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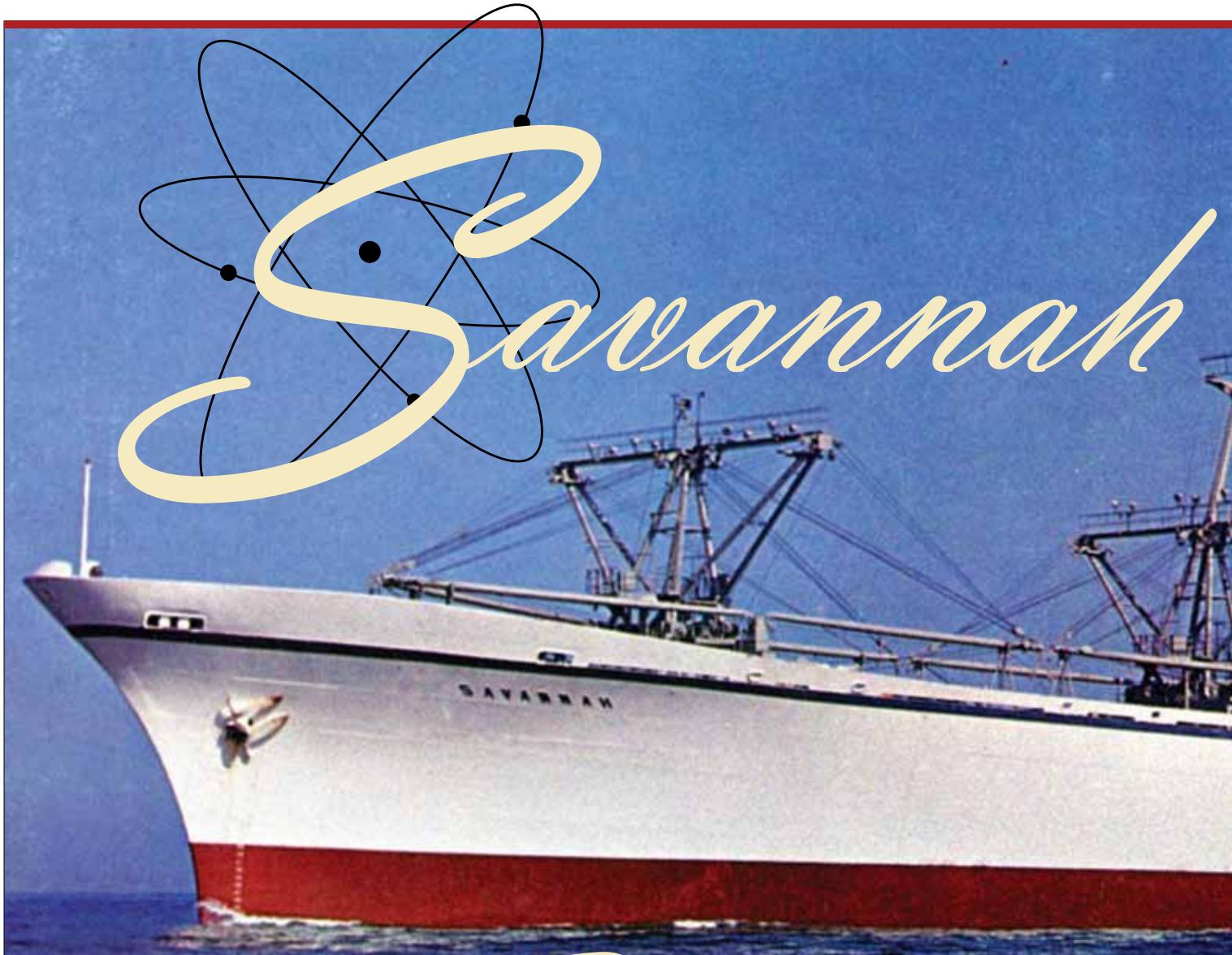
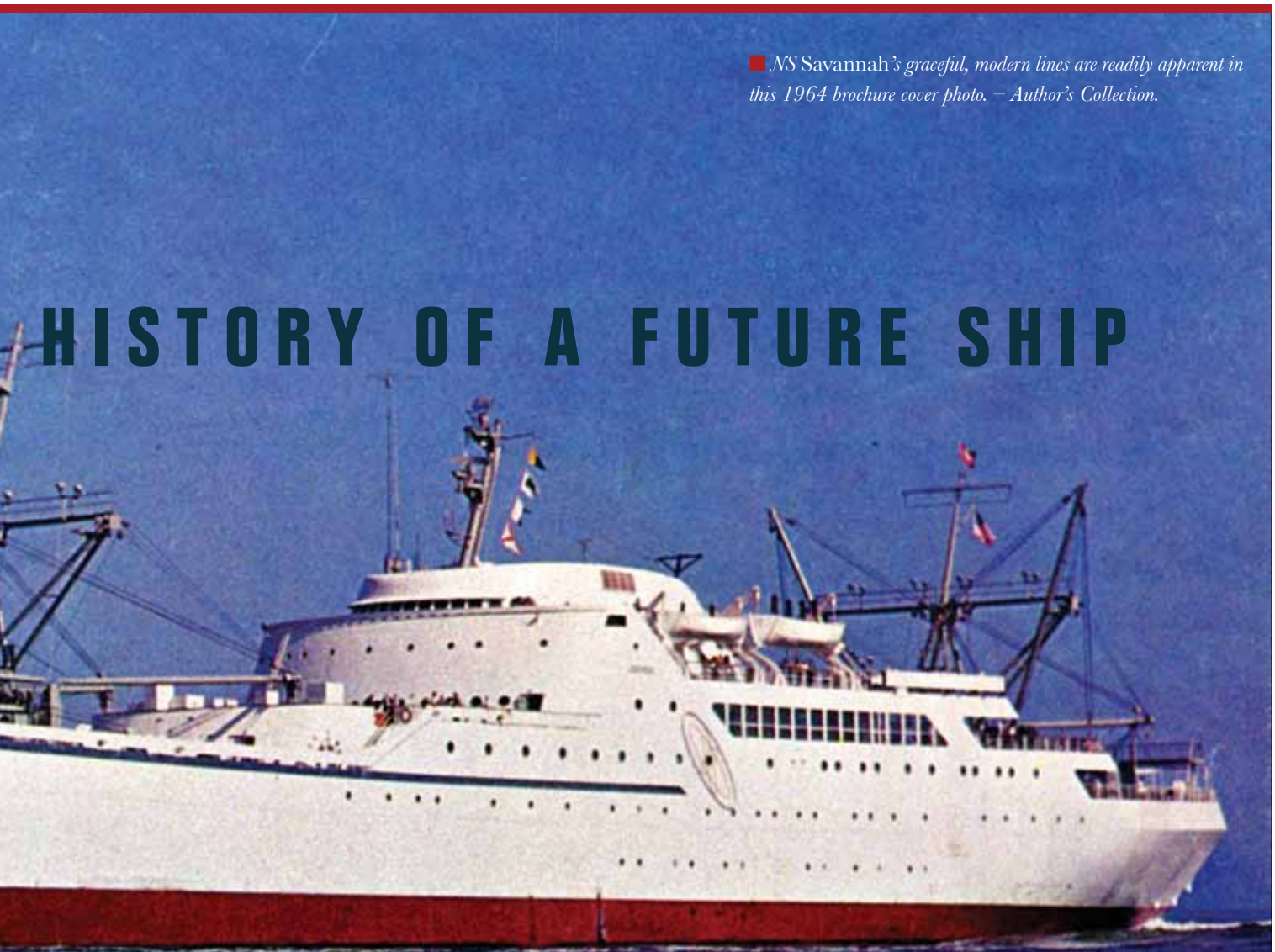
Savannah



