized companies operate with only 40-60 percent borrowed capital. This may be due both to conservative financing policies of these firms and to the applicable statutory provisions of the subsidy laws governing them. In any case such conservative financing patterns have the effect of lowering the rate of return possible on equity capital and raising the required rate of return on total capital invested in U.S.-flag subsidized shipping firms.

U.S.-flag firms which assemble the capital required for a large scale, high speed, express container ship system will presumably want to finance their operations on something like the airline pattern of about 80 percent debt obligations. A high level of debt at low average interest rates would put U.S. firms so financed in a better position to compete on ocean-freight rates than their less favorably situated foreign competitors.

FUEL

Except for the NS *Savannah* the merchant ships of the world are run on oil. Oil is readily available all over the world at standard prices for all customers. U.S.-flag ships should operate at higher speeds than their foreign competitors because with very high wage rates overall costs are minimized at higher speeds for U.S.-flag ships than for their foreign competitors who have lower paid crews. The current operating differential subsidy tends to distort this relationship and induce U.S.-flag operators to prefer about the same speed as their competitors.

U.S.-flag ships should be faster and use more fuel regardless of whether it is oil or nuclear material. There would probably be an additional economic advantage to the United States if nuclear power became economically competitive for some of the larger and faster ships. The United States is a net importer of oil but could possibly be one of the principal world suppliers of nuclear fuel material. Nuclear fuel obtained solely from a domestic source would replace oil some of which is purchased abroad with dollars thus aiding the balance of international payments.

SUMMARY

Containerized handling systems, regardless of the kind of fuel used in the ships in the system, will be advantageous for the United States because a large amount of capital must be assembled to substitute for the hand labor now used in break bulk shipping systems. Such substitution will be more beneficial to U.S. shippers and shipping firms than to their foreign counterparts because U.S. labor costs are from two to five times equivalent foreign labor costs. The net result should make U.S. exports more competitive in third country markets by reducing the substantial ocean freight rate differentials that now exists

for many products. Increased export sales because of lower ocean freight rates will help to maintain and improve the U.S. international balance-of-payments position.

G. INDUSTRY RESEARCH AND INTEREST IN NUCLEAR POWER SINCE THE "SAVANNAH" PROJECT

All segments of the marine transportation industry have expressed some interest in nuclear-powered merchant ships. These include shipping companies, nuclear reactor manufacturers, design firms and shipyards.

OPERATOR INTEREST

American Export Isbrandtsen Lines, Inc. (AEIL) has shown the greatest interest in nuclear power beginning with their contract to operate the NS *Savannah* during the second round of demonstration voyages. This interest has continued with their current operation of the NS *Savannah* commercial operation through a subsidiary known as First Atomic Ship Transport, Inc.

AEIL expressed further interest in the operation of a commercial nuclear cargo fleet in a joint letter to Dr. Glenn T. Seaborg, Chairman, U.S. Atomic Energy Commission, and Mr. Nicholas Johnson, Maritime Administrator, on October 30, 1964. This expression of interest was general in nature but it advised that AEIL had an active interest in cooperating with the Commission and other Government agencies to design, construct, and commercially operate a group of nuclear-propelled vessels for the offshore trades of the United States at the earliest possible date. This commercial interest in the maritime application of nuclear power formed the basis for further research studies on the subject.

AEIL has followed through on its original interest by filing with the Maritime Administration on January 26, 1966, an application for construction differential subsidy (CDS) for three high-speed cellular container vessels, with either nuclear or conventional powerplants, for operation on Trade Route No. 12, United States to the Far East. (See ch. II.) This application outlines the ship, the trade, and the AEIL estimate of cost to themselves and the Government if the ships were to be constructed with nuclear power under certain assumed provisions of the proposed Garmatz bill (H.R. 766) and Cotton bill (S. 2949), or constructed with conventional power under the subsidy provisions of the Merchant Marine Act of 1936.¹

Other shipping companies in the United States are aware of the technical feasibility of nuclear power. American President Lines, American Mail Line, and Moore-McCormack Lines have cooperated with two naval architectural firms in undertaking trade route studies for the Maritime Administration on the economic feasibility of nuclear power for ships. In addition, it is understood that one unsubsidized operator is considering nuclear power as a possible alternative source of power for new proposed high-speed ships.

¹ AEIL is continuing to refine the design and develop further details which will be submitted to the Maritime Administration in support of the application. The Maritime Administration has reviewed all information currently available and has suggested that AEIL develop and submit additional supporting information.

MARITIME ADMINISTRATION SOLICITATION OF INDUSTRY INTEREST

The Maritime Administration sent a letter soliciting industry interest in nuclear powered merchant ships to 56 U.S.-flag ship operators on April 25, 1966. As of May 17, 1966, 31 operators had replied. The operators are in general interested. However, few are in any position to make independent evaluations of the economic competitiveness of nuclear power. The gist of the replies to date is that they will be interested only when the economic competitiveness of nuclear power has been proved.

REACTOR MANUFACTURER INTEREST

Private industrial reactor manufacturers have made several unsolicited proposals for marine nuclear reactors. The Babcock & Wilcox Corp., Combustion Engineering Corp., Westinghouse Electric Co., General Electric Corp., and United Nuclear are known to have made studies relating to reactors for ships. (See ch. IV.)

Babcock & Wilcox' interest in merchant ship reactors began with their work on the NS *Savannah* for which they supplied the reactor and associated equipment. This company has continued its interest by developing advanced designs and doing additional research to improve their pressurized water reactor (PWR) concept. Babcock & Wilcox, through their foreign affiliates, have been working with other countries and have done much of the engineering and design work on the German bulk carrier, *Otto Hahn*, which is scheduled for trials during the first half of 1967. (See ch. IX.)

SHIPYARD INTEREST

The interest of shipyards toward nuclear power in merchant ships has been limited; however, several who have built nuclear vessels for the Navy have expressed interest in a nuclear merchant ship program.

NAVAL ARCHITECTURE FIRM INTEREST

In conjunction with the interest expressed by AEIL, other operators and the reactor manufacturers, three naval architectural firms have been most active. They are J. J. McMullen Associates, Inc., G. G. Sharp, Inc., and J. J. Henry Co., Inc., who are currently under contract with the Maritime Administration for ocean shipping system studies including an evaluation of the use of nuclear power.

SUMMARY

The results of industry research and interest of the letter solicitation to the industry indicate that leadership and substantial financial support for the next generation of nuclear ships will depend upon the Federal Government because of the uncertainties and costs involved in a technology in its early stages of development.

H. POSSIBLE PROGRAMS FOR FURTHER NUCLEAR POWER APPLICATIONS IN THE MERCHANT MARINE

The trends in trade and development of maritime transportation systems are of advantage to the United States. Both our merchant ma-

rine and our position in international trade are likely to gain by these changes.

Nuclear power offers the United States the opportunity to increase this gain and to further the goals of our national policy. The economies of scale in nuclear powerplant costs can be utilized as horsepower requirements increase in maritime application. The following program is presented as the Government action required. It suggests both long-range and near-term goals.

INTERIM PROGRAM

Purpose.—An interim program or programs should be undertaken to: (1) gain further experience with crew assignments, pay, and number of billets required; (2) resolve liability, insurance, and port safety problems left outstanding by the *Savannah* project; (3) provide a new base point for AEC and MarAd economic and cost calculations.

Construction of the first nuclear-powered ship was approved by Congress nearly 10 years ago (July 30, 1956). The ship has been in operation for over 4 years. The *Savannah* is now a one-of-a-kind special ship which has been very successful in many ways. Some unresolved problems remain however with respect to the operation of nuclear-powered ships which cannot be, or at least are highly unlikely to be, resolved without some additional merchant ships powered with nuclear reactors (see chapter V).

A number of Navy ships and stationary electric powerplants have been equipped with nuclear reactors since the *Savannah* project. There has been no opportunity to apply any advancements or refinements in nuclear reactor design to merchant ships since the *Savannah*. Engineering calculations for the next ships thus rests on the *Savannah* experience and Navy and electric powerplants built since the *Savannah*. A new fleet of nuclear ships would provide an opportunity to check the validity of the engineering extrapolations and calculations being used for the next nuclear ships.

Possible scope.—The interim program would include from two to four ships built for a high-speed, express service, containerized shipping system. The program would award all these nuclear ships to a single bidder.

Benefits.—The interim program would provide a continuing method for resolving or working toward the resolution of the problems which stand in the way of widespread use of nuclear power for merchant ships if and when it becomes economically competitive with fossil fuel.

It would provide some additional experience with pressurized water reactors although benefits in this area may be limited.

It would provide a wider base for the nuclear reactor industry in the United States. It should aid the industry in maintaining world leadership in the nuclear reactor technology.

LONG-RANGE PROGRAM

Purpose.—A long-range objective of the civilian maritime program would be the development of nuclear propulsion systems that, together with improved cargo handling and other nonnuclear innovations, can contribute to increased productivity and commercial competitiveness of the U.S. merchant marine.

Possible scope.—The scope of the program would be determined on a cooperative basis by AEC and the Department of Commerce. Based on current knowledge it appears that plants in the range of 50,000 to 140,000 shaft horsepower will be required. After the criteria for nuclear power has been established, the AEC anticipates that the most economical way to achieve the objectives will be through a land-based test facility. The determination of whether to proceed with a test facility would in part depend upon the expected benefits from such a program.

Benefits.—The benefits from the long-range program will depend upon the results which can be obtained from the cooperative venture of the AEC and MarAd.

The program would be set up in stages so that planning, programing and budgeting techniques can be used to obtain the optimum results from the money spent and the programs can be altered as experience warrants. Assuming that nuclear power for civilian maritime applications does prove to be economic, numerous long-range benefits may result:

1. The international merchant marine economic competition will become less sensitive to labor costs where the United States is at a disadvantage and more sensitive to the availability and cost of capital where the United States has an advantage.

2. Nuclear reactor industry may be able to extend their competitive advantages by providing reactors not only for U.S. maritime application but possibly for export on the world market.

3. A successful program utilizing nuclear reactors in a containerized transportation system which reduces real costs of exporting U.S. products will improve the U.S. position in world markets and hence the overall balance of international payments position.

CHAPTER II.—NUCLEAR SHIP CONSTRUCTION AND OPERATING COSTS

INTRODUCTION

The most important aspect in considering the use of nuclear power in merchant vessels is its potential to lower the overall ocean transportation costs to the operator and to the Government (when subsidy is involved). This could be due to potential savings in operating costs which may be made possible by the use of nuclear fuel which is estimated in the future to cost about half as much as fossil fuel.

The numerous studies have concluded that, in the next generation (near term) of nuclear ships, the probability of their being economically superior to equivalent oil-fired ships without additional Government assistance is remote. However, after nuclear entry costs have been absorbed, long-range application of nuclear power can be expected to produce savings which may result in savings to both the operator and for the Government (when subsidy is involved).

In order to reach the economies that nuclear power portends, three major objectives must be considered:

(1) The present high capital cost differences between the nuclear-powered ship and its oil-fired equivalent must be reduced materially.

(2) The cost of nuclear fuel must be reduced to the point where the saving in nuclear fuel cost as compared to fossil fuel will be sufficient to amortize the added capital cost of the nuclear plant and leave a sufficient margin for added profits and other additional operating costs associated with nuclear power.

(3) The operating costs of nuclear ships must be brought down to a point more nearly approaching that of the equivalent oil-fired ship; this means crew cost, maintenance and repair expense, refueling costs, shore staff, insurance expense, and so forth.

In any marine nuclear power application program, it must be the industry and Government goal to attain these three objectives.

NUCLEAR SHIP CONSTRUCTION COST

In order to illustrate the relative cost of nuclear-powered ships in a high-speed container ship application, the following tabulation shows the characteristics of the nuclear-powered ships proposed by American Export Isbrandtsen Lines (AEIL). The ships' general characteristics have been reviewed by the Maritime Administration and found

to be reasonable for the proposed container service from the United States to the Far East.

Characteristics :

Length overall-----	813 feet.
Beam-----	92 feet.
Design draft-----	26 feet, 6 inches.
Displacement, design-----	32,000 tons.
Service speed-----	29-30 knots.
Power shaft horsepower twinscrew-----	105,000.
Bale cubic-----	1,780,000 cubic feet.
Dry cargo deadweight-----	16,200 tons.
Stowage for 20 feet by 8 feet by 8 feet containers-----	1,364.
Crusing radius at 30-knot full displacement-----	Unlimited.

The construction cost of these ships have been estimated by AEIL and the Government. Since all ship and nuclear information is of a preliminary nature, these estimates must of necessity be approximations; however, the cost can be accepted as being representative. The Government estimates reflect recent increases in the shipbuilding market that apply to the oil-fired ship and the conventional portion of the nuclear ship. In addition, Government estimates of the nuclear ship includes reactor cost estimated by AEC in chapter III. The industry and Government ship construction estimates are as follows:

[Amounts in millions]

Near term:

(1) Government estimate:¹

Each of 3 nuclear ships-----	Construction cost \$44. 0
Each of 3 oil-fired ships-----	26. 0
Difference per ship-----	<u>18. 0</u>

(2) Industry estimate (AEIL CDS application, Jan. 26, 1966):

Each of 3 nuclear ships-----	34. 2
Each of 3 oil-fired ships-----	23. 4
Difference per ship-----	<u>10. 8</u>

Long term:

(1) Government estimate,¹ using Government reactor cost estimates:

Each of 3 nuclear ships-----	34. 0
Each of 3 oil-fired ships-----	26. 0
Difference per ship-----	<u>8. 0</u>

(2) Government estimate,² using industry reactor cost estimates:

Each of 3 nuclear ships-----	33. 0
Each of 3 oil-fired ships-----	26. 0
Difference per ship-----	<u>7. 0</u>

¹ MarAd estimate for conventional portion of ship combined with AEC estimate of propulsion plant including reactor. (See chapter III.)

² MarAd estimate for conventional portion of ship combined with an industry estimate of propulsion plant including reactor.

The near-term construction cost indicates the construction cost of three nuclear ships will exceed that of three equivalent oil-fired ships as follows:

3 nuclear ships (using Government reactor estimates)-----	\$54, 000, 000
3 nuclear ships (using industry reactor estimates)-----	32, 400, 000

OPERATING COSTS

In addition to a wide range of opinion as to the near-term ship construction costs, there is also a difference of estimates on operating

costs. To illustrate the range of estimates and the possible future advantages of nuclear power, the following table was developed showing only the totals for operating costs that vary between oil-fired ships with nuclear ships. To simplify the presentation, operating costs assumed to be the same for both oil- and nuclear-powered ships have been omitted from this comparison. The item "Vessel expense" includes crew, maintenance and repair, shore staff, standby tug hire, conventional marine insurance, and so forth. The nuclear fuel cost of Government estimates reflects those set out in chapter III. The nuclear fuel estimate¹ in the industry estimate (col. 3) is that used by AEIL in its application to the Maritime Administration. Fuel oil is taken at \$2.30 per barrel, which reflects price fluctuation ranging from \$2.10 per barrel in New York to about \$2.50 per barrel in the Far East. These estimates are considered relatively stable since the price of oil in New York has not fluctuated materially since 1956. Since known oil reserves continue to expand, no price increase is seen in the foreseeable future.

