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1. INTRODUCTION AND SUMMARY

1.1 Summary of Significant Events

A nuclear ship was first proposed by President Eisenhower in 1955 as evidence of this country's interest in the peaceful uses of atomic energy. In 1956, Congress authorized the program in Public Law 848, which provided funds for the design and construction of a vessel, subsequently named the NS Savannah.

On October 15, 1956, the President directed the Atomic Energy Commission (AEC) and the Maritime Administration (Marad) to proceed with design and construction. To complement this effort, the entire project was placed under the direction of a dual status staff chosen jointly by Marad and the AEC. The vessel was designed by George G. Sharp, Inc., Naval Architects of New York; and The Babcock and Wilcox Company (B&W) was awarded a fixed price contract for the design and construction of the nuclear power plant auxiliaries. The New York Shipbuilding Corporation (NYS) was selected to construct and test the ship at their Camden, New Jersey shipyard. In 1958, the States Marine Lines, Inc., was engaged as the operating agent for the ship. Todd Shipyard Corporation was chosen to provide the maintenance facility in May 1960. In 1963, American Export Isbrandtsen Lines Inc., (AEIL) became the operating agent. First Atomic Ship Transport Inc., (FAST) a subsidiary of AEIL, placed the NS Savannah in routine cargo service in September 1965. The shuffle of Core I fuel elements began in August 1968 and was completed late that year.

The NS Savannah, a vessel of the P-2 class (specifically P2-N1-MA40a) is powered by a pressurized-water nuclear reactor and has a design speed of 22 knots at 22,000 shaft horsepower. The normal cruising speed is 20.25 knots at 20,000 shaft horsepower. The ship was intended to promote international goodwill by being displayed in the seaports of the world. Consequently, it was made as attractive and modern as any

vessel afloat, and its nuclear power plant was designed with an exceptional degree of reliability and safety.

The prime objectives of the creators of the NS Savannah were to demonstrate the advanced technology and peaceful use of nuclear energy and resolve the problems resulting from marine reactor operation. The operation of a working test-bed laboratory ship has provided a tool to be used in the development of economical ships and is establishing acceptable standards for the design of ship and reactor, operating practices, manning, port entry and operation, and safety of crew and the general public. It is necessary, therefore, that entry into the domestic and foreign ports be in accordance with mutually acceptable regulations and operational procedures. The successful culmination of these objectives led to the general acceptance of the NS Savannah's safety and reliability by governmental authorities, cargo shippers, and the general public.

New regulatory procedures, inspection standards, and training requirements have been developed. The relation of manning to the ship's layout, design, and service has been studied. The high degree of safety, reliability and performance has gained for the NS Savannah an acceptance of nuclear ships in the ports visited.

A chronology of significant events in the NS Savannah program is shown in Table 1-1.

The NS Savannah completed its program of domestic and foreign port visitation in March 1965. Since that time the ship has been in commercial cargo operations. The ports visited are listed in Table 1-2.

1.2. Principal Safety Features of the Ship

1.2.1. The Hull

The hull design of the NS Savannah is that of a conventional vessel with trim and modern lines, designed in accordance with the latest practice in naval architecture and hydrodynamics.

Table 1-1. Chronology of Significant Events

Proposed by President	April 1955
Approved by Congress	July 1956
Selection of the Babcock & Wilcox Company	October 1956
Selection of George G. Sharp, Inc.	April 1957
Selection of New York Shipbuilding Corporation	November 1957
Keel laid	May 1958
Selection of General Agent, States Marine Lines, Inc.	September 1958
Launched	July 1959
Selection of Todd Shipyard Corporation	May 1960
Component testing started	July 1960
Systems testing started	November 1960
Public hearing	March 1961
AEC fueling authorization	July 1961
Prefueling testing complete	September 1961
Fueling	November 1961
Initial criticality	December 1961
10% testing complete	January 1962
Initial sea trial	March 1962
Delivery	May 1962
Commencement of initial voyage	August 1962
Initial voyage complete	February 1963
Cancellation of General Agent contract with States Marine Lines, Inc.	May 1963
New staff formation	June 1963
Selection of new General Agent, American Export Isbrandtsen Lines, Inc.	July 1963
AEIL sea trials	February 1964
Resume port operation	May 1964
Port visitation program complete	March 1965
Begin scheduled commercial operation	September 1965
Core Shuffle Operation Completed	October 1968