by Captain Terry Tilton, USN, Ret.

Exactly 60 years ago, in 1959, First Lady Mamie Eisenhower christened the ship known as *Savannah*, the world's first nuclear-powered merchant ship. Nuclear power at sea had been around for several years. In 1954, the commanding officer of the nuclear-powered submarine *Nautilus*, CDR Eugene P. Wilkinson, sent the message "Underway under nuclear power" to President Eisenhower. Ocean-going nuclear power has proved to be even more reliable and safe than early predictions. Even before the *Nautilus*, the maritime industry envisioned commercial ships with nuclear propulsion. *Savannah* would simply be the first of such a fleet.

Now, almost 50 years since her withdrawal from commercial service, it can be concluded that the *Savannah* experiment was successful. This may run counter to some previous determinations made by maritime experts, most of whom, regrettably, are unfamiliar with the ship's gestation, design, expectations and operational standards. In the context



NS Savannah*'s graceful, modern lines are readily apparent in this 1964 brochure cover photo. – Author's Collection.*

HISTORY OF A FUTURE SHIP

of nuclear ship history, it's appropriate to review the aspects of the first commercial nuclear ship.

Just as Russia beat the United States in the launching of the Sputnik orbital satellite in 1957, and sent the first person into space, they sent a nuclear icebreaker, *Lenin,* to sea in 1957. *Lenin* didn't have commercial applications; its mission was to support Artic military operations. Accordingly, her photos and data were recorded in *Jane's Fighting Ships*. *Lenin* used pressurized water reactors to generate steam to drive turbo-electric generators that drove huge motors connected to three propellers. Despite the existence of *Lenin,* it's legitimate and appropriate to call *Savannah* the first commercial nuclear surface ship.

The transition from oil to nuclear power may be as important as the transition from wind to steam power. But the use of nuclear energy for propulsion would have to wait until after World War II.

Well aware that the Russians were building the *Lenin*, whose construction was approved in 1953, Congress pushed to accelerate the development of a cargo/passenger variant, ultimately the *Savannah*. As the Department of Commerce and the Atomic Energy Commission pushed the nuclear merchant program, the Navy had already proved the success of the concept with the *Nautilus*. In 1957, *Seawolf* went to sea with a competitive liquid metal-sodium reactor. In that year, the Navy had six more nuclear submarines in construction.