This table also includes an oil-fired equivalent ship with which to compare the relative operating cost of the near- and long-term nuclear applications. This table does not include annual amortization and interest charges for the additional construction of the nuclear-powered ship in excess of that for the oil-fired counterpart. For simplification, all costs are at today's price levels.

Column 1. Shows an industry estimate (considered reasonable by the Government) of the annual operating cost of each of three equivalent oil-fired ships for either near- or long-term cost comparison.

Column 2. Shows the Government estimate of the annual operating cost of each of three nuclear ships built now (near term) over a 25-year period.

Column 3. Shows industry estimate of the annual operating cost of each of three nuclear ships built now (near term) over a 25-year period.

Column 4. Shows the long-term cost of each of three nuclear-powered ships built after completion of a land-based prototype development program and assumes the availability of low-cost nuclear fuel.

This table does not in any way reflect an operating differential subsidy as it is intended here to show a comparison of absolute costs.

COMPARISON OF SELECTED OPERATING EXPENSE FOR OIL AND NUCLEAR POWERED SHIPS

[Amounts in thousands]

	Near or long term, 1 of 3 oil fired (Government estimate)	Near term, 1 of 3 nuclear (Government estimate)	Near term, 1 of 3 nuclear (industry estimate)	Long term 2d generation nuclear (Gov- ernment estimate)
	(1)	(2)	(3)	(4)
Vessel expense ¹	\$1,100	\$2,000	\$1,750	\$1,400
Fuel.....	2,200	1,650	² 1,050	1,100
Total.....	3,300	3,650	2,800	2,500
Annual cost (greater than oil).....		350		
Annual cost (less than oil).....			500	800

¹ Does not include construction cost, amortization and interest charges or allowance for 3d party liability.

² Garmatz/Cotton waiver of use charge for 1st 5 years.

¹ These nuclear fuel estimates by reactor manufacturers for maritime reactors are covered in the NUS 265A, Summary Report, April 1966.

This table shows on a near term basis (col. 2) that if three nuclear ships are built, it will probably cost about \$1 million ($350,000 \times 3$) more to operate per year than three equivalent oil-fired ships.

In column 3, however, the estimates from industry sources on near-term nuclear application show, over a 25-year period, that the average annual cost for operating a group of three nuclear ships will be approximately \$1,500,000 less than three equivalent oil-fired ships. This variation is primarily due to a difference in Government and industry estimates as to the future costs of nuclear fuel. Industry has also taken a more optimistic view toward the size of the crew on a nuclear ship, and have not included training costs, and standby tug requirements.

Column 4 reflects Government estimates of the long-term advantage of nuclear power in the second generation of nuclear ships applying nuclear fuel cost goals which AEC hopes will be reached through a research and development program effort and reflects reduced operating costs that MarAd hopes to see develop during the operational period of near-term nuclear ships. Under these conditions, the annual operating cost of the nuclear ship is about \$800,000 (expressed in today's dollars) less than the equivalent oil-fired ship.

This saving will be reduced by the annual cost to finance the difference in construction cost between a nuclear ship and the oil-fired equivalent ship. The additional construction cost of a nuclear ship in the 105,000 shaft horsepower size is estimated to be in the range of \$7 to \$8 million. The annual cost to finance this investment is estimated to be from \$700,000 to \$800,000 per year which indicates that a nuclear ship has the prospects of being equal to or may have a slight advantage over the oil-fired equivalent ship.

These estimates are extremely sensitive to any change in the basic assumptions such as fuel costs, operating costs, and capital investment costs. For example, if the cost of nuclear fuel does not meet the target cost of 1.5 mills shaft horsepower per hour and costs 20 percent more, that is 1.8 mills shaft horsepower per hour, then the estimated savings in the annual operating costs would be reduced by approximately \$200,000 per year. Conversely, if nuclear fuel costs can be reduced to 1.3 mills shaft horsepower per hour, the nuclear ship will show a substantial advantage over the oil-fired ship. Likewise, plus or minus variations in operating cost or the reactor plant cost would have a similar effect on predicted savings. These estimates include current underwriters and Maritime Administration estimates of the increased premiums necessary for marine hull and machinery, and write out P. & I. insurance for a nuclear-powered ship. The estimate does not include any premium cost for third party nuclear liability insurance for the reason that such insurance for ships is not available. The *Savannah* is covered for third party liability by an extension of Price Anderson. Such extension is applicable only to the *Savannah*. See chapter VII for a more detailed statement on this issue.

This relative economical position of nuclear power as compared with oil is as reasonable as can be developed in view of the number of unresolved questions that surround the long-term construction and operating costs of nuclear powered ships in a fleet, starting approximately 10 to 15 years in the future. It is believed, however, that these assumptions are conservative and that after an extended period of proven

reliability with a near-term nuclear fleet, such items as insurance and maintenance and repair may be reduced below the assumptions made here for the second generation ships (long term). In view of these factors, it must be emphasized that estimates do not lend themselves to a meaningful prediction as to how long it will take to recover the nuclear entry cost. These estimates do, however, indicate a reasonable chance for their recovery if expectation of reduced nuclear fuel cost, construction, and operating cost can be realized, and if the predictions of future ship power requirements and world trade trends follow present indications. Any other cost reduction breakthroughs that the advanced reactor test program might develop would materially enhance the benefits of a nuclear program beyond present estimates.

The next application of nuclear power in our merchant marine should be in an environment favoring its use. This environment, developed in chapter I, envisions the development of integrated transportation systems which will require, in order to be most profitable, large, high-speed ships in a power range favorable to nuclear power.

At the present time the trade routes which present the most favorable atmosphere for containerization in a integrated transportation system concept precludes the use of one ship in order to provide the required sailing frequency.

It does seem probable that the requirements of these systems could be met with two, three, or four ships. The best developed proposal to date presented by AEIL is based upon the use of three ships in the United States to Far East trade.

Since it is contemplated to give all U.S. shipowners an opportunity to offer proposals to participate in this program, the range of possibilities has been extended to include a possible four-ship system. The eventual number of ships decided upon will depend ultimately upon the characteristics of trade route selected and the total "entry" cost to the Government.

The range of the total cost to the Government for the additional costs associated exclusively with nuclear power of a two-, three-, or four-ship program is as follows:

NUCLEAR ENTRY COST

[In millions of dollars]

Item	Number of ships		
	Col. 2	Col. 3	Col. 4
Ship construction cost ¹	34.0	54.0	72.0
Government administrative and design costs.....	9.0	9.4	9.8
Test facility and R. & D. program ²	100.0	100.0	100.0
Nuclear ship operating assistance ¹	22.5	27.5	30.0
Total.....	165.5	190.9	211.8
Round off.....	165.0	191.0	212.0

¹ This table does not include the usual construction subsidy for the equivalent oil-fired ship or the usual operating differential subsidy for a conventional ship. These costs will be in addition to those shown.

² This value is for a 10-year program. Included in this amount is the cost of the test facility and a 5-year research and development program is \$74,200,000 as shown in ch. IV.

CHAPTER III.—NUCLEAR PLANT COST

Although many uncertainties must be resolved before nuclear propulsion for civilian merchant ships will be economically feasible, some representative cost numbers and other related factors have been set forth for nuclear maritime plants on: (a) NS *Savannah*, (b) present PWR maritime technology, and (c) future PWR maritime objectives. These can be reviewed in order to present the growth and application potential of the nuclear plant.

NS "SAVANNAH"

The 1957 memorandum of understanding between the Chairman, Atomic Energy Commission, and the Secretary of Commerce agreed to a cooperative program including certain cost-sharing principles during the design, construction, and demonstration operation. As provided in this agreement, the "nuclear powerplant" was defined to include the "reactor" and "propulsion plant." The "reactor" was defined to mean "a nuclear heat source including a complete core, pressure vessel, coolant loops, shielding, and instrumentation immediately associated therewith." This also included the containment, foundations, and ventilation systems. The "propulsion plant" was defined to mean "all ship propulsion equipment except the reactor."

With the above clarification of terminology, the supplied reactor for the NS *Savannah* (excluding irradiations programs and supporting R. & D. efforts) resulted in the following initial expenses:

A. FUEL COSTS

Core I— $\$2.03 \times 10^6$.

B. CAPITAL COSTS

The following costs are the approximate breakdown for reactor fabrication and installation as defined above yet including the initial installation tests at the shipyard. Core I is listed separately above and not totaled in the following numbers:

"Reactor" (as defined)	\$8,670,000
Shipyard installation of "reactor"	8,770,000
Total	¹ 17,440,000

¹ This is part of the total AEC costs shown in ch. V.

C. OPERATING COSTS

Operation costs of the NS *Savannah* during the first 3 years following delivery included costs of crew training, plant design upgrading, public visitation, and evaluation of port operating criteria. The ves-

sel was delivered to a commercial shipping company on August 20, 1965, under a charter arrangement for service as a scheduled cargo carrier. Although the ship was not designed to be an efficient working cargo vessel, the costs associated with this recent phase of the *Savannah* program represent the most definitive data available for a nuclear commercial vessel. (See ch. V.) (Costs to be obtained by MarAd from FAST, Inc.)

OTHER NUCLEAR PLANT COSTS

The cost numbers presented here are representative in view of the uncertainties earlier mentioned in this chapter and chapter IV and since a specific nuclear plant has not been identified for a specific ship system.

A. CAPITAL COSTS

As discussed earlier, the terminology "nuclear powerplant" encompasses the "reactor" and the "propulsion plant." As shown below the cost of the "reactor" with conventional type acceptance, containment and the "propulsion plant" are installed costs including system tests (nondevelopmental tests) after installation. First plant costs and plants following the first are indicated with the assumption that the following plants are the identical design, from the same manufacturer, and installed by the same shipyard.

INSTALLED "NUCLEAR PROPULSION PLANT" COSTS

	NS Savannah	Present PWR maritime technology	Future PWR maritime objective
SHP	20-22,000	70-75,000 ¹ 105,000	70-75,000 105,000
Mwt	80	220	220
Core life (Efph)	15,600	25,000	37,500
Plant cost (\$×10 ⁶): ²			
First	33.9	24 30	(³) (³)
Follow		20 26	14 17-18

¹ Extrapolations in view of interest in larger sizes and does not include research and development costs or any requirements for test programs other than that normally provided by the industry or central station reactors.

² Prices do not include cost of reactor core which is normally considered an operating cost.

³ 1st plant planned as land test facility as provided in nuclear program of ch. IV and appendix.

B. OPERATING COSTS

(1) *Nuclear fuel cycle cost estimates.*—There may be seven or eight variables and/or assumptions made in determining the fuel cycle cost estimates; that is, fabrication cost, uranium cost, investment charges, spent fuel recovery cost, credit for discharged uranium and plutonium, plant factors, etc. This will vary from first core loadings to subsequent core loadings as charges for material and interest rates changes and the reactor core physics become definitely known. The following table is estimated to apply for civilian maritime applications at the power levels shown. These estimates are for the first core loading but can be assumed as applicable to subsequent core loadings. Improved economics may be achieved as a result of research and development altered economic conditions.

FUEL CYCLE COST ESTIMATES¹

Reactor	Fuel cycle mills/shaft horsepower- hour	Shaft horsepower	Design plant factor (percent) ²
Present PWR maritime technology-----	2.3	75,000-105,000	70
Future PWR maritime technology ³ -----	1.5	75,000-105,000	90

¹ Fuel costs do not include research and development costs, and are dependent upon the contractor that designs the core and provides the fuel, what other work is being conducted at the same contractor's plant, the interest rate, and those many considerations included in the design plant factor.

² Design plant factor is defined as ratio of hours of annual plant availability resulting from refueling, maintenance, repair, etc. to hours per year, as if plant were not shipborne.

³ Based upon demonstration in a test facility.

(2) *Maintenance and repair.*—Until the NS *Savannah* has been operating as a commercial cargo vessel for a longer time, it is not considered practicable to set forth a precise nuclear base of ship maintenance and repair costs. In addition, such operating and maintenance costs can be affected significantly by plant design, characteristics and concepts, extent of manufacturer's and shipbuilder's guarantees, and by the extent of spare parts included in basic plant estimates.

CHAPTER IV—NUCLEAR POWERPLANTS FOR MERCHANT SHIPS

INTRODUCTION

The use of pressurized water reactor plants is well established. The basic technology, including engineering and fabrication of current systems, is well known: water chemistry, fuel and cladding, heat flux and performance criteria, safety, control and instrumentation, reliability of components, maintenance problems, etc. Improvements in size and weight are desirable, although incentives from these improvements must be measured in terms of reduced costs.

Therefore, the main questions to be resolved relate to whether improved designs of PWR's specifically for the maritime application could indeed be achieved within the required performance, cost, reliability, and safety envelopes; and whether, if attained, these characteristics, plus potential improvements would be sufficient to assure reasonable economics for widespread merchant marine application.

Many manufacturers have expressed interest in developing and producing reactor plants for civilian maritime application. Recently, several manufacturers—Babcock & Wilcox, Combustion Engineering, Westinghouse, and United Nuclear—have forwarded unsolicited proposals for compact or integral pressurized water designs for maritime application. All have concluded that a compact plant type approach is required if the improved size and cost criteria are to be met. Although meaningful evaluations and comparisons of such unsolicited proposals are difficult, the technological differences among the pressurized water plant designs do not appear to be significant although the engineering designs may differ. These designs, considered as conceptual, were not in response to any government specific ship or reactor plant criteria and specifications, and there are probably many significant differences in the assumptions other than those which are readily identifiable in comparative tabulations. Furthermore, the companies consider that the details of these proposals are proprietary. The depth of detail made available in support of the proposals varied significantly.

A typical compact integral pressurized water reactor encloses the primary loop within the reactor pressure vessel—core and control rods, heat exchanger, and pumps—to provide the minimum volume to contain and shield. In general, core designs are typical of pressurized water reactors using slightly enriched oxide fuel clad with stainless steel or zirconium and utilizing burnable poisons distributed within the core. Water treatment is conventional. A number of the designs proposed once-through steam generators which are a departure from conventional pressurized water reactor steam generators. Containment is close to the reactor and is partially filled with water which provides both shielding and vapor suppression.

Although most of the technology exists to design integral pressurized water reactors, there are many of the major features which require development, experimental and engineering verification, including those features related to proof of fabrication, reliability, and maintainability of such an advanced plant. For example, in the integral plant design, the proximity of the various components near the reactor core will require extensive analysis and tests to insure proper component and shield location, adequate protection from radiation effects, and ability to maintain components and instrumentation. In addition, the potential advantages of the integral plant design may decrease as the rating of the reactor plant increases.

Continued reliability of the proposed reactor propulsion plant at full power operation will require demonstration, and a number of the performance characteristics coupled into economic incentives are considered to be more stringent than those which have been demanded from proven pressurized water reactor plant designs. Plant automation would be an important objective for achieving more economic nuclear ship operation. It must be anticipated that a number of technical areas related to automation, safety and licensing will require development efforts as widespread applications are considered.