Table 1-2. Ports Visited by NS Savannah

Public Visitation Program

Savannah, Georgia
Norfolk, Virginia
Panama Canal (transit only)
Seattle, Washington
San Francisco, California
Long Beach, California
Los Angeles, California
Honolulu, Hawaii
Portland, Oregon
San Diego, California
Balboa, Canal Zone
Galveston, Texas
Houston, Texas
New Orleans, Louisiana
Baltimore, Maryland
Boston, Massachusetts
New York, New York
Bremerhaven, Germany
Hamburg, Germany
Dublin, Ireland
Southampton, England
Hoboken, New Jersey
Providence, Rhode Island
Portland, Maine
Oslo, Norway
Copenhagen, Denmark
Halsingborg, Sweden
Malmo, Sweden
Rotterdam, The Netherlands
Antwerp, Belgium
Le Havre, France
Brooklyn, New York
Philadelphia, Pennsylvania
Lisbon, Portugal
Barcelona, Spain
Naples, Italy
Wilmington, North Carolina
Charleston, South Carolina
Jacksonville, Florida
San Juan, Puerto Rico
Piraeus, Greece
Port Everglades, Florida
Mobile, Alabama

Commercial Cargo Operation

Philadelphia, Pennsylvania
Baltimore, Maryland
Hoboken, New Jersey
Bilbao, Spain
Le Havre, France
Bremerhaven, Germany
Hamburg, Germany
Bayonne, New Jersey
New York, New York
Norfolk, Virginia
Boston, Massachusetts
Marseilles, France
Savannah, Georgia
Charleston, South Carolina
Genoa, Italy
Leghorn, Italy
Cadiz, Spain
Rota, Spain
Naples, Italy
Barcelona, Spain
Lisbon, Portugal
Piraeus, Greece
Galveston, Texas
Venice, Italy
Trieste, Italy
Rijeka, Yugoslavia
Tunis, Tunisia
Pusan, Korea
Inchon, Korea
Hong Kong, BCC
Keelung, Taiwan
Kaohsiung, Taiwan
Manila, Philippine Islands
Alicante, Spain
New London, Connecticut
Brunswick, Georgia
Naha, Okinawa
Gijon, Spain
New Haven, Connecticut
Famagusta, Cyprus
Ashdod, Israel
Haifa, Israel
Beirut, Lebanon
Split, Yugoslavia

The principal safety features in the hull design may be summarized as follows:

1. The hull is divided by 10 watertight bulkheads terminating at the B-deck level.

2. The ship will remain afloat if any two of the nine compartments are flooded within the meaning of U.S. Coast Guard (USCG) stability requirements.

3. Conventional all-welded steel construction is employed with full-continuity of structural members, except for a few longitudinal riveted seams serving as crack arresters in accordance with latest practices.

4. A 5-foot deep watertight double-bottom extends under all nine compartments but not under fore peak or after peak ballast tanks.

5. Special care was taken in the selection of materials to minimize galvanic corrosion.

6. The reactor compartment is reinforced outboard of the containment vessel with additional longitudinal and athwartship bulkheads, in addition to a laminated redwood and steel collision mat on each side, to minimize penetration in the event of a collision amidships.

7. The design details and construction of all components and systems are in accordance with the latest regulations of the Safety of Life at Sea Convention (SOLAS), Marad, USCG, the U.S. Public Health Service, the American Bureau of Shipping (ABS), and other regulatory bodies.

1.2.2. The Power Plant

From the beginning of the project, analyses of hypothetical casualties and topical reports covering every phase of the design were prepared and reviewed by the regulatory agencies as well as Oak Ridge National Laboratory (ORNL). In addition, a comprehensive analysis of reactor safeguards was prepared for review by the AEC and for the critical examination of the AEC's Advisory Committee on Reactor Safeguards (ACRS).

1.2.2.1. General

In the design and construction of the power plant, a special philosophy of safety and reliability was adopted at the outset of the project. Both preparatory and concurrent research and development work and special operational testing were undertaken in many areas, including a series of critical experiments on various configurations and designs for the reactor core, full scale testing of a prototype control rod drive mechanism and system under simulated reactor conditions, irradiation tests of fuel elements and pellets, containment vessel leak rate tests, and filter efficiency tests.

1.2.2.2. Particular Safety Features

Of the many safety features in the power plant design (described in detail later), 17 merit special mention.