SAVANNAH GESTATION

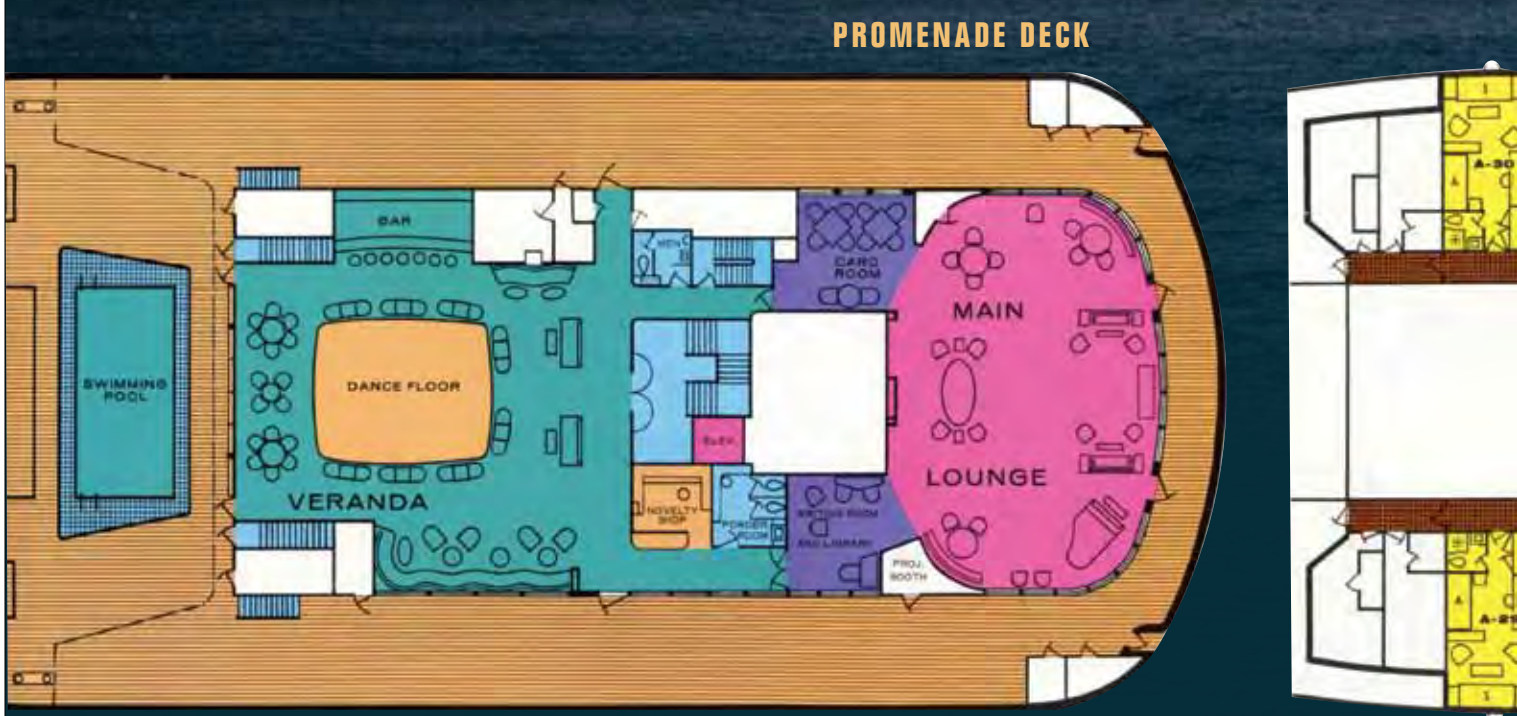
After the April 1955 proposal for a nuclear commercial ship, a year passed before Congress authorized it on July 30, 1956 (Public Law 848). The president gave the go-ahead authorization on October 15 for a practical at-sea demonstration, or "test bed." The AEC and the Department of Commerce would jointly head the venture. One of several

available reactor types had yet to be identified as appropriate in the new ship. Babcock & Wilcox came onto the project April 4, 1957, as prime contractor for the entire propulsion plant. In the late 1950s, only five private shipyards were qualified to construct nuclear ships: Electric Boat, Newport News, New York Shipbuilding, Ingalls, and the Bethlehem Steel shipyard in Quincy, Massachusetts. New York Shipbuilding won the construction award November 15, 1957.

Someone would have to design the ship. She needed an appropriate name; an early proposal was the mundane *Atomic Queen.* Frank Braynard, the ship enthusiast emeritus, had a big hand in determining the name for the nuclear ship. After all, he helped to locate the remains of the original *Savannah*, the first ship to use steam in an Atlantic crossing.

Braynard suggested that this history-making name be assigned to the proposed nuclear-powered ship, and that the keel be laid on National Maritime Day, May 22, designated by President Franklin Roosevelt in 1933. Braynard got his wish; the keel went down on Maritime Day in 1958. Mrs. Richard Nixon, wife of the vice president, officiated at the ceremony.

From the outset, there was no expectation of commercial success. More of a floating laboratory, *Savannah* would demonstrate the viability of nuclear power in commercial ships: since the ship's fuel required little space, and there would be no need for ancillary fueling equipment such as pumps, piping and valves, there was more room for cargo. Nuclear fuel promised higher cruising speeds, and its expected life exceeded three years. Stack gas, soot and effluent wouldn't mar the beautiful



Deck plans as published in a 1964 American Export Lines brochure. – Author's Collection.