The following projections represent a 5-year program to conduct research and development and to construct a test facility, that can be started in any subsequent fiscal year if a determination is made that such a program is justifiable. The total cost of the 5-year program would be approximately \$75 million which includes \$35 million for the land-based test facility.

A 5-YEAR PROGRAM

	1st	2d	3d	4th	5th
R. & D. program:					
PWR base program.....	5.0	6.0	6.0	10.0	10.0
Advanced systems.....	.2	.5	.5	.5	.5
Land-based test facility.....	3.0	32.0	0	0	0
Cooperative program.....	(1)	(1)	(1)	(1)	(1)

¹ The unknown nature of a cooperative program makes any estimate of funding uncertain at this time. It is expected that funds required by the AEC for reactor plants for the shipbuilding program will be included in the authorization and appropriations sponsored by the Department of Commerce.

SUMMARY

Current pressurized water plant technology can support a construction program. The economic satisfaction, however, of the long-term costs will require development and demonstration of advanced nuclear systems to answer many current unresolved issues affecting a satisfactory shipping system. These unresolved issues encompass cost sensitivities to manning, maintenance, operating aspects, installation, weight and space, and safety. Some of the factors which could affect these issues are plant layout, safeguards, reliability, core life, maintainability, quality assurance, specifications, plant automation, port criteria, public relations, and union attitude. The current AEC civilian maritime nuclear propulsion program (see app. I) is cognizant of these issues and has been discussed with the Bureau of the Budget and the Joint Committee on Atomic Energy.

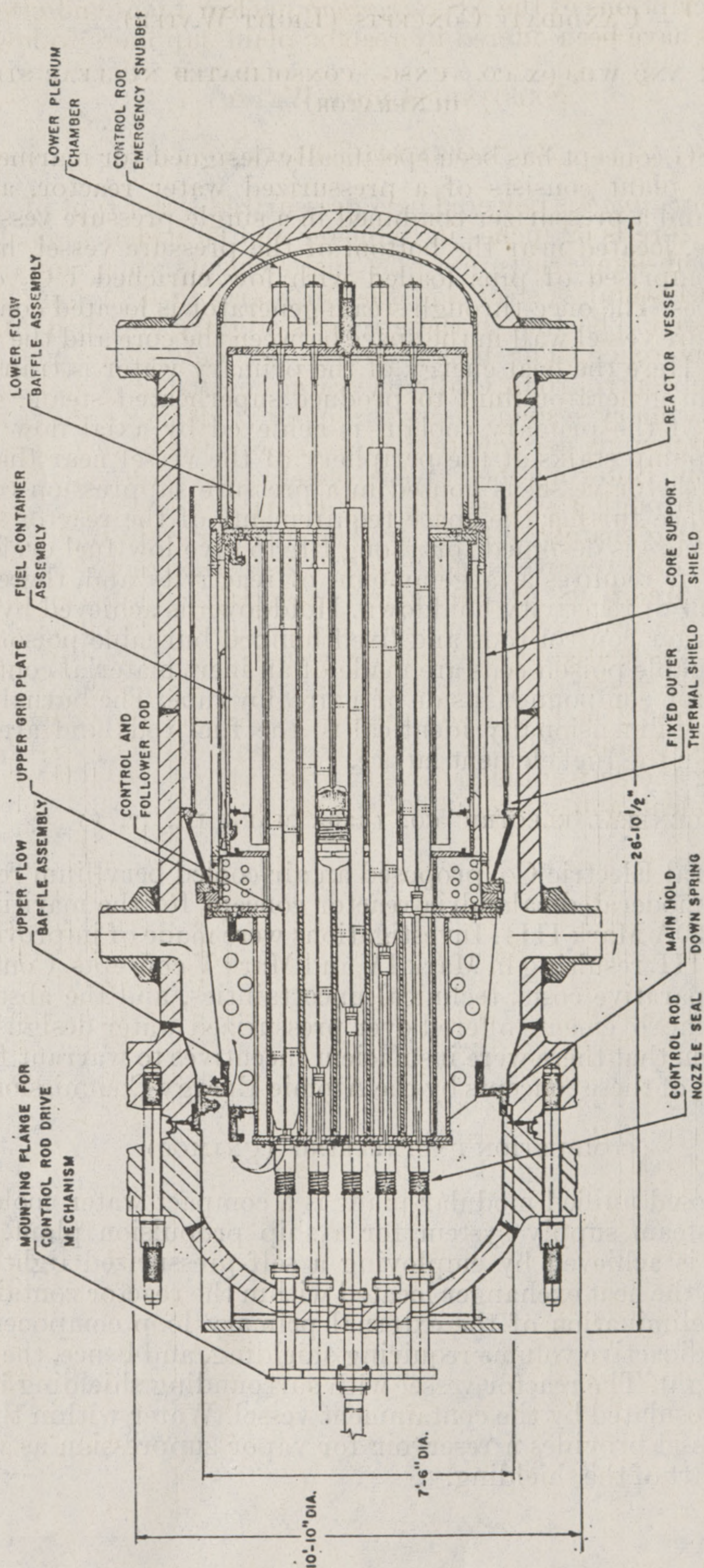
Brief descriptions of the NS *Savannah* nuclear plant and other concepts which have been offered by reactor plant suppliers follow:

EXISTING (LIGHT WATER)

NS "SAVANNAH" REACTOR

The NS *Savannah* is powered by a pressurized water type of reactor. The reactor core is 62 inches in diameter and 66 inches high. Within the honeycomb-like structure are 32 fuel elements, each containing a bundle of 164 stainless steel-clad fuel rods arranged in four bundles of 41 rods each. The fuel in these rods is slightly enriched (4.4 percent uranium oxide). The fission process is controlled by 21 boron stainless steel control rods. Ordinary water circulated in a closed loop called the "primary system" flows through the elements under a pressure of 1,750 pounds per square inch to remove the heat generated by atomic fission. Entering the reactor vessel at the bottom it heats up as it flows through the hot core and emerges from the top of the vessel at approximately 521° F. It then circulates through two heat exchangers which remove enough heat to keep the reactor at an average temperature of 508° F. Secondary water flows at a lower temperature around the heat exchanger tubes and being at a much lower pressure boils as it is heated by the primary water.

The pressure vessel enclosing the core, measure 25 feet 10½ inches in height, 8 feet 2 inches inside diameter and has a primary shield of steel and lead tank of water. The containment vessel of steel plate is 50.5 feet long and 35 feet diameter. The gross weight of the reactor system, containment, and shielding is 2,500 tons.



REACTOR VESSEL AND INTERNALS

CANDIDATE CONCEPTS (LIGHT WATER)

BABCOCK AND WILCOX CO. (CNSG—CONSOLIDATED NUCLEAR STEAM GENERATOR)

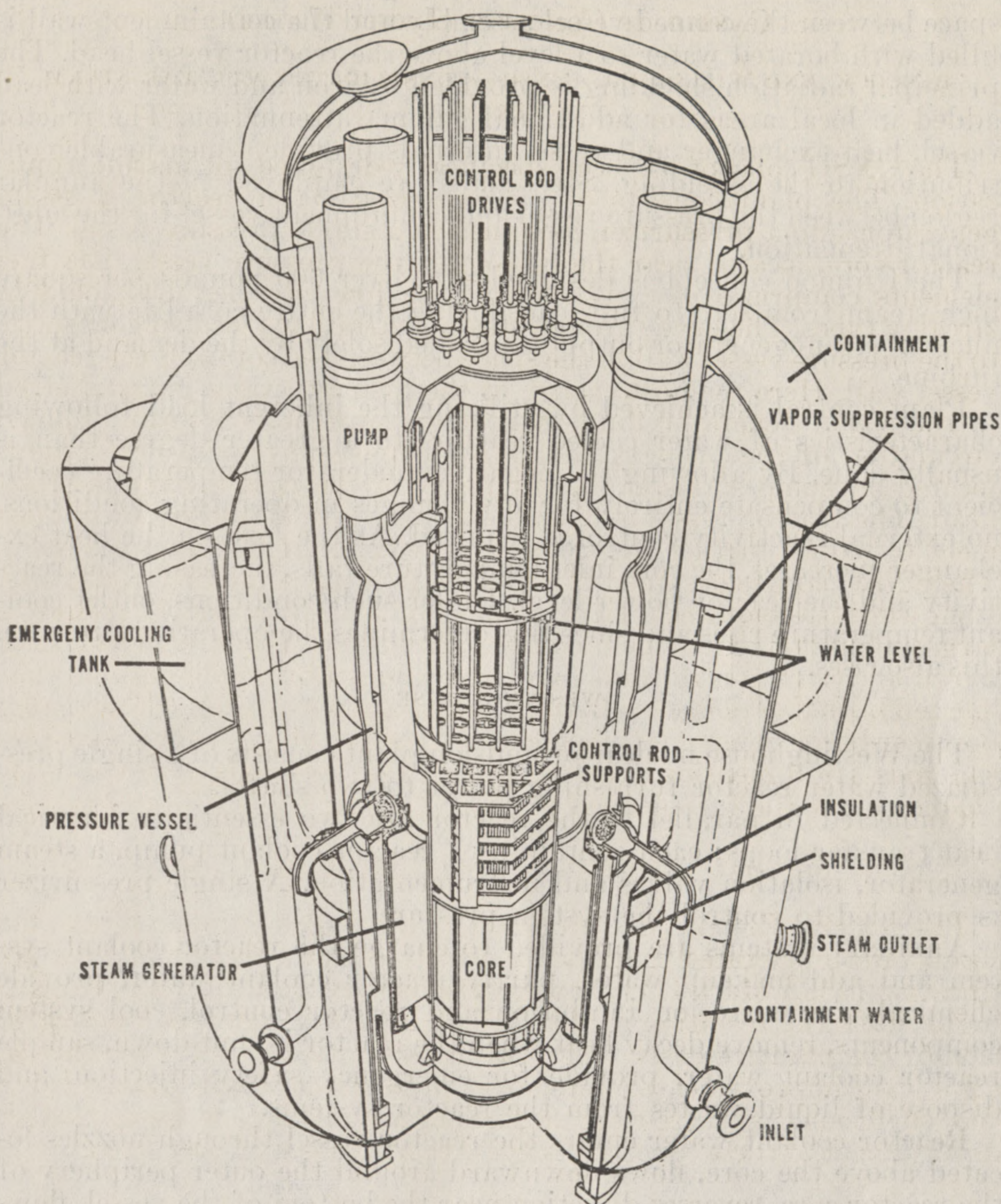
The CNSG concept has been specifically designed for marine application. The plant consists of a pressurized water reactor, a steam generator, and a pressurizer combined in a single pressure vessel. The reactor core, located near the bottom of the pressure vessel, has fuel elements comprised of pins loaded with low enriched UO_2 clad in zircaloy tubes. The once-through steam generator is located concentric to the pressure vessel wall in the space between the core and the reactor vessel wall. Here the heat energy of the primary water is transferred to the steam generator fluid to produce superheated steam. Forced circulation of the primary coolant is achieved by axial flow pumps located on pump stalks at the periphery of the vessel near the vessel head. The reactor vessel is housed in a pressure suppression containment to reduce further the space requirements of the reactor system. The CNSG core is designed for a long life to give low fuel cycle costs. Long core life requires a large amount of reactivity and, therefore, a large amount of reactivity holddown. Holddown is achieved by use of movable cluster control rods and fixed lumped burnable poisons. The lumped burnable poison rods are made of an inert material containing boron or boron compounds inside of a zircaloy tube. The burnable poison rods are dimensionally identical to the fuel rods and are interchangeable in the fuel element lattice.

GENERAL ELECTRIC CO. (630A MARK III, IV, V)

The General Electric Co. proposed an air-cooled beryllium reflected light water moderated calandria reactor concept for the maritime application (630A Mark III). Investigations were made of improvements in the Mark III, resulting in Mark IV and Mark V concepts. Consideration of comparative costs, technical uncertainties, and the absence of significant improvements offered over pressurized water designs led to the conclusion that there were insufficient incentives to warrant further development of these concepts by the Atomic Energy Commission.

COMBUSTION ENGINEERING (UNIMOD)

The proposed unified modular plant is a compact water cooled and moderated steam supply system for a ship propulsion plant. Plant compaction is achieved by employing a self-pressurized light water reactor with the heat exchanger located within the reactor containment vessel. The elimination of the external primary loop components reduces the radioactive volume requiring shielding, and hence, the shield size and weight. The reactor vessel with surrounding shielding is completely encapsulated by the containment vessel. Water within the containment vessel provides a reservoir for vapor suppression as well as providing part of the shielding.



CNSG REACTOR AND CONTAINMENT

The once-through heat exchanger is arranged along the inside periphery of the reactor vessel. It is comprised of six independent circumferential segments, any five of which will provide full steam flow. The core can be refueled without removal of the heat exchangers.

Primary water leaving the core flows upward to the steam dome, radially into the six heat exchanger segments where it makes a downward pass followed by an upward pass over the total length of the exchanger, into three down-comers located between each pair of heat exchanger segments, out through the three pumps, back into the reactor vessel, and down to the core inlet.

The reactor vessel is insulated inside the coaming which extends around the vessel, pumps, and the cold shutdown mechanisms. The

space between the canned vessel assembly and the containment wall is filled with borated water to a level above the reactor vessel head. The principal radiation shielding is provided by iron and water with lead added in local areas for additional gamma attenuation. The reactor vessel, heat exchanger and vessel internals provide a measurable contribution to the shielding. Steel slabs are employed in the annular region between the pressure vessel and containment vessel for the additional attenuation.

The Unimod concept is designed to deliver 600 pounds per square inch steam from zero to full load during the entire core life with the nuclear steam generator output controlled solely by the demand at the turbine.

Plant control is achieved by utilizing the inherent load following characteristics of water cooled reactors to a greater degree than is usually done. By allowing the negative moderator temperature coefficient to compensate entirely for any changes in operating conditions, no external reactivity control is required. As the load on the heat exchanger increases, the core inlet temperature falls, increasing the reactivity and the reactor power level. Under such conditions, outlet coolant temperature rises and since this determines the operating pressure, this also rises.

WESTINGHOUSE

The Westinghouse nuclear propulsion plant consists of a single pressurized water reactor furnishing power to two shafts.