1. Reactor System Containment - The reactor and primary coolant system are located inside a containment vessel. Any failure of the primary system would be contained. The containment system, consisting of a USCG approved pressure vessel and associated isolation valves, is designed and hydrostatically tested to withstand a pressure of 173 psig. In pneumatic tests at 60 psig, this system is routinely demonstrated to have a leak rate of less than 1.2% of the contained volume per day.

2. Containment Vessel Isolation - The reactor system is operated with the containment vessel hermetically sealed at all times, and the penetrating pipe lines are closed by automatic valves if the pressure inside the containment vessel rises above 5 psig for any reason whatsoever. The steel containment vessel, moreover, is sufficiently thick that no danger of penetration exists as a result of the formation of any high speed missiles within the containment vessel, such as a thermocouple well from the primary system.

3. Radioactive Waste Control - The power plant operates with a minimum of radioactive waste disposal.

Gaseous and liquid wastes are discharged in accordance with the "Standards for Protection Against Radiation" (10CFR Part 20)[1] and the NS Savannah Technical Specifications. Solid wastes are kept aboard the ship and periodically discharged to a licensed waste disposal facility.

4. Shielding - The reactor vessel is surrounded laterally by 33 inches of water and 1 to 4 inches of lead shielding so that maintenance work is possible shortly after shutdown. The secondary shielding around the containment vessel reduces the surface dose level at full reactor power to no more than 100 mr per week.

5. Radiation Monitoring - The radiation level in all fluid systems of the power plant, at strategic locations in the reactor compartment and throughout the ship is continuously monitored such that any unusual rise at any location actuates an alarm in the control room and identifies the location. The living quarters around the perimeter of the reactor compartment and other adjacent locations have ORNL type film badges mounted in appropriate places.

6. Plant Reliability by Use of Multiple Components - In all cases where it is practical, multiple components in parallel are provided so that failure of one will not affect power to the propeller, or in the case of loss of one primary loop, will not reduce reactor power to less than 48 MW-t corresponding to a speed of 17 knots. Examples are 2 main boilers, 2 independent primary loops, 2 primary pumps in each loop, 3 primary water demineralizers, 3 primary charging pumps, 160 pressurizer heaters, 21 alternate fail safe scram mechanisms, an independent soluble poison shutdown system, 2 main turbine generators with condensers, 2 auxiliary diesel generators complete with starting and cooling systems, 2 boiler feed pumps, and 2 main electrical distribution systems.

7. Power Plant Reliability by Duplication of Instrumentation and Monitors - Duplication of instruments, both at the point of detection and at the control

panel, is also employed in numerous instances, for the same purpose as in item 6.

8. Operability of the Power Plant With Failed Fuel Elements - The reactor system has adequate waste containing and diluting features to allow operation with limited fuel element failure and consequent leakage of fission products to the primary system.

9. Emergency Propulsion - A 750-horsepower reversible electric motor powered by the auxiliary diesel generators is provided for propulsion in the event of loss of all reactor power.

10. Emergency Steam - In the event of loss of all shipboard service steam, a small boiler of 7500 pounds per hour capacity provides steam for heating and hotel services.

11. Emergency Electric Power - In the event of loss of all electrical generation below decks, a bridge-deck level 300-kilowatt diesel generator will automatically continue to provide electricity to vital services.

12. Reactor Decay Heat Removal - At least two different means of heat removal are available for removing decay heat after reactor shutdown.

13. Reactor Shutdown - A reactor safety system will automatically shut down the reactor on occurrence of any one of several abnormal conditions before any consequent damage can occur. The reactor will also remain shut down, regardless of the ship's attitude, until started up again manually.

14. Ship Maneuvering Rates - The reactor system is capable of responding to the turbine throttle demand at rates faster than the best that can be achieved in conventional marine power plants.

15. Centralized Power Plant Control - The power plant is controlled at all times from a central control room with sufficient instrumentation to keep the operators informed at all times of the performance of all power plant systems.

16. Ship Movement - The power plant is designed to operate satisfactorily under the customary criteria of pitch and roll for a modern merchant ship.

17. Protection of Reactor System From Chlorides - Means are provided by which a sea-water leak through any condenser tube-sheet is detected. Chloride levels in both the primary and secondary systems are maintained at safe values or the plant is shut down to prevent the possibility of chloride stress corrosion in the primary or secondary loops.