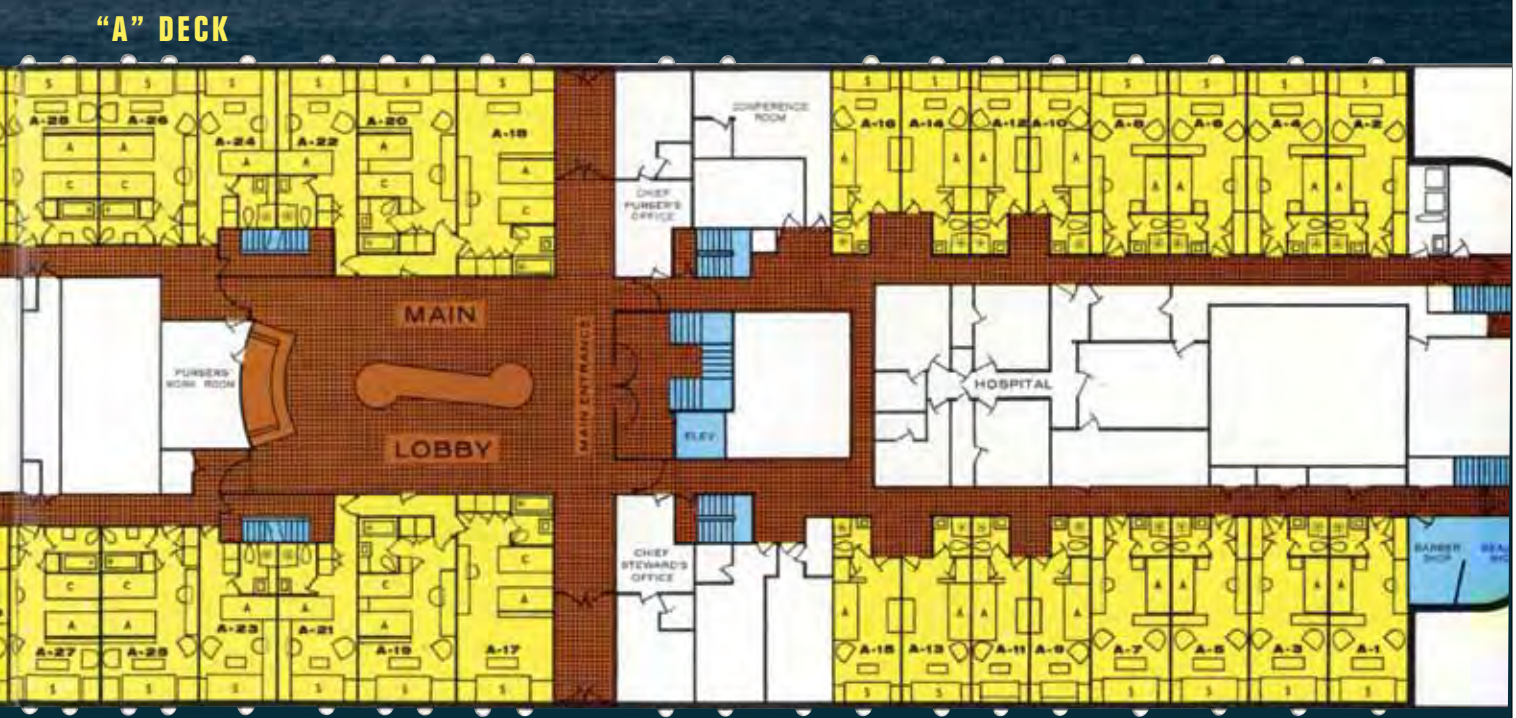
white ship or bother the passengers by the pool.

MISSIONS AND EXPECTATIONS

There were several disadvantages to nuclear, including the enormous initial outlay for the ship and reactor equipment. Engineering training, to develop the unique skills necessary to operate the power plant, would be lengthy and expensive. Deck officers would also need reactor training. Special health and monitoring considerations had to be incorporated. The containment vessel for the reactor needed the ability to withstand every possible disaster at sea. The process of nuclear refueling would be time-consuming, very expensive and limited to just a few locations. Shore facilities to support the ship and handle nuclear waste would be needed. But, despite all of this, *Savannah* would allow the evaluation of first-generation nuclear power to develop operating experience and demonstrate the viability of moving into a second generation for commercial applications. Even as the public witnessed the keel laying, reactors half the size of the *Savannah*'s neared development.

A nuclear reactor is basically an atomic furnace. The fuel consists of thimble-sized pellets of uranium oxide loaded into steel tubes. Multiple tubes are bundled to make a fuel element. When the fuel elements are in place, boron stainless steel control rods are used to regulate the nuclear reaction. With the control rods in the down position, the neutrons released by the enriched uranium oxide are absorbed by the rods. The rods are withdrawn to start the reactor and allow neutrons to split the atoms in the uranium.

Savannah *in New York harbor. – Braun Bros. Collection, SSHSA Archives.*



A STEAM GENERATOR drives both turbine-driven electrical generators and main propulsive machinery, much like that in a conventional steam plant. Two auxiliary diesel-driven generators could handle the ship in the event of a reactor shutdown. Once stabilized, a single 750-kilowatt diesel generator could drive a large electrical motor for emergency "take home" capability, making a maximum speed of about 5 knots.

THE NUCLEAR WASTE problem was glossed over by the AEC in its technical information pamphlet: "There are radioactive liquids and gasses discharged during reactor operations. The standard practice is to collect most such wastes for disposal, usually by burial on land." In 1959, it was expected that in the future radioactive waste would be recycled and even sold at a profit.