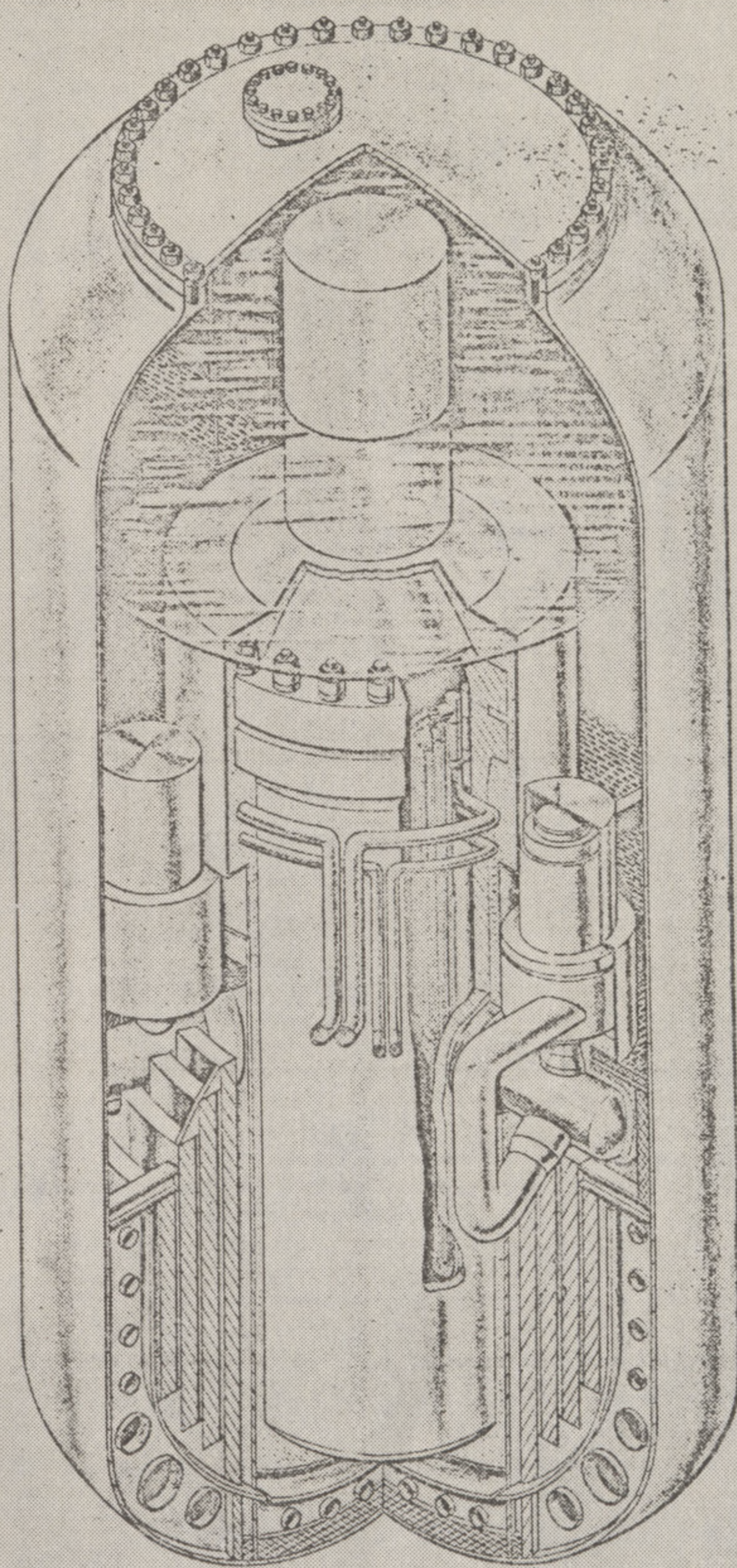
Connected in parallel to the reactor are two essentially identical heat transfer loops; each containing a reactor coolant pump, a steam generator, isolation valves and instrumentation. A single pressurizer is provided to control the system pressure.

Auxiliary systems are provided to charge the reactor coolant system and add makeup water, purify reactor coolant water, provide chemicals for corrosion inhibition and reactor control, cool system components, remove decay heat when the reactor is shut down, sample reactor coolant water, provide for emergency safety injection, and dispose of liquid wastes from the reactor systems.

Reactor coolant water enters the reactor vessel through nozzles located above the core, flows downward around the outer periphery of the reactor core, reverses direction near the bottom of the vessel, flows upward through the reactor core to remove heat generated by the nuclear chain reactor, and then leaves the vessel through nozzles located above the core.

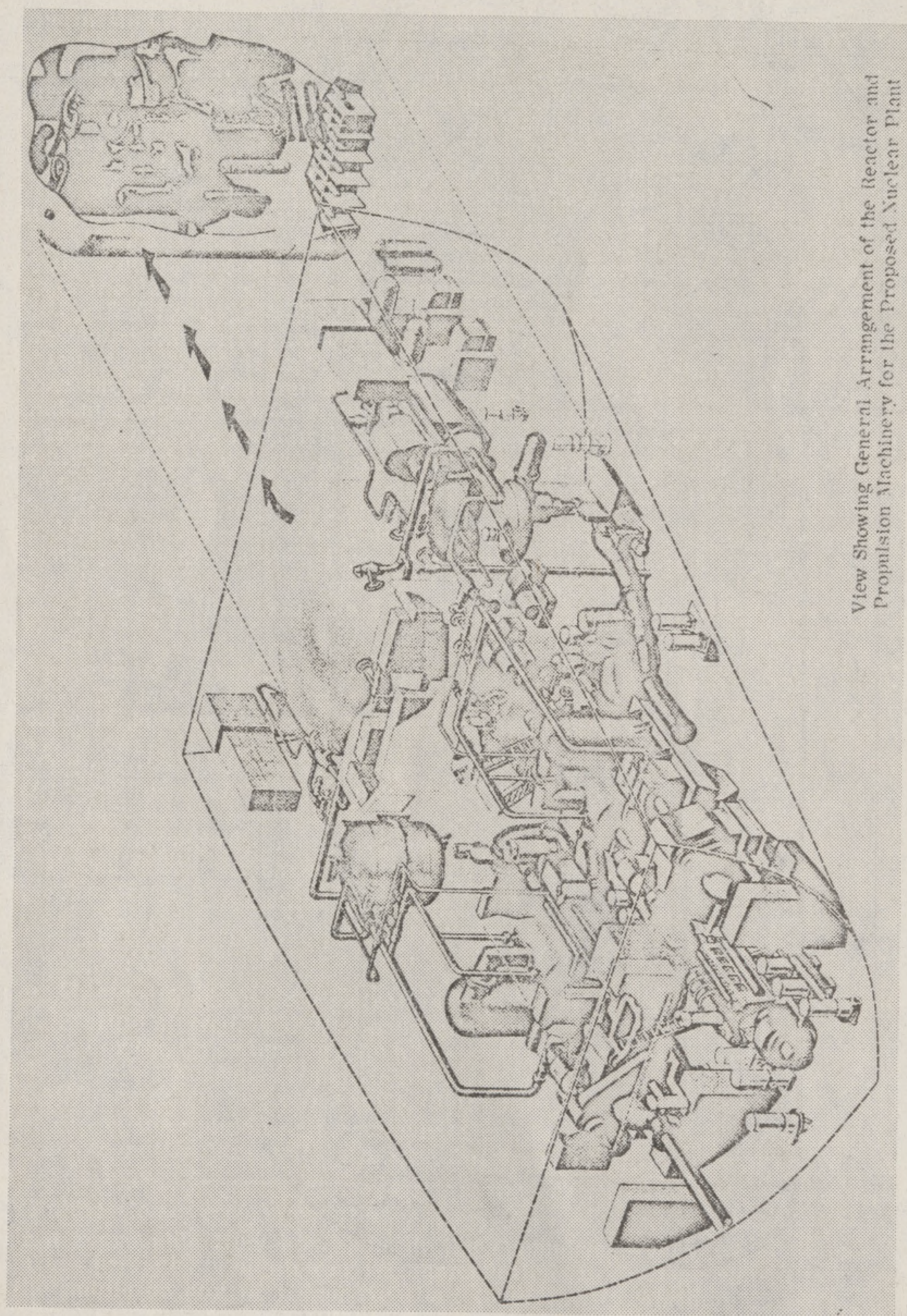
The reactor coolant system is located inside the plant container, a vertical cylindrical structure that forms an integral part of the ship's structure. It consists of an inner and an outer shell. The inner shell is reinforced concrete which acts as radiation shielding, and also protects the outer shell from thermal and mechanical shock.

The condensate and feed water cycle contains three stages of feed water heating and conventional deaeration. Each condenser has two main condensate pumps, with the second serving as a complete spare. There are three feed booster pumps and three main boiler feed pumps; the third pump, in both cases serving as a spare.



CONTAINMENT PACKAGE CUTAWAY

MARITIME REACTORS
UNIMOD LAND BASED PROTOTYPE
United States Atomic Energy Commission
COMBUSTION ENGINEERING, INC.



View Showing General Arrangement of the Reactor and Propulsion Machinery for the Proposed Nuclear Plant

In addition to the main propulsion engine there is a separate emergency propulsion system consisting of two 1,250 shaft horsepower electric propulsion motors and their associated starters. Each motor drives one of the main propulsion shafts through its main reduction gear. The large, standby diesel generator can be used to provide power for these two motors.

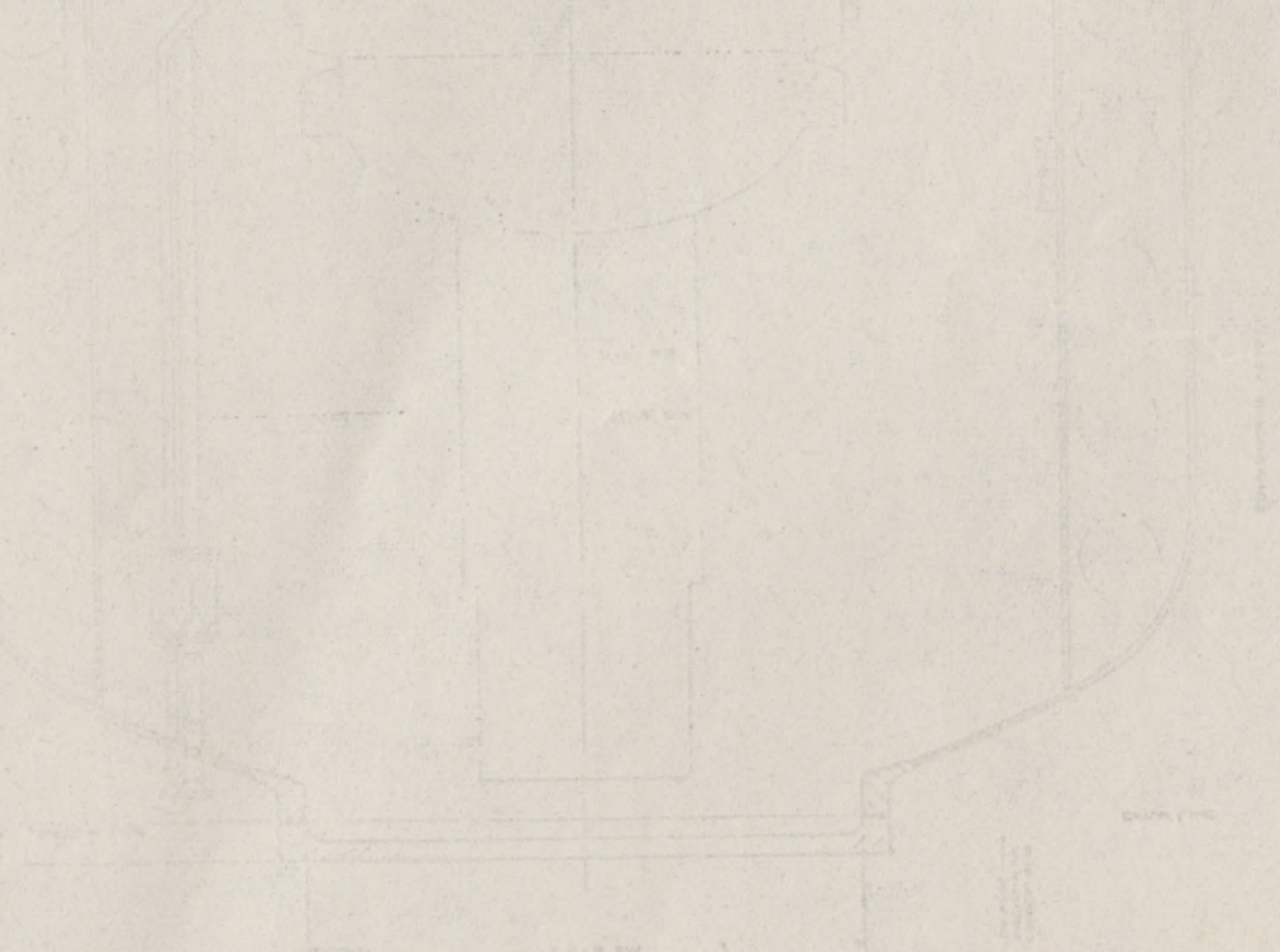
UNITED NUCLEAR CORP.

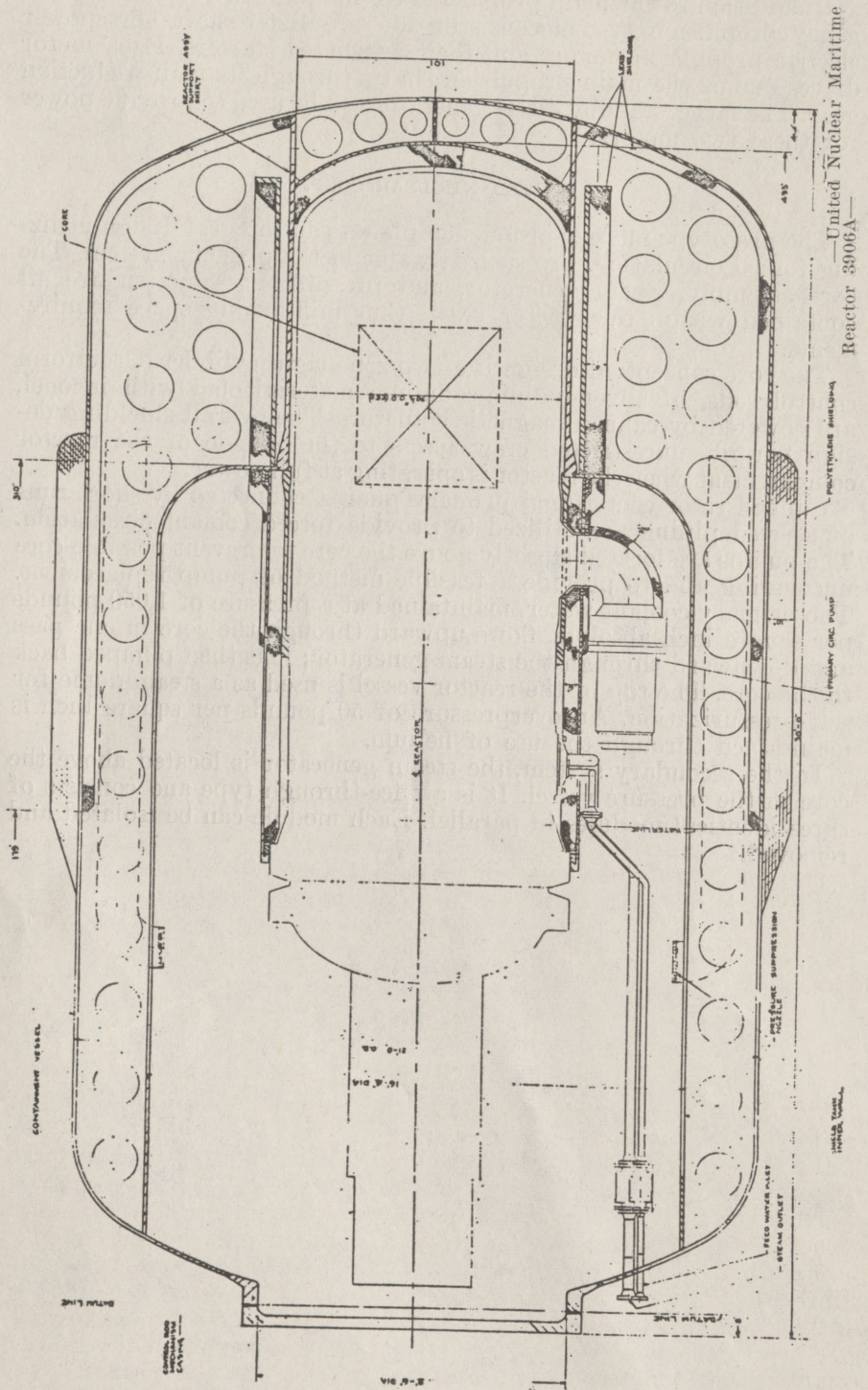
The prototype nuclear propulsion plant is an integral design utilizing forced circulation, pressurized water in the primary system. The core assembly, steam generator, and pressurizing function are all contained within the reactor vessel thus minimizing space requirements.

The core conceptual design is a two-zone right cylinder. Cruciform control rods, of silver-indium-cadmium material clad with inconel, are powered by canned magnetic actuators. The overall shielding design permits unrestricted crew access to the outside of the reactor compartment when the reactor is operating at full power.

Canned rotor centrifugal primary pumps, connected by short runs of sleeved piping are utilized to provide forced coolant circulation. The pumps are located slightly above the core to prevent possible core uncovering and to provide a feasible method of pump replacement. The primary coolant water, maintained at a pressure of 1,050 pounds per square inch absolute, flows upward through the core in one pass and downward through the steam generator; it is then pumped back to the core. The top of the reactor vessel is used as a steam dome for self-pressurization. An overpressure of 50 pounds per square inch is maintained through the use of helium.

In the secondary system, the steam generator is located above the core in the pressure vessel. It is a once-through type and consists of three identical modules in parallel. Each module can be isolated and removed.





CHAPTER V.—NS “SAVANNAH” EXPERIENCE

PROGRAM GOALS AT INCEPTION

The NS *Savannah* was built to demonstrate to the world the U.S. interest in peaceful applications of atomic energy while concurrently precipitating solutions to problems that would confront a second generation nuclear-powered merchant vessel. The program was designed to prove a nuclear reactor was a reliable, safe and practical heat source for merchant ship propulsion.

APPROVAL, DESIGN AND TESTING OF THE NS “SAVANNAH”

DESIGN AND CONSTRUCTION

The first nuclear-powered merchant ship was proposed in 1955. The Congress approved construction (Public Law 848, 84th Cong., sec. 716 of Merchant Marine Act, 1936, as amended) on July 30, 1956.

The keel was laid approximately 2 years later in May 1958. The ship was launched in July 1959 and the reactor powerplant achieved initial criticality on December 22, 1961. At this time only three central power stations were critical—Shippingport, Dresden, and Yankee. One unusual feature was the construction and installation of the reactor and reactor support system without benefit of prototype development.

TESTING

A thoroughly comprehensive test program was initiated for this first nuclear reactor powered ship to determine that all systems would perform as required. These included extensive dockside tests at reduced power, followed by incremental power increases at sea until full power (22,000 shaft horsepower) was achieved during sea trials on April 4, 1962, and the ship was accepted as completed by the U.S. Government on May 1, 1962.

DEMONSTRATION

From August 20, 1962, to March 1963, the NS *Savannah* visited 11 major ports on all three U.S. coasts and Hawaii. She traveled 30,722 miles in this first demonstration series.

In March of 1963 the vessel made her first call to the specially prepared nuclear servicing facility at Galveston, Tex. The maintenance period was to last about 2 months and was intended to permit some general system upgrading and repair work, in addition to completion of testing required for annual U.S. Coast Guard and American Bureau of Shipping certifications.

At the completion of the maintenance period, labor troubles with the crew developed and the general agency agreement with States Marine Lines was terminated. This was to delay the vessel's port visitation itinerary by 1 year.

In May 1964 the *Savannah*, now under general agency agreement to the American Export-Isbrandtsen Lines, began a series of foreign demonstration voyages to 12 foreign countries and 36 domestic and foreign ports.

In March 1965, the visitation phase of *Savannah* operation was brought to a close with a final public appearance at the home of her nuclear servicing facility in Galveston. She had traveled 89,818 miles, had been host to 1,389,780 visitors—foreign and domestic, had carried a total of some 848 passengers, and 4,799 tons of cargo. The operation had not been directed toward revenue, but she had earned \$385,550. Throughout the port visitations as carried out both States Marine Lines and American Export-Isbrandtsen Lines, the reliability and practicality of nuclear power were amply demonstrated. In all her underway cruising, nuclear power was available 99.8 percent of the time. The ship met all advanced schedules without a single plant failure. With records like these, even the most skeptical could agree that nuclear power had been proven safe, reliable, feasible, and practical for certain types of merchant ship propulsion.

COSTS OF THE "SAVANNAH" PROGRAM

The costs of the *Savannah* program were split between the Maritime Administration and the Atomic Energy Commission.

The approximate total costs to AEC and MarAd of the program up to August 20, 1965, when commercial operation commenced, were as follows:

	<i>In thousands</i>
(1) Construction costs of the ship delivered, including naval architect's fee for specifications and design; and also the reactor and power plant -----	\$50,392
(2) Facilities costs, including the servicing barge <i>Atomic Servant</i> , fuel shipping facilities, Galveston facilities, and film documentation--	2,499
(3) Operating costs, including States Marine Lines, American Export-Isbrandtsen Lines, technical maintenance-----	22,596
(4) Research and development-----	21,928
 Total Estimated Cost for AEC/MarAd <i>Savannah</i> program (AEC \$59,916; MarAd \$37,499)-----	 97,415

Future nuclear-powered ships will not need to be demonstration vessels and can thus avoid the high costs of passenger accommodation and the finish detail associated with it. Furthermore, these vessels will have the benefits of technology and precedents established by *Savannah* and the many stationary power station reactors that have since been put into commercial operation. It is anticipated that a much less rigorous testing program may possibly be adequate to establish the reliability and safety of the nuclear reactor and ship systems involved.

COMMERCIAL ADAPTABILITY OF THE "SAVANNAH" AND SUCCESSOR NUCLEAR MERCHANT SHIPS

NS "SAVANNAH"

The *Savannah* approximates the size of a conventional C-4 *Mariner* design that was developed in 1950 and whose general design has

become economically attractive to shipowners engaged in long trans-oceanic trade routes.

The *Mariner* type vessel accommodates about 750,000 cubic feet of bale capacity as compared to 652,000 on the *Savannah*. The difference in this cargo-carrying capacity can be attributed to several factors, but principally the extensive reactor compartment required to house the reactor and support systems. There has been a reduction in *Savannah* manpower requirements since the early demonstration voyages; however, there still remains about a 10-man crew differential as compared to a conventional powered vessel such as the *Mariner*. (See ch. VI for additional information on nuclear ship manning.)

In terms of commercial adaptability for future use, the NS *Savannah* could be modified in several areas to permit greater economic gains, and this concept is currently under review.

In comparison with the *Savannah*, future nuclear powered merchant ships should have the advantage of radically smaller and more compact powerplant designs that will occupy no more space than comparable fossil fuel fired heat exchangers. Accordingly, crew sizes should be reduced and comparable to those employed on fossil type mechanized vessels. (See ch. VI, Manning of Nuclear Merchant Ships.)

The *Savannah* was designed and constructed as a combination passenger and cargo vessel to demonstrate the peaceful application of nuclear power to the world at large and to concurrently precipitate solutions to problems that would likely be encountered by the second generation nuclear ship. These objectives have been attained. In order to implement an overall favorable economic environment for a nuclear ship, it will be necessary to consider full utilization of the latest ship mechanization technology.

"SAVANNAH" LABOR EXPERIENCES

STATES MARINE LINES GENERAL AGENCY AGREEMENT

The NS *Savannah* had a number of labor troubles during the period of the States Marine Lines general agency agreement, ending only with the termination of the agreement on May 17, 1963. The basic problem was the proper wage differential between the deck officers and the engineering officers. The deck officers were represented by the Masters, Mates, and Pilots (M.M. & P.) and the engineers by the Marine Engineers Beneficial Association (MEBA). In addition, States Marine Lines employed members of the American Radio Association (ARA) and National Maritime Union (NMU).

The troubles began with a demand by MEBA for wage schedules which placed the engineers above their traditional relationship with the deck officers union. This led to an impasse in bargaining and eventually to an arbitration award (known as the *Gellhorn* decision) to the M.M. & P., which set the wage schedule for deck officers on the *Savannah*, but also added a proviso that certain differentials should be maintained (e.g., captain \$200/month above earnings of the chief engineer) between certain other deck officers and their comparably ranked engineering officers.

The decision had the effect of making collective bargaining, in the usual sense of the word, impossible for States Marine Lines because the engineers refused to accept the differential imposed by the *Gellhorn* decision.

The *Savannah* continued to operate while the *Gellhorn* decision was tested in the courts and held legal. When all legal means of upsetting the decision and all means of negotiating a settlement acceptable to both M.M. & P. and MEBA were exhausted, the Government canceled the States Marine Lines general agency agreement on May 17, 1963.

AMERICAN EXPORT ISBRANDTSEN LINES GENERAL AGENCY AGREEMENT

On July 23, 1963, the Government signed a new general agency agreement with American Export Isbrandtsen Lines (AEIL). AEIL ships were manned by the NMU and its affiliate, the Brotherhood of Marine Officers, which includes both deck and engine officers.

Under the AEIL agreement all officers received special training. The ship has operated smoothly and strike free since the resumption of operations in May 1964.

The labor problems which beset the *Savannah* were due to inter-union relationships. The reactor engineers used their special nuclear reactor training as the rationale for demanding a smaller than traditional differential between deck and engineering officers, and the inter-union relations have prevented a reasonable settlement. The arbitration provisions of marine labor contracts provide only for arbitration between each individual union and shipping firms. There is no provision as a rule for arbitration for disputes which involve two or more unions on the same ship.

ACCOMPLISHMENTS OF THE "SAVANNAH" PROGRAM

The *Savannah* program was set up to demonstrate a practical and reliable peaceful use for atomic energy. The program has been extremely successful in meeting this goal. Ship operating and safety criteria have been developed to reflect acceptable limits for domestic and foreign operation. Close liaison has been established with domestic and foreign regulatory authorities in order to tailor the ship performance to meet the most stringent operating requirements.

PORT ENTRY PROCEDURES ESTABLISHED

The NS *Savannah* as of March 10, 1965, had visited 28 domestic ports and 18 foreign ports in 13 countries. Since commercial operation of the vessel was initiated in August of 1965, the vessel has completed six foreign voyages to Mediterranean and north European ports. Port operating criteria have been developed in conjunction with the U.S. Atomic Energy Commission and the regulatory agencies of foreign host governments. Port operating plans have been developed for all ports of call for the vessel and these are reviewed and approved by all interested agencies.

The pattern for foreign acceptance agreements has been worked out so that future nuclear powered merchant vessels may be required

to file only the usual commercial entry and clearance documents and follow the nuclear precautions negotiated for the *Savannah*.

SERVICE FACILITIES ESTABLISHED

Besides the usual shipyard drydocking facilities, nuclear ships require special equipment to handle the nuclear fuel. These facilities have been established at the Todd Shipyards in Galveston, Tex.

The service facility, established at a cost of approximately \$2.5 million, together with the *Savannah* technical staff, services only one ship, the NS *Savannah*. This servicing facility must be retained if the *Savannah* is to continue in operation. The same facility with only a few additional personnel could handle the nuclear servicing of at least six more nuclear ships. This assumes alternate annual servicing and refueling requirements.

RELIABILITY OF THE NUCLEAR PLANT ESTABLISHED

The *Savannah's* commercial operation has been routine to date, with no delay to her overall scheduling due to plant failure. She has had availability of power 100 percent of the time while under way. Repair and maintenance have been of the kind normally expected and of a routine nature.

The *Savannah* has had a full winter of operation on the Atlantic without incident, including one extremely violent storm, February 23 to 25, 1966, during the westward crossing on voyage 4. A part of the captain's report on this voyage is as follows:

Although the wind was blowing steadily from the northwest at forces 8 to 10 (approximately 60 to 65 knots) the swell and sea was not organized from any one direction. Swells and seas seemed to be coming from several directions at one time, it was impossible to stabilize the vessel by choosing any particular heading or by use of the rudder. The inclinometer reading was observed during some of the deeper rolls to reach approximately 38 degrees to the port and starboard were common and continued for a period of over an hour and a half. During this time neither the nuclear system nor the secondary system gave any indications that any adverse effects were being induced by the excessive vessel motion. With the exception of the resetting of the overflux scram trip point to 34 megawatts the engine department heavy weather precautions set forth in appendix A were fully implemented. The mere fact that *Savannah* survived through these tremendous swell heights and adverse weather conditions without a scram (automatic nuclear plant shutdown) occurring or even the secondary system tripping out was a welcome demonstration of the reliability of a nuclear system aboard the vessel.

Under such severe weather conditions as those described, conventionally powered ships have been known to lose all propulsive power due to excessive rolling and pitching. The performance of the *Savannah* powerplant has demonstrated reliability in weather as severe as will likely be encountered by merchant vessels anywhere in the world.

COMMERCIAL OPERATION SHOWN PRACTICAL

The NS *Savannah* entered into experimental commercial operation on August 20, 1965, under a Bareboat Charter Agreement between First Atomic Ship Transport, Inc. (FAST), a wholly owned subsidiary of American Export Isbrandtsen Lines, Inc., and the Maritime

Administration to operate on trade routes 5, 7, 8, 9, and 10 to north Europe and the Mediterranean. Such experimental commercial operation is provided for in section 715 of the Merchant Marine Act, 1936, as amended. The commercial phase is to establish that a nongovernment organization can muster the technical competence to operate a commercial nuclear ship and can obtain the required Atomic Energy Commission license.

By June 1966, prior to the *Savannah's* annual outage at Todd Shipyards in Galveston, Tex., she will have completed a total of six commercial voyages, three to north Europe and three to the Mediterranean, and will have traveled approximately 57,000 miles and burned 21 pounds of U^{235} . When combined with the demonstration operation, she will have traveled an overall total of approximately 147,000 miles, and burned 56 pounds of U^{235} . She will have earned approximately \$1.9 million in revenue; carried 31,000 tons of cargo, with cargo space utilization aboard amounting to 92 percent outbound and 50 percent inbound.

It has been estimated that the total deficit for the first year of commercial operation will amount to \$1,338,556. This is the difference between the anticipated cargo revenue and projected operating costs, and reflects the estimated cost to the Government during the first year of the experimental commercial operation under the Bareboat Charter.

As a financial incentive to FAST, the Bareboat Charter Agreement has been so prepared that any reduction in the total deficit, as a result of increased cargo revenue or reduced operating costs, will be equally shared by the Government and FAST up to an amount of \$400,000. Any additional deficit savings will be for the sole credit of the Government.