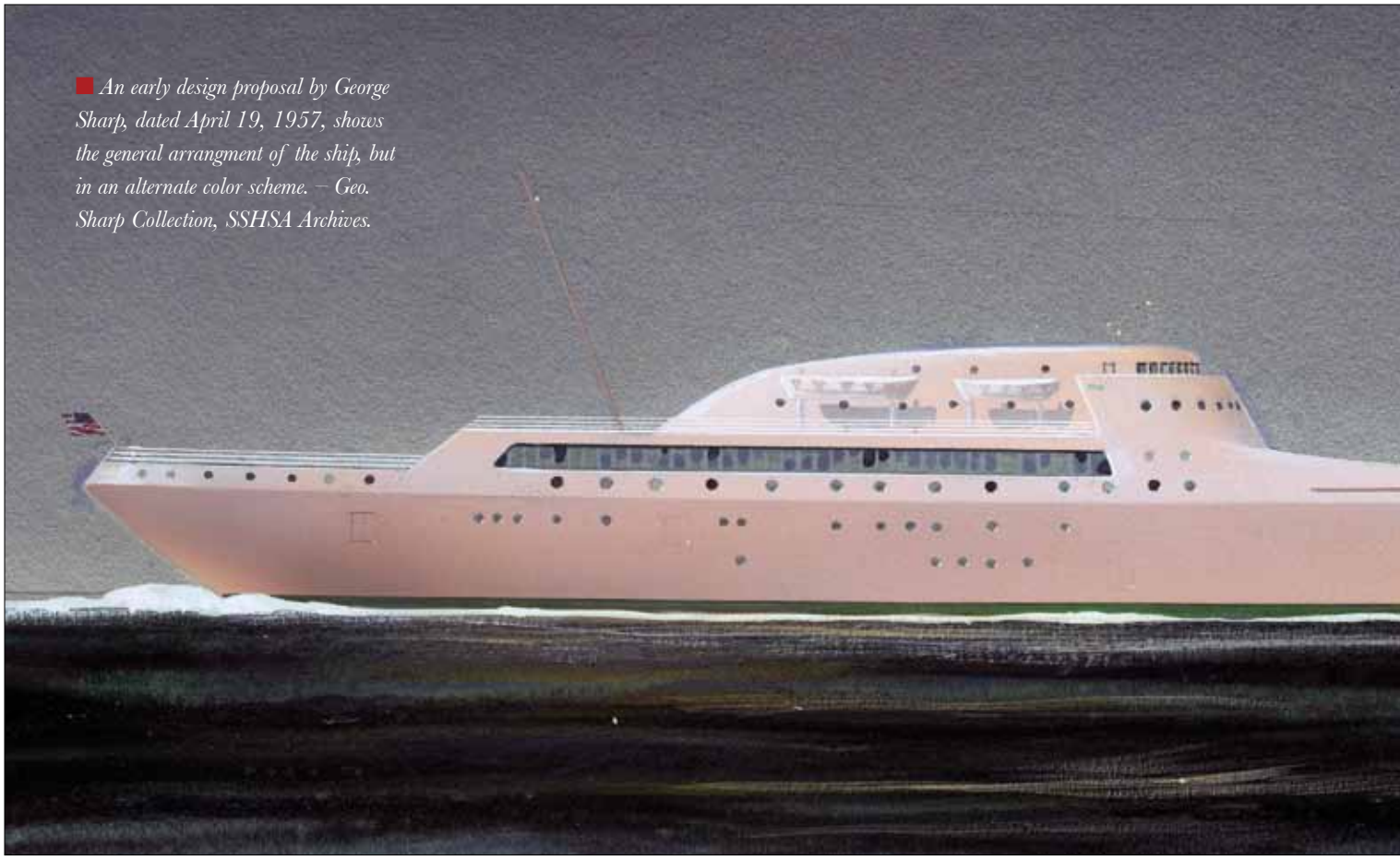
AN APPROPRIATE DESIGN

THE DESIGN OF THE POWER PLANT AND the ship happened at the same time. In 1957, George Sharp and his team, including Lorentz Hansen, designed *Savannah* inside and out with a sleek, futuristic, purposeful look. Sharp had many successes, including the three Panama Line combination ships, the Farrell "heavenly trio," and the three postwar "coffee liners" – *Del Norte* and her two sisters. *Savannah* borrowed elements from *Del Norte*, including a circular bridge front, a dummy funnel, an indoor/outdoor promenade, and sofa beds instead of upper berths. The yacht-like ship even boasted hydraulic stabilizers, unique to a cargo ship.