Conversely, expenses in excess of the postulated deficit of \$1,338,556 will be shared equally by FAST and the Government up to an amount of \$200,000. Thereafter, excess costs up to \$600,000 will be borne 75 percent by the Government and 25 percent by FAST.

Should the annual deficit increase beyond \$600,000, the entire balance will be fully borne by the Government.

UNRESOLVED SUBJECTS CONNECTED WITH THE "SAVANNAH" AND FUTURE NUCLEAR-POWERED SHIPS

LABOR RULES AND COMPENSATION

The difficulty which States Marine Lines encountered with labor unions between the engineers (MEBA) and the deck officers (M.M. & P.) was bypassed for the *Savannah* by transferring the ship to another general agent which operated with different unions. Almost all other U.S.-flag operators' ships are manned by the MEBA and M.M. & P. combination. The problem of compensation for deck versus engineering officers has never been resolved between MEBA and M.M. & P. and may prove to be impossible to resolve under ordinary collective bargaining procedures. It may be advisable to recommend specific legislation to deal with this issue at the same time that construction of the next group of nuclear ships is authorized.

INSURANCE AND INDEMNITY COVERAGE FOR THE "SAVANNAH" AND
SUCCESSOR SHIPS

There is as yet no commercial nuclear-energy liability coverage available for the *Savannah* as "financial protection" under the Price-Anderson Act (sec. 170, Atomic Energy Act of 1954, as amended). In connection with its licensing of First Atomic Ship Transport, Inc. (FAST), as the *Savannah* operator, in August 1965, the Atomic Energy Commission was informed by the Nuclear Energy Liability Association that consideration was being given to this problem.

Governmental indemnification for nuclear liability has been provided for the *Savannah* pursuant to section 170(1) of the Atomic Energy Act of 1954, as amended. This indemnification authority is limited to the *Savannah*. (For additional statement on indemnity, see ch. VII.)

Under the charter, FAST carries commercial marine protection and indemnity insurance in the amount of \$25 million, from which nuclear liability risks are excluded, although it would have been possible to obtain \$2,500,000 of marine P. & I. insurance which included nuclear coverage.

For the purpose of reducing operating expenses under the special charter covering the *Savannah* (under which the Government shares in certain costs and participates in financial gains), the Government assumed the marine hull insurance risks, and the war risk hull and protection and indemnity risks.

SUMMARY

The NS *Savannah* was built to demonstrate the safe, reliable, and practical peaceful use of atomic energy for merchant ships. It was also designed to be the pilot effort to initiate the resolution of problems of insurance, indemnification, port clearance, manning and public acceptance changes required to permit nuclear ships to move freely in the world's commercial channels. The demonstration phase of the program ended on August 20, 1965, when the NS *Savannah* was licensed and chartered to FAST.

The program has been costly, but most of the goals have been achieved. The ship has proved extremely reliable under all conditions. The public acceptance here and abroad of nuclear power has been enthusiastic. Future nuclear-powered ships will not encounter the type of economic and institutional problems which had to be overcome with the *Savannah* although all labor, insurance, and indemnity questions are not yet resolved.

CHAPTER VI.—MANNING OF NUCLEAR MERCHANT SHIPS

INTRODUCTION

Manning today's nuclear-powered merchant vessels is the same basic problem to labor, management, and Government as is that faced in manning mechanized fossil-fueled vessels. Acceptable manning scales that are consistent with the technology available for today's propulsion, navigation, and ship-handling systems must be developed.

An unfortunate aspect of the present nuclear merchant ship program is that the NS *Savannah*, while in her operational infancy, developed a labor problem that has remained unresolved to this day. Many people vividly recall the labor issues that beset the world's first nuclear-powered merchant ship on her first assignment. Fewer people are aware of the impressive achievements that have been made by the vessel and her crew since her reactivation in 1964. (See ch. V for more detail on the *Savannah* experiences.) Consideration should be given as to how these experiences can be best applied to the next generation of nuclear-powered merchant ships.

BACKGROUND

The cause of the major labor problem that beset the *Savannah* program was the previous lack of clear understanding on the part of labor, management, and various Government agencies as to the exact nature of manpower requirements that would be necessary to safely and successfully operate this vessel. Being a new concept and without comparable precedent, the proper manning compatible with operating requirements was not firmly established in sufficient time to permit careful review and consideration by all parties before the vessel was at or near completion. It was not possible to state what the anticipated minimum manpower requirements would be for (a) USCG certification, and (b) for union contract negotiations until after a review of the initial operation.

New ratings or designations were developed to provide the necessary disciplines required aboard the vessel. Tests were prepared and given to all prospective reactor operators as a requirement of the U.S. Atomic Energy Commission. Thus, a new regulatory agency with its requirements had imposed additional standards that had to be met by seagoing marine engineers. In addition, the senior deck officers were now required to display some proficiency of understanding as to the behavior and nature of this new type powerplant.

TRAINING

To date, under Government sponsorship, there have been at least nine separate training programs for *Savannah* engineering officers

and four programs for deck officers. The periods of instruction, from initial academic indoctrination to AEC licensing, have run from 5½ to 35 months and have included candidates whose academic training ranges from eighth grade elementary school to candidates for Ph. D. in nuclear engineering.

a. Engineering officers

On the basis of experience, the optimum combination of background and time for training of *Savannah* engineering officers appears to be as follows:

(1) A recent graduate of a maritime academy or one with equivalent knowledge, having between 1 and 2 years of active sea experience.

(2) A concentrated training period of about 16 weeks at the U.S. Merchant Marine Academy, followed by an additional 12 weeks of shipboard checkout. It should be emphasized that full utilization of an analog control console simulator is included in the initial 16-week program.

In terms of selection and required training of officers for second and subsequent generation ships, the criteria for officer selection should approximate that which has been proven to be best for a concentrated and abbreviated course of instruction related to the nuclear power-plant actually installed on the ship to be operated. The total time in training for Coast Guard licensed engineering officers, exclusive of first ship requirements, should be estimated at 24 weeks. Again, this will be dependent on the degree of proficiency that will be required to serve the mechanized features of the ship. If the "module replacement" maintenance philosophy dominates (i.e., replacing units from onboard spares, as necessary, and having damaged unit sent ashore for repair), it will tend to minimize the overall period of training required.

b. Deck officers

Selection and training of deck officers has also been varied. The range of time has gone from 4 months of academic training coupled with an additional 4 months of practical training to the present approach of several weeks of on-the-job training for junior officer replacements. In terms of future senior officer requirements, it is postulated that 4 to 6 weeks of concentrated effort at "preship delivery" time would suffice to permit the prospective senior officers to become acquainted with the ship arrangements, ship operating criteria, port operating criteria, safety requirements, and overall administrative requirements.

NS "SAVANNAH" MANNING

The NS *Savannah* is basically a conventional ship in which the reactor has been substituted for conventional boilers. From a manning standpoint, it is possible to consider all other portions of the engine-room, the turbines, gears, auxiliaries, and, indeed, the remainder of the ship, as comparable to a conventional ship of the same complexity.

In the original manning of the ship, dictates of regulatory bodies played a major role. The *Savannah* would have to build its own safety record. Constant checks of equipment, operating conditions, and of the crew itself, added to the workload. The ship would have to be manned

in port in a condition ready to move. Entirely new operating practices unique to this ship were instituted to insure maximum safety. New job categories appeared, unknown anywhere else in the fleet, such as water chemist, health physicist technician, nuclear adviser. The initial experimental operating period, with States Marine Lines as agent, saw an engineroom powerplant manning of 39 compared to approximately 18 for an equal power conventional-type, fossil-fueled plant, or approximately 11 for today's mechanized fossil-fueled plant.

It was recognized that experience would provide the opportunity to review the safety and operating requirements. Satisfactory performance would lead to reduction in workload and reduction in manning. Following the first phase of the experimental demonstration operation, and after the *Savannah* was transferred to American Export Isbrandtsen Lines, engineroom manning was reduced to 35. The demonstration period was continued with this manning level. At the end of this period, sufficient experience had been gained to completely reevaluate the workload created by safety requirements, and also to review the skill requirements of the specialized plant equipment on board. When the ship was chartered to First Atomic Ship Transport, Inc., for experimental commercial operation, powerplant manning was reduced to 26.

Deck and stewards department manning during these three periods varied to some degree as a function of whether the ship carried passengers (demonstration periods), and the stewards department was also influenced by the total manning assigned. Basically, however, deck and stewards department manning followed conventional ship patterns.

It can be expected that the *Savannah* engine department manning will be reduced even further as experience justifies combining special personnel requirements and revising existing operating procedures. Particularly noteworthy is the fact that the specialized tasks of the completely new ratings (water chemist, health physicist, etc.) have been reduced in requirements and demonstrated to be performable by other crew members.

FUTURE NUCLEAR SHIPS

Manning of the engine department on the next nuclear ship will be a function of three elements. The first of these is the degree to which technological advances in conventional powerplants are carried over into design of the nuclear plant. The second is the degree to which the safety and regulatory bodies are willing to carry over results of the *Savannah's* experience. The third would be the type of propulsion system and the characteristics of the reactor adopted for the next group of nuclear-powered ships as they relate to port operation, site criteria, and the need or lack of continuous mobility of the ships.

On the new conventional mechanized ships, owners are authorized by the U.S. Coast Guard to operate with a two-man engineroom watch. The Coast Guard has indicated they will review a request for a one-man watch, providing certain additional types of control equipment are added. In the meanwhile, technology is rapidly approaching the capability of operating conventional plants without 24-hour watchstanding attention. Control consoles incorporating plant self-monitoring and self-regulation features can provide hands-off adjustments

within preset operating ranges. Nonresponse of the plant triggers alarms to bring out the day-working maintenance crew.

Trends in total ship manning are toward incorporation of this maintenance crew into an overall maintenance department responsible for work throughout the ship. An engine department as such will be replaced by this maintenance department.

This trend in conventional powerplants finds certain advantages in the current state of nuclear plant design. The fact that the reactor must be operated remotely has led to use of sophisticated console equipment and considerable self-monitoring and self-correction even in the *Savannah*. While it is not practical to conjecture on the final manning structure, this advanced control feature, which has always been an essential element in nuclear power application, lends promise to ultimately achieving the same "no-watch" engine room that conventional power offers.

Safety and regulatory bodies may well become the controlling agencies in determining both powerplant manning and total ship manning for future nuclear ships. Operating requirements, such as special port watches, chemical analyses, radiation monitoring, which a safety agency may insist on, have importance in determining crew size. For the next flight of nuclear ships, the degree to which regulatory bodies permit designers to take advantage of the self-monitoring and self-regulating capabilities of the plant will be a major influence on manning requirements.

There is no need to discuss licensed or unlicensed personnel complements of the deck and the stewards departments since their basic responsibilities will remain the same on any type of modern ship regardless of the propulsion plant used. It is assumed that these billets will be manned in accordance with the standards presently under evaluation on the new mechanized ship. With the introduction of advanced navigation, communication, and ship-handling equipment, it is reasonable to expect that suitable reductions will be forthcoming in these areas on both nuclear- and fossil-fueled ships.

As a matter of fact, proposals now being made for construction and operation of nuclear-powered ships contain manning analyses which provide only one additional man, a health physicist/water chemist on the nuclear ship, compared to conventional counterparts.

WAGES FOR NUCLEAR SHIP CREWS

Wages and overtime pay for personnel employed on nuclear-powered vessels will be an integral part of the determination of the number of crew to be employed in accordance with the collective-bargaining agreement.

With regard to future wage scales for near-term nuclear-powered ships, it can only be postulated that premium pay may be sought by the personnel aboard these ships. It will be mandatory that mechanization and/or automation be fully utilized on future nuclear-powered ships if premium pay is to be considered.

SUMMARY

Approximately 8 years have elapsed since the first discussions were held about manning of a nuclear-powered merchant ship. During this

period, manning scales, job descriptions, and wage scales have been developed to satisfy every interested regulatory agency, labor organization, and sponsor, both in the United States and, in some instances, abroad.

New, rigid standards of safety for nuclear merchant ships have been established and achieved as mandatory operating conditions.

Much has been learned about manning of nuclear-powered merchant ships, including selection of prospective officer candidates, training, licensing, disposition, capability, and habitability questions associated with complex environs.

A new and vigorous approach to ship mechanization was being developed by counterparts involved in the construction and operation of conventional fossil-fired vessels at the same time that the *Savannah* manning was being worked out.

Although there are many areas that will require definition on the part of the regulatory agencies, there is adequate precedent for the development of an acceptable manning scale consistent with the required objectives.

The ability to train licensed officers in the disciplines that will be required has been demonstrated on both the mechanized and nuclear-type vessels currently in service.

There remains the unresolved and potential utilization problems of seagoing personnel that are affiliated with labor unions under contract to the majority of American-flag shipowners. This question requires immediate attention and resolution in order that all major U.S. steamship companies will be free to consider adding high-speed, nuclear-powered, commercially competitive vessels to their fleet.

It would be premature to positively identify the specific manning requirements of a nuclear vessel or to assign a specific dollar value to the wages that might be involved; however, it is justifiable to assume that the numbers involved should be competitive with present-day and future manning requirements as they apply to new mechanized fossil-fueled ships.

Prior to entering into a contract to construct any near-term nuclear-powered ship, it will be necessary for labor, management, and the Government to consolidate efforts and develop the precedents and procedures to properly staff such a ship.

CHAPTER VII.—SAFETY, LICENSING, AND INDEMNIFICATION

INTRODUCTION

In the construction and operation of any ship, due cognizance must be taken of the considerations of safety, licensing, and indemnification. With nuclear ships some not-so-familiar requirements must be faced. Any nuclear powerplant, if improperly designed or operated, could result in the accidental release of radioactive fission products which could cause hazards to living organisms in the vicinity of the plant. Widespread use of nuclear power to generate electricity, in this country and abroad, is testimony, however, to the general belief that, through proper design and operating practices, any hazards associated with nuclear powerplant operation can be reduced to acceptable levels. Up to this time, there has not been a single radiation accident resulting in a lost-time injury in a licensed U.S. power reactor facility. Further, as discussed in greater detail below, the nuclear ship *Savannah* has now operated in and out of some of the busiest ports of the world and has gained widespread acceptance by the host governments.

The following paragraphs delineate the safety, licensing, and indemnification problems that will be encountered in the construction and operation of a nuclear merchant fleet. These problems are significant in their technical difficulty and in their economic impact.

SUMMARY

Experience with the NS *Savannah* has proved that nuclear ships can be operated safely and the required licenses can be obtained. No member of the public or the *Savannah's* crew has received any exposure to radiation sufficient to cause a measurable health detriment as a result of NS *Savannah* operations. Advances in the design technology and accident-prevention control can be expected to keep abreast of larger plants and growth in number of ships.

The prospects for, and the need of extending some form of Government-sponsored indemnification to nuclear ships should be further explored.

NS "SAVANNAH" EXPERIENCE—HIGHLIGHTS RELATED TO SAFETY AND LICENSING

Shortly after the NS *Savannah* program was initiated, in 1956, the Babcock & Wilcox Co. was selected as the supplier of the nuclear powerplant. Reactors in operation at that time were either small, located at a remote site, or were in the military program—the Shippingport and Dresden reactors were still under construction.

Before the *Savannah's* containment vessel was built it was assumed that its leak rate at 30 pounds per square inch gage would be less than

0.2 percent of the contained volume per day. Early tests, at least on one occasion, showed leak rates over 10 percent per day. After considerable modification of penetrations, a leak rate of about 0.7 percent per day at 60 pounds per square inch gage can be demonstrated at any time today. This is substantially lower than the approved technical specifications of 1.2 percent per day at 60 pounds per square inch gage.

Today when the reactor is operating, the compartment is always maintained at a negative pressure and all air exhausted from the compartment is filtered through a sophisticated six-stage filter designed to remove particulate matter and radioactive halogen gases that could leak from the containment vessel after a major accident. A dual-fan, dual-filter system which can be powered by the emergency power system guarantees system dependability.

Originally, the only propulsion equipment other than main plant permanently installed was a nonreversible, low-starting torque, take-home motor. Its only intended purpose was for return of the ship to port in case of a loss of power. That take-home motor has been upgraded and now has a high-starting torque, is reversible, and has been demonstrated to be capable of moving the ship clear of its pier.

System modifications and operating principles of the *Savannah* are rigidly controlled by documents approved by the AEC regulatory staff. These are the technical specifications and the port operation criteria. The technical specifications serve to assure that plant equipment is maintained and operated in a safe manner. The port operation criteria specify the procedures that must be followed in bringing the ship into densely populated port areas.

Prior to August 1965, the NS *Savannah* was operated under the demonstration program by the AEC-Maritime Administration Joint Group. Such operation was authorized, from the safety viewpoint, by various AEC memorandums and authorizations, the U.S. Coast Guard, the American Bureau of Shipping, and the U.S. Public Health Service. Since August 1965, the *Savannah* has been operated commercially under Bareboat Charter by First Atomic Ship Transport Inc. (FAST), under AEC operating license NS-1 and appropriate authorizations by other regulatory bodies.

Since initial sea trials in March 1962, the *Savannah* has visited 55 ports in 14 countries. The only port that has denied entrance to the *Savannah* is Istanbul, Turkey. That denial is considered the result of political and not technical considerations.

Today the ship operates commercially in and out of many ports in the world. On the basis of *Savannah* experience, it appears that future nuclear ships can operate safely and receive the required licenses.

ACCIDENT CONSEQUENCE CONTROL ON FUTURE SHIPS

It appears likely that future nuclear ships may have higher horsepower plants than does the NS *Savannah*. Strides made in the technology of accident prevention and control since the *Savannah* was designed and built are expected to offset any associated increase in potential hazards. Pressure-reduction systems integral to containment-

vessel designs may prevent high pressures in the containment vessel after a major primary system rupture. This concept is now in use at the Humboldt Bay electric powerplant. Seals now are used in electrical containment penetrations which permit virtually zero leakage.

On a future ship design, the designer would have a full appreciation for the value of the reactor compartment and exhaust system as an engineered safeguard. The compartment and its exhaust system can be designed to afford maximum integrity and reliability.

Experience with the *Savannah* has shown the value of including an auxiliary propulsion system. It is desirable for ultimate safety of the ship and possible port operations to have an adequate auxiliary power source.

AEC LICENSING OF FUTURE SHIPS

At present in addition to a construction permit, an operating license is required by the AEC for all reactors. The nature of this license and requirements therefore are described in part 50, title 10 of the Code of Federal Regulations. Briefly, the major requirements for such a license are the submittal and acceptance of a thorough analysis of the plant features and the plant operating procedures. The analysis must show that the plant can be operated as proposed without undue hazard to the health and safety of the public. Such licenses have been issued to the *Savannah*, to about 20 nuclear electric powerplants, and to several score of small reactor facilities.

SOLAS CONVENTION REQUIREMENTS

In May and June of 1960, an International Convention for the Safety of Life at Sea (SOLAS) met in London, England. At that convention representatives of the United States and 39 other governments agreed upon certain regulations related to safety of life at sea. The regulations adopted were transmitted to the Senate in the President's message to the Senate dated April 27, 1961. The resulting treaty was ratified by the U.S. Senate on April 12, 1962, and became effective May 26, 1965. Chapter VIII of those regulations applies specifically to nuclear ships. All other chapters apply to both nuclear and conventional ships. The regulations prescribe a ship safety certificate for nuclear ships. A 1960 SOLAS Convention safety certificate was issued to the *Savannah* on July 1, 1965.

Generally, the regulations of chapter VIII of the SOLAS Convention do not result in requirements over and above those already made by the U.S. Coast Guard and the Atomic Energy Commission. Chapter VIII of the SOLAS Convention requires that a document entitled "Safety Assessment" be prepared and submitted to those countries where the ship is engaged in international commerce.

REGULATIONS AFFECTING MANNING

Manning of future nuclear ships will be determined by economic considerations, labor union policies, U.S. Coast Guard regulations, and AEC regulations. All but the latter are common to both nuclear and conventional ships and therefore will not be discussed here. Pertinent AEC regulations include the following:

AEC regulations contained in 10 CFR 50.54 (i), (j), (k), (l), and (m) require that—

(1) Reactors must be operated only by licensed reactor operators.

(2) Individuals designated to direct the licensed activities of licensed reactor operators must be licensed as senior reactor operators.

(3) A licensed operator or senior operator must be present at the controls of the reactor at all times during operation of the facility. AEC regulations contained in 10 CFR 20 set forth standards for protection against radiation exposure. While these standards do not include specific manning requirements, they make it necessary that personnel with health physics training be available. These personnel assume responsibility for preventing the occurrence of radiation exposures, managing activities subsequent to any inadvertent releases of radioactive materials and maintaining records.

REFUELING—SAFETY AND LICENSING CONSIDERATIONS

The NS *Savannah* has not yet been refueled. A number of naval reactors and a number of electric-power-producing reactors have been refueled. Therefore, the technology is understood; it is believed that refueling can be performed safely; and electric power nuclear plants have been licensed for such activities. Equipment and facilities have been provided at Galveston, Tex., for refueling the *Savannah* and it is planned that this facility will be licensed to conduct refueling activities many years before any future ships will be ready for refueling.

It is foreseeable that future nuclear ships can be refueled at the same Galveston facility with only minor modifications to the facility being required.

NUCLEAR INDEMNIFICATION—THIRD PARTY LIABILITY

Essential to any program for construction and operation of nuclear ships will be adequate financial protection against nuclear incidents in the form of insurance or governmental protection or both. New legislation would be required to provide governmental indemnification. In considering new legislation, it would be important to give thought to the terms and conditions which might be imposed by ports outside the United States for the entry of foreign nuclear ships.

Nuclear indemnity protection against liability incident to the design, development, construction, operation, repair, and maintenance or use of the NS *Savannah* was authorized under special amendment to the Price-Anderson Act (sec. 170(1) of the Atomic Energy Act of 1954, as amended (72 Stat. 525)). The application to the *Savannah* of the Price-Anderson indemnity concept (originally designed for land-based reactors in the United States) was not considered a precedent for future nuclear ships. The Joint Committee on Atomic Energy indicated in its report that they were recommending the extension of Price-Anderson to cover the *Savannah* because of possible roadblocks in the ship's operation and to provide adequate protection to the public.

Under the Atomic Energy Act (sec. 170(1)), the Atomic Energy Commission is authorized to enter into an agreement of indemnification with any person engaged in the design, development, construction, operation, repair, and maintenance or use of the *Savannah*, indemnifying that person, and any other person who may be legally liable, in the amount of \$500 million for each nuclear incident. The Commission is also authorized to require financial protection of such type and amount as it may deem appropriate. The Government indemnity would apply above the amount of financial protection; however, the \$500 million would be reduced by the amount that the financial protection exceeds \$60 million. The act does not prescribe the basis for legal liability, leaving such determination to local law. For this reason, considerable difficulty is being experienced in gaining acceptance of the *Savannah* in foreign countries unless local law provides a system of absolute liability in the case of nuclear ships.

Pursuant to the act, the Atomic Energy Commission entered into an agreement with the Maritime Administration for purposes of the demonstration program of the *Savannah*. No underlying financial protection was required or available. With the inception of private commercial operation by First Atomic Ship Transport, Inc. (FAST), the Atomic Energy Commission entered into an agreement of indemnification with FAST when that company was licensed as operator of the *Savannah*. The Commission has not, thus far, required FAST to provide financial protection pending the availability of the terms and the cost of nuclear liability insurance that might be provided by the insurance industry. It is understood, however, that commercial underwriters are giving consideration to providing nuclear liability coverage. The prospects of such coverage should be further explored, and an examination should be made of the possible continuing need for some form of complete governmental indemnification.

The need for governmental indemnification in a program involving maritime reactors is analogous to the need for such indemnification in the development of land-based reactors, which resulted in the enactment of the Price-Anderson Act. As stated in a study by the Atomic Energy Commission (published June 1965), the Congress had two principal objectives in adopting the indemnity provisions of the Price-Anderson Act, namely, (1) to assure the availability of funds to satisfy public liability claims in the event of a catastrophic nuclear accident; and (2) to remove the deterrent to industrial activity in atomic energy presented by the threat of enormous liability claims if such an accident were to occur. It is apparent that a similar and substantial deterrent exists in the field of maritime reactors.

The Maritime Administration is conducting a study of feasible alternative solutions.

CHAPTER VIII.—DEFENSE CONSIDERATIONS FOR NUCLEAR MERCHANT SHIPS

The Department of Defense supports maintenance of a U.S.-flag merchant marine of sufficient size to meet national defense sealift requirements.

DOD believes that the high speed, endurance, and logistic freedom of nuclear-powered cargo ships would be beneficial in some military situations. It appears, however, that cargo vessels equipped with currently proposed nuclear propulsion plants will be considerably more expensive to build and operate than conventionally powered ships. Accordingly, it is unlikely that many such ships would be built without a large added subsidy. We continue to be interested in developments which would reduce our overall sealift costs and which would contribute to a more viable merchant marine. We would therefore encourage the development of an economical nuclear powerplant for merchant ship installation which would make these ships cost competitive with conventionally powered cargo vessels.

In the near term, new concepts in cargo handling which offer the potential of major reductions in loading and unloading time are more important to DOD than improvements in cargo-ship endurance and speed. We cannot at this time endorse a large added subsidy for nuclear propulsion in cargo liners based on the military advantages which might accrue.

Reasons for DOD interest in more rapid cargo handling and greater speed are:

- Reduction of cargo delivery time.

- Reduction or possible elimination of overseas prepositioning requirements.

- Reduction of ship vulnerability and exposure in a hostile environment.

- Reduction in the number of ships requiring convoy protection in a hostile environment.

Ship- and cargo-handling speed can be improved without utilizing nuclear propulsion. However, use of nuclear propulsion, contributing long endurance at high speed, would probably result in greater overall improvement.

An active merchant marine nuclear propulsion program would encourage greater industrial participation in the field and should broaden the technological base.

CHAPTER IX.—FOREIGN MARITIME NUCLEAR POWER PROGRAMS

BELGIUM

The Belgian Belgonucleaire Co., in cooperation with the United Kingdom Atomic Energy Authority and the Belgian Centre d'Etude de l'Energie Nucleaire (CEN) at Mol, has undertaken a study of ship propulsion reactors in a project called Vulcain. The name is derived from the fact that the Vulcain syndicate was formed in 1959 from 30 Belgian companies to finance the detailed design study of a spectral shift reactor concept. Publication of a favorable report in 1962 led to the conclusion of an agreement for collaboration between the United Kingdom and AEA and the Vulcain syndicate.

The aim of the agreement is to carry the development work on the reactor through to the stage of design suitable for industrial application. Design work is being done both in England and Belgium; and experimental work, at the Mol center.

Although the United Kingdom Government decided in 1965 to postpone the construction of a nuclear propelled merchant ship, the British are continuing their cooperation with the Belgians in research and development work on this concept.

FEDERAL REPUBLIC OF GERMANY

A 38-megawatt-ton pressurized water reactor built by Arbeitsgemeinschaft Babcock/Interatom will provide power for the first German nuclear ship, a 15,000-ton bulk carrier named the *Otto Hahn*. The ship hull was launched in mid-1964 and completion is now scheduled for 1967.

In 1965, the United States entered into an arrangement with Gesellschaft fuer Kernenergieverwertung in Schiffbau und Schifffahrt m.b.H. (GKSS), a nonprofit company supported by the German Government, which is responsible for the construction and operation of the ship. Under this arrangement, the Atomic Energy Commission will lease fuel for the first core of the *Otto Hahn* and provide information on the NS *Savannah*, and in return will receive detailed information on the *Otto Hahn* project. The *Otto Hahn* will probably be the world's second nuclear-propelled merchant ship.

The \$12.5 million project is being financed by a \$8.5 million contribution from the West German Government and a \$4 million Euratom contribution toward the construction of the reactor.

ITALY

A marine nuclear propulsion study on a pressurized water reactor plant is being carried out in association with the Italian Fiat Co. and ANSALDO (shipbuilders of Genoa). There is also a contract between

the Italian AEC (CNEN) and these two firms, and with Euratom. The firms are supplying about 60 percent of the funds and Euratom about 40 percent. The study has been in progress since 1962, and present arrangements provide for its continuation to 1967 with a total cost of \$5 to \$7 million. Plans at present call for the construction of a 53,000-ton tanker, the powerplant of which would consist of a pressurized water reactor capable of developing 25,000 shaft horsepower. Both the Italian Navy and Italian shipping companies have expressed interest, but in the absence of either definite plans or available funds, the future of the project is uncertain.

JAPAN

The Japanese Ministry of Transportation and the Nuclear-Powered Ship Research Association (a private industrial group) began studies on a nuclear-powered ship in 1957. As a result of these studies and the recommendations of the Japanese AEC's Atomic Ship Committee, the Japan Nuclear Ship Development Agency (JNSDA) was established in June 1963 for the purpose of designing and building a small (6,700 ton) nuclear-powered oceanographic ship. A 35 megawatts ton light water moderated and cooled, indirect cycle reactor was selected for use in the ship, which was originally scheduled for completion in 1968. However, financial problems connected with its construction have resulted in a decision to delay the start of construction at least until fiscal year 1967. Originally planned as an all-Japanese project, indications now are that the Government leans toward U.S. industry equipment.

THE NETHERLANDS

The Reactor Centrum Nederland (RCN), the Dutch National Reactor Center located at Petten, is the major nuclear research laboratory in the Netherlands. Activities there are largely concentrated on the development of a 60 megawatts ton pressured water reactor for ship propulsion. The work is being carried out under an association contract with Euratom.

A detailed reference design for a prototype marine reactor has been completed, and funds have been requested to begin the construction of a land-based prototype pressurized water reactor. The Dutch Government is expected to hand down a decision in 1966.

NORWAY

A Norwegian nuclear-propelled bulk carrier project was accepted by the European Nuclear Agency for a joint European evaluation study in 1961. After submission of the study in April 1962, it was decided, late in 1962, to postpone further joint European nuclear propulsion efforts. Concurrently, the Norwegian Institute for Atomenergi, the Norwegian national atomic energy research organization, in an effort jointly supported by Norwegian and Swedish industry, has worked on the design of a 27,000 shaft horsepower ship reactor for a 67,000-ton bulk carrier. However, it has recently been reported that Swedish interests have been withdrawn from the project at this time. The Norwegians have not yet made a decision as to the future of the program.