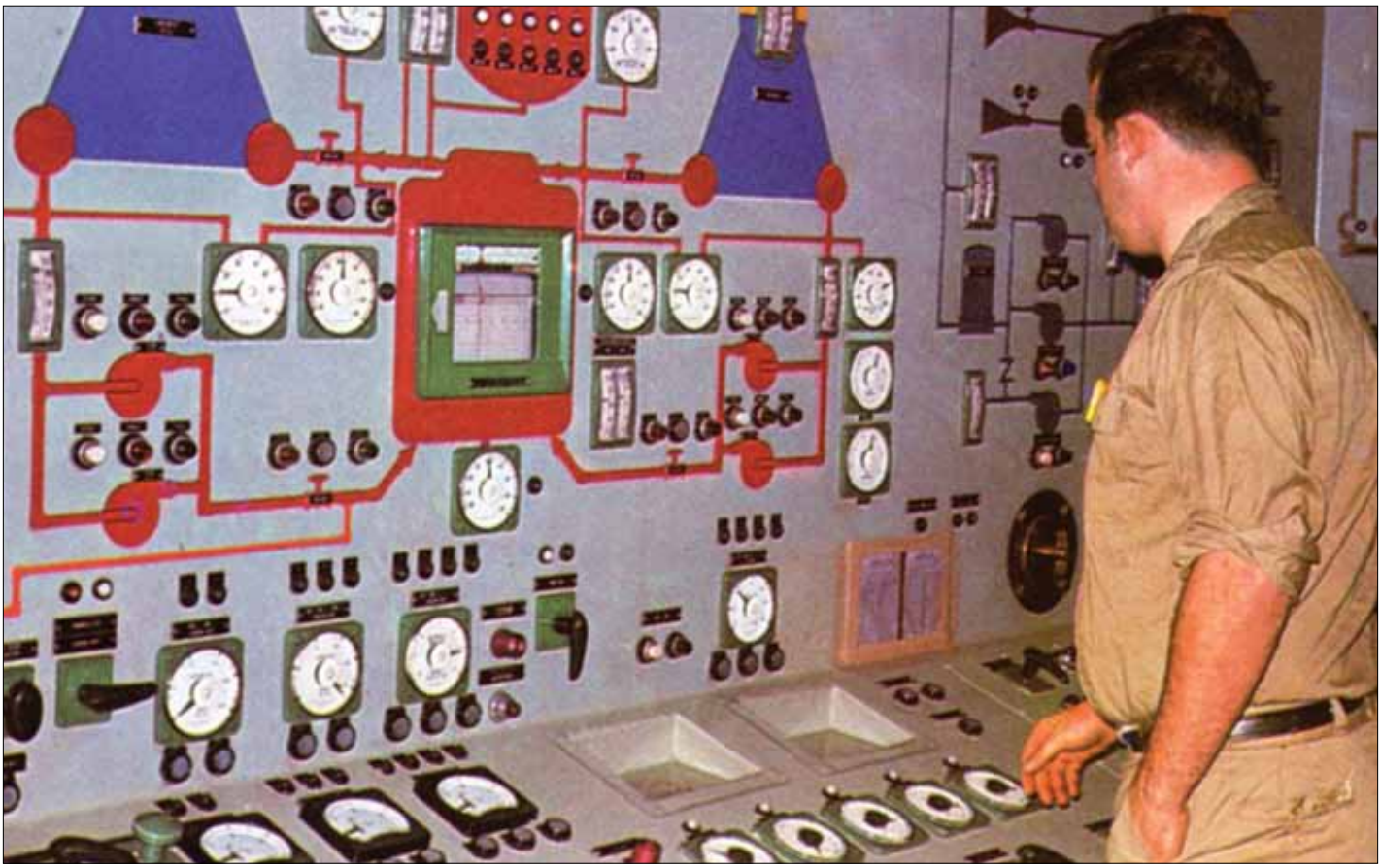
ON THE DOWN SIDE, the streamlined appearance of the ship's mast and cargo-handling gear made for less efficiency than other cargo ships because the design restricted forward access to the cargo hatches. Lift capacity measured less than that of similar cargo ships of that era; doubling to lift heavier objects slowed operations. Shorter booms reduced reach across the pier by six feet. Some hatch covers had different and unique dimensions.

THE *SAVANNAH* WAS based on the 35 Mariner ships designed a decade earlier. Accommodating the reactor space made a mere length difference between perpendiculars of only 16 feet. She measured five percent longer overall – 595 feet instead of 564, mostly attributable to the graceful bow. The beam came to 78 feet instead of 76, and the displacement was virtually the same – *Savannah* at 21,800 tons and the Mariners at 21,095.

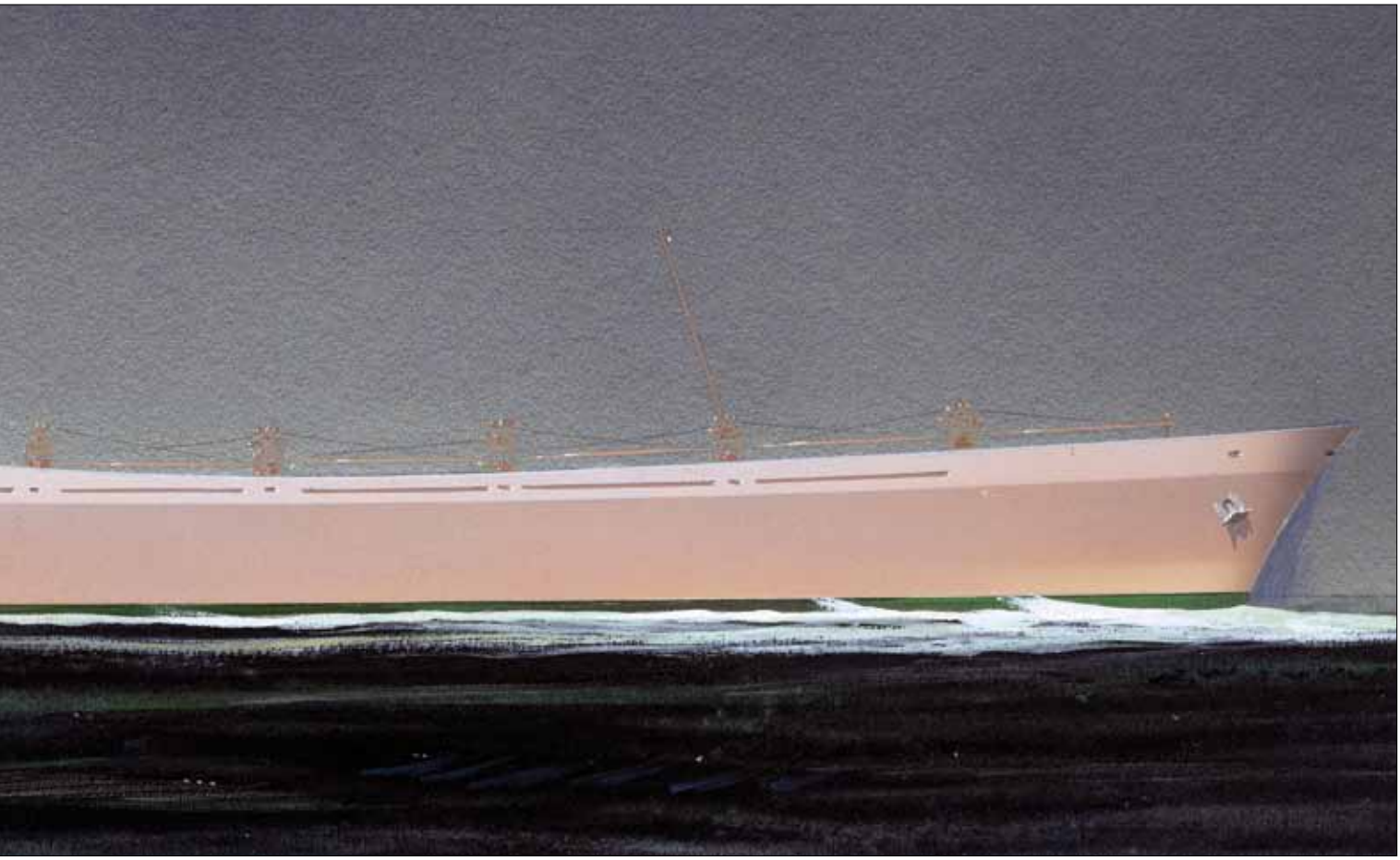
THE NUCLEAR SHIP generated 20,000 horsepower plus a 10 percent overload, against the Mariner ships with 17,500 hp plus a 10 percent overload to 19,250. Both ships could sustain an easy 20 knots. *Savannah* touched 23 knots during trials, but the Mariners proved faster in transit: *Cotton Mariner*, en route from Panama to San Francisco, averaged 22.9 knots. The *Savannah*'s cargo capacity proved quite a bit less than the conventional mariner type: 575,000 cubic feet versus 750,000. The passenger capabilities of *Savannah* necessitated a much larger crew, 110 instead of 58.

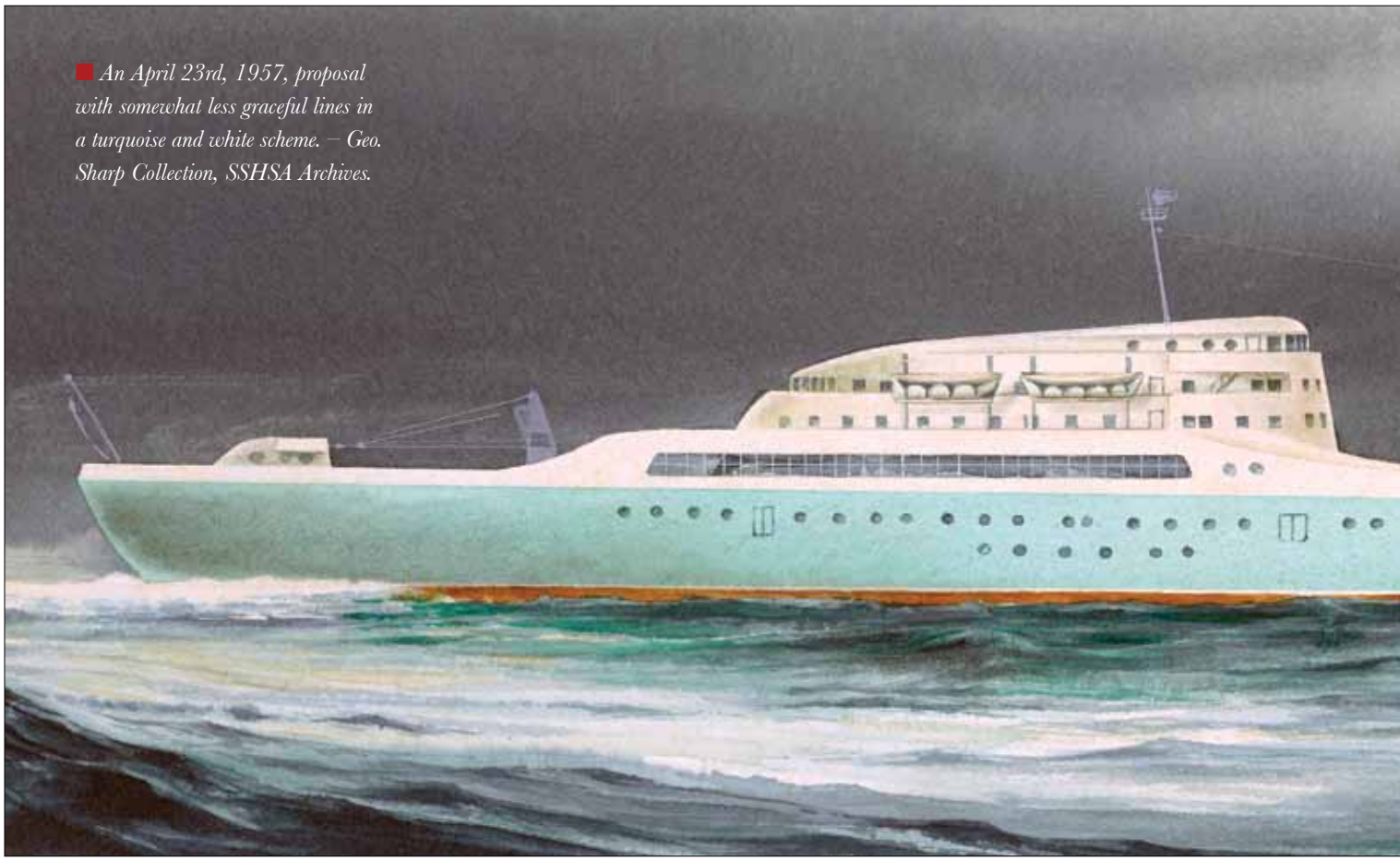


An early design proposal by George Sharp, dated April 19, 1957, shows the general arrangment of the ship, but in an alternate color scheme. – Geo. Sharp Collection, SSHSA Archives.