SOVIET UNION

The U.S.S.R. built and placed in service in December 1959 the nuclear-powered icebreaker *Lenin*, the first nuclear surface ship in the world. Powered by three nuclear reactors and developing a total ship horsepower of 44,000, the 16,000-displacement-ton *Lenin* has successfully completed six navigation seasons in the Arctic.

At the 1964 Geneva Conference, the Soviet Union announced construction of two additional nuclear icebreakers to be in service by 1971. The new ships are reported to be improved nuclear designs to the *Lenin* and will have two reactors each instead of three. Pressurized water-type reactors will be used. The Soviet AEC Chairman Petro-syants stated that the "creation of a nuclear surface fleet is very promising." He continued that the opening of the Arctic Ocean is their first priority and, "We want to make it passable in any season, 12 months in the year. For us, icebreakers increase the load capacity of our merchant fleet."

UNITED KINGDOM

The main objective of the United Kingdom's nuclear marine program has been the search for a reactor concept which would be economically attractive to a wide range of shipping. A design and development program was announced in 1961, and in 1962 a technical advisory panel, originated to assess and advise on six ship reactor designs, recommended that future development be concentrated on the Vulcain spectral shaft concept, a type of pressurized water reactor being developed jointly by the United Kingdom Atomic Energy Authority and a consortium of Belgian firms (the Vulcain syndicate), and the integral boiling reactor. In 1965, however, after a reevaluation of the program, the United Kingdom Government announced the decision not to build a nuclear-propelled merchant ship now because the prospects of building a ship that would be economical to operate did not justify the large expenditure necessary to build a prototype. A small research and development program on the present types of reactors for merchant ship use and the joint United Kingdom-Belgian Vulcain effort are being continued.

New proposals for a British nuclear merchant ship were presented at the British nuclear forum late in March 1966. The proposals envision fast container ships of as much as 80,000 shaft horsepower; ore ships are being considered as "second string" candidates. The proposals are by a private group which will ask Government subsidy. The second ships is expected to be economic.

CHINA

It has been reported by French nuclear periodicals that the Chinese Nuclear Energy Commission and the Ministry of Transport began development in 1962 of a nuclear ship with the technical aid of Russia. They continued the development with further aid of Czechoslovakia, Rumania, and Poland during 1963. A committee on nuclear propulsion was established at Tien-Tsin in 1963 and ship construction is reported to have begun in April 1964 at Tien-Tsin and may be already complete.

The ship is named *Zan Than* (voice of the people) and described as 20,000 gross tons, propelled by two screws at 23.5 knots with two main propulsion units and two steam generators capable of 22,000 shaft horsepower each. The reactor is a 180-megawatt-ton pressurized water reactor with 98 fuel elements with zircalloy tubes containing UO_2 pellets having 1.7 percent enriched uranium. An auxiliary propulsion engine is also provided. Refueling is to be accomplished in a special land-based facility.

EURATOM

The present 1963-67 budget for the European Community includes a budget item for reactor development for merchant-ship propulsion in the amount of \$6 million. These funds supplement national support for active work on ship propulsion in three countries—Germany, Italy, and Norway.

NUCLEAR MERCHANT SHIP EXPORT CONTROL PERMITS (U.S. DEPARTMENT OF COMMERCE)

The following companies have applied for the export of nuclear reactor information for the purposes of foreign interest in merchant ship propulsion:

A. APPROVALS

Babcock & Wilcox:

- To Germany Babcock & Wilson for *Otto Hahn*.
- Japan shipbuilders for possible merchant ship.
- Japan oceanographic ship.
- Sweden for ship program.

General Electric:

- To Japan shipbuilder.
- To England ship group.
- To German shipbuilder.
- To Norway.

B. PENDING

Babcock & Wilcox:

- Germany to ship contractor.
- Japan oceanographic ship.
- Japan for nuclear ship components.

DeLaval: Italy for nuclear tanker project.

Westinghouse: Japan for oceanographic ship.

APPENDIX

ATOMIC ENERGY COMMISSION, CIVILIAN MARITIME NUCLEAR PROPULSION PROGRAM

THE OBJECTIVE

1. The long-range objective of the civilian maritime nuclear propulsion program of the AEC is to develop nuclear propulsion systems that, together with improved cargo handling and other nonnuclear innovations, can contribute to the productivity and commercial competitiveness of the U.S. merchant marine.

2. *AEC program plan.*—The program plan recognizes that the AEC and the Department of Commerce must work closely together and in cooperation with interested segments of industry if a commercially competitive nuclear merchant marine is to be achieved. The program contemplates leadership by the AEC in the research and development programs for the reactor plants and by the Department of Commerce in the nonnuclear areas such as those effecting improvements in ship design, cargo handling, and operating procedures. Cooperative Government-industry development of the most promising nuclear propulsion plant concepts, at appropriate stages, also is visualized.

3. The technical feasibility of the use of pressurized water reactors for ship propulsion has been successfully demonstrated. The main questions to be resolved relate to whether improved designs of pressurized water reactors specifically for the civilian maritime application can be achieved within the required performance, cost, reliability, and safety envelopes; and whether, if attained, these characteristics, plus potential improvements, would be sufficient to assure reasonable economics for merchant marine application.

4. Research, the development and testing of components, and testing of selected reactor systems may proceed in parallel with shipboard application. The combination of results obtained from these activities could facilitate an accelerated rate of progress and assist significantly in promoting the use of nuclear power which is one of the basic objectives of the Atomic Energy Commission.

5. Encouragement of cooperative arrangements between Government and industry as an important part of the total development and demonstration program is based upon the expectation that such arrangements would reduce Government expenditures and provide maximum incentives for effectiveness in cost reduction in a program whose basic objective is strongly economics oriented. As has proven effective in other AEC programs, the cooperative efforts should be carried out

¹ The above program was discussed with the Bureau of Budget and the Joint Committee on Atomic Energy prior to the preparation of the joint document titled "U.S. Nuclear Merchant Fleet."

in a manner which recognizes that (a) maximum involvement of industry would be desirable; (b) the competitive system should be strengthened; and (c) results should be available for the common good.

6. The AEC program proposes a near-term and long-term effort. The initial effort will be directed to studies and formulation of the reactor plant criteria, including the preliminary design and the detailed specifications and standards which would be required for practical civilian maritime application.

7. When agreement has been reached on the Department of Commerce objectives and requirements and if it is determined that the benefits from the program are worth the costs involved, a more extensive research and development program would be in order. A land-based test facility would probably be a vital element to achieve the desired objectives. Reasons for this include the following:

(a) Since reliability of shipboard reactors, as well as economic performance, is essential, extensive testing of individual components and of the assembled advanced reactor system would be necessary.

(b) Experience with *Savannah* illustrated limitations in using a shipboard reactor for development and testing.

(c) A test facility could permit utilization of extensive test and operational instrumentation and procedures, particularly that required to measure reliability, detailed plant and incore performances as they may affect design margins, transient performance and safety, cost and abnormal plant operating conditions, and casualty control.

(d) The facility could serve as a engineering test bed on which competitive and backup component designs and arrangements from a number of reactor plant contractors and component vendors could be evaluated and improved, and in general could serve as a multipurpose test facility in which follow-on R. & D. can be performed.

(e) Time and money could be saved in reaching long-range goals by use of land-based facilities for testing components and systems. For example, land-based facilities can assist in the validation of design engineering and construction characteristics, including capital, operating and maintenance costs, and permit essential and/or desirable design changes and improvements to be accomplished and proven at minimum cost and delay to the plant design and to any related ship program.

(f) Training opportunities could be made available to companies wishing to use them.

8. Assuming that analysis of economic and other advantages relative to costs indicated the desirability of proceeding with substantial development programs for nuclear-powered merchant ship reactors, a land-based test facility need not be a prerequisite to ship construction. Near-term interest has been expressed recently in highly reliable, high-speed, nuclear-powered ships handling large volumes of special cargo and serving specific very long distance trade routes. Some ship operators have expressed interest in investing capital in anticipation of this potential market and possible increases in high-value cargo volume which could result from such service. Their willingness to undertake these investments is, of course, contingent upon a Government contribution roughly equal to the excess of construction and operating costs over those of conventionally powered ships. The fol-

lowing advantages could result from a nuclear-powered ship construction program:

(a) Nuclear industry would gain additional experience.

(b) Ship operators would obtain familiarity with nuclear power technology which cannot be duplicated in a land-based test facility.

(c) Participation and interest in the maritime nuclear power program would be sustained which would help reduce costs and effect improvements. These could be particularly useful to the AEC's longer range research and development program.

(d) Such efforts could contribute to resolution of nuclear ship operating questions such as those relating to safety, indemnification, and port clearance.

9. Thus, the civilian maritime reactor program should be flexible enough (1) to pursue advanced reactor programs to achieve major improvements in plant performance and economics; and (2) to support industry-based nuclear maritime efforts and engineering development in connection with direct shipboard application.

10. *Reactor plant technology status.*—Nuclear power systems using two basically different reactor concepts have been considered for use as propulsion plants in the merchant marine in recent years. One of these is the pressurized water concept; the other uses the gas cycle. Recent investigations and comparisons of these efforts have concluded that, clearly, the much greater experience with pressurized water reactors makes them a logical choice for near-term exploitation.

11. *Commission sponsored maritime program including plans for test facility.*—

(a) In fiscal year 1966 and fiscal year 1967, detailed program objectives, preliminary plant design, detailed design criteria, applicable standards and specifications, and meaningful economic parameters will be developed with the Department of Commerce, reactor plant suppliers, ship operators, and shipbuilders.

(b) At an appropriate time, research and development efforts would be undertaken on the PWR system directed principally to several key engineering and technological areas associated with the objective of constructing a compact pressurized water plant with promise for broad maritime application. These efforts may include investigation of areas such as steam generation, gas and/or self pressurization, automatic control systems, reactor vessel designs, auxiliary components and systems, fuel and reactor design, containment designs, and the conduct of special test and critical experiments to verify system and reactor characteristics, and safety parameters.

(c) The aforementioned effort may be expected to yield the data which are prerequisites for establishing the detailed technical design and evaluating the economic feasibility of the specific improved PWR system. This information would be applicable to the design of the land-based reactor test facility with its related reactor plant control system, as well as to the design of the site facilities necessary for the test and operation of the improved powerplant under conditions simulating as closely as possible shipboard operations.

(d) Preliminary designs, component designs and development, materials development, operational and maintenance concepts, et cetera, with their relationships to the basic plant design, would be solicited and procured from industry on a competitive basis in compliance with

plant objectives and specifications developed with the Department of Commerce and reactor plant industry to meet the program objectives of simplified design, low capital and operating costs, reliable and safe plant.

(e) As the basic reactor plant designs were completed, all equipment and components (with the necessary associated systems engineering efforts) would be procured from industry on a competitive basis. The higher risk areas and higher cost components would be covered as appropriate in terms of backup and alternate designs. The plant would be designed to permit utilization of interchangeable components and systems from various competitive manufacturers; major attention would be devoted to economically attractive concepts.

(f) At the present time, no allowance is made for the propulsion machinery installation, other than those parts intimately connected to the reactor plant. However, it is anticipated that the Department of Commerce would participate closely in the test facility design, installation, and operation in order to provide maximum benefits to the overall civilian maritime program, including training, shipbuilding, and operating programs.

12. *Other advanced reactor concepts.*—The promise of nuclear power for maritime application and the recognition that continuing emphasis will be placed on economic performance in the long term, makes it desirable that the potentials of other advanced reactor concepts be assessed for civilian maritime application.

13. Thus, other reactor concepts in the AEC's programs of advanced systems and general reactor technology would be investigated in order to identify any which indicate improved potentials over advanced pressurized water systems sufficient to warrant further development as part of the maritime program.

14. *Shipbuilding program.*—The Commission's role in a shipbuilding program is subordinate to that of the Department of Commerce's determination of needs, costs, and benefits. However, the Commission views its role as one of encouraging the use of reactors offered by industry which show reasonable economic promise for specific applications and will encourage nuclear reactor manufacturers and shipbuilders to proceed with construction of nuclear-powered vessels. The AEC would be in a position to function as a service organization offering limited technical support, where asked, and guidance and supervision on matters pertaining to safety and licensing or the AEC may enter into cooperative financial arrangements for the nuclear propulsion plant.

15. The Government's effort on a shipbuilding program would be contingent upon the benefits to be received in relation to costs; the characteristics of the specific cooperative proposal; the extent of commitments by the shipowner, the shipbuilder, and the reactor manufacturer; and the approval of this program by the administration, including an evaluation of program priority relative to competing demands for funds. It is recognized that the economic evaluation and potential for specific shipboard applications will be dependent not only on the nuclear plant characteristics but on the improvements in ship design, cargo handling, operating procedures, and other nonnuclear items which come under the cognizance of the Department of Commerce.

16. *Relationship of the reactor plant development program to a shipbuilding program.*—The basic objective in proceeding with an AEC civilian maritime reactor plant program is to facilitate the introduction of safe, reliable, and competitive nuclear powerplants to merchant ships. The AEC's civilian maritime nuclear propulsion program plan seeks to achieve this objective through continued technical progress.

17. In summary, the Government and industrial participants in any civilian maritime nuclear propulsion program have a choice of the following options or combinations thereof, but not necessarily all, depending on the policies, relative priorities, and availability of funds:

(a) Proceed with a nuclear shipbuilding program immediately where current pressurized water technology is adequate.

Leadership by shipowners, nuclear industry, Department of Commerce. Support by AEC.

(b) Proceed with a ship prototype where reactor technology is adequate for a first step only but where operational experience is needed.

Leadership by shipowners, nuclear industry, Department of Commerce. Support by AEC.

(c) Proceed with a research and development program, where major technological and economical advances are necessary, and possibly build a land-based test facility after significant advances have been made.

Leadership by AEC, nuclear industry. Support by Department of Commerce, shipowners.

(d) Proceed with the research and development program, probably including the construction of a land-based test facility, where current technology must be advanced to achieve the required performance, reliability, economy, and safety.

Leadership by AEC, nuclear industry. Support by Department of Commerce, shipowners.

18. *Funding.*—The funding for the R. & D. program in fiscal year 1966 and fiscal year 1967 is \$0.5 million per year. The following projections represent a logical follow-on 5-year program to conduct research and development and construct the test facility that can be started in any subsequent year, if the determination is made that the program is justifiable.

R. & D. PROGRAM

	A 5-year program				
	1st	2d	3d	4th	5th
PWR base program.....	5.0	6.0	6.0	10.0	10.0
Advanced systems.....	.2	.5	.5	.5	.5
Land-based test facility.....	3.0	32.0	0	0	0
Cooperative program ¹					

¹ The unknown nature of a cooperative program makes any estimate of funding uncertain at this time. It is expected that funds required by the AEC for reactor plants for the shipbuilding program will be included in the authorization and appropriations sponsored by the Department of Commerce.