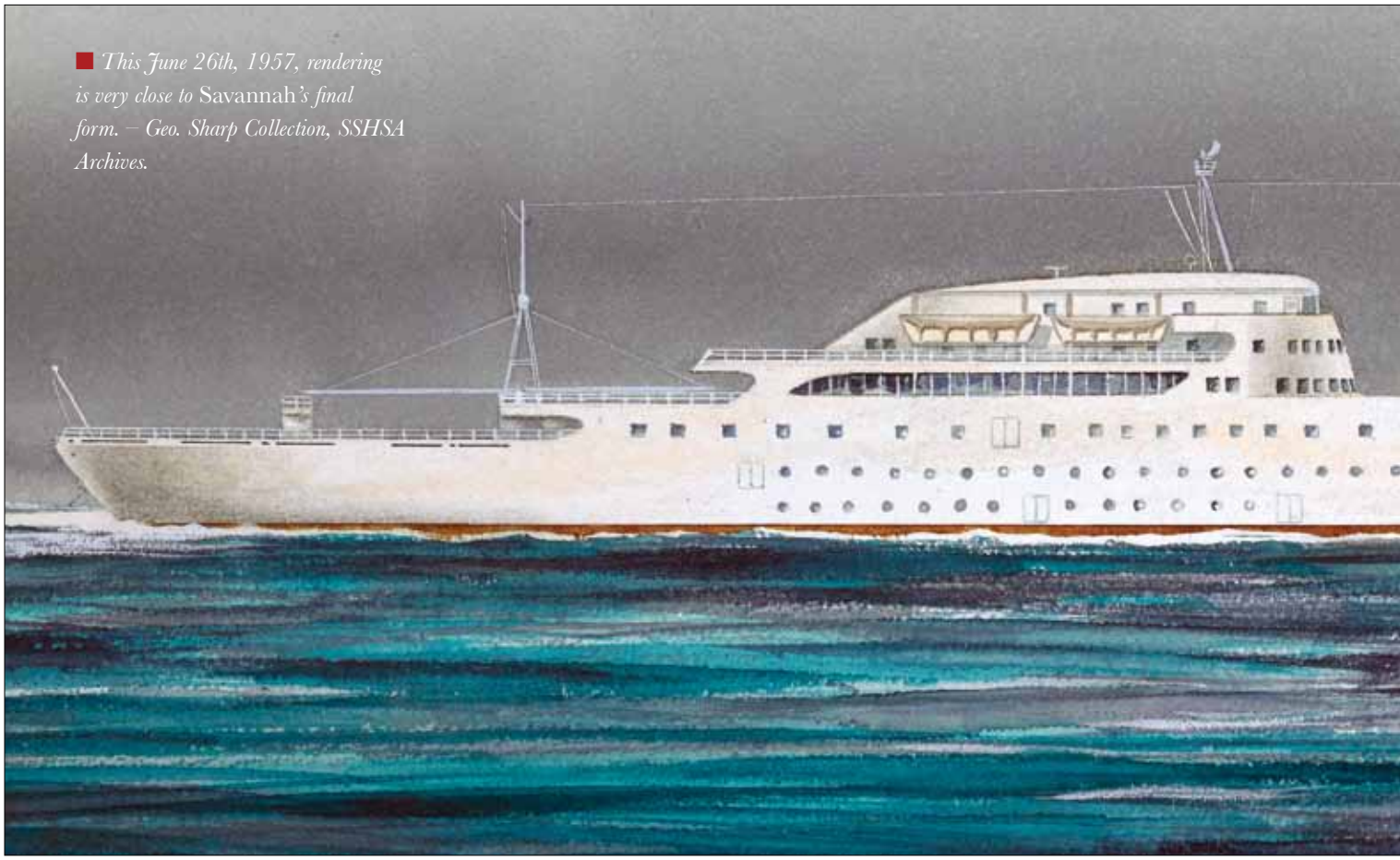


■ *This photo shows a small portion of the plethora of switches and dials in* Savannah*'s control room. – Author's Collection.*





An April 23rd, 1957, proposal with somewhat less graceful lines in a turquoise and white scheme. – Geo. Sharp Collection, SSHSA Archives.



This June 26th, 1957, rendering is very close to Savannah*'s final form. – Geo. Sharp Collection, SSHSA Archives.*

■ Savannah*'s dining room in reality (above) and in a concept rendering by Jack Healy's design team provide an interesting contrast. – Author's Collection and Geo. Sharp Collection, SSHSA Archives.*

Beyond these comparisons, the pricing was the big difference. The final tally on *Savannah* exceeded $50 million. The cost of the nuclear plant, fuel, containment and other reactor ancillary equipment reached $30 million. As a comparison, Ingalls in Pascagoula had just built five Mariner-type ships for $40 million, $8 million each. The exorbitant pricing precluded any nuclear-powered cousins. Another comparison: the 1958-built, 617-ft passenger liners *Brasil* and *Argentina*, which carried 553 passengers, had been contracted for $26 million each.

MODERN INTERIORS

Jack Healy led the team that developed the interior design and decoration for the futuristic nuclear ship. These spaces took on special significance because the press and public were expected to visit. They needed to look modern to match the spectacular hull and machinery. Described as strikingly elegant, the interior was perhaps not as revolutionary as the exterior in order to minimize reminders that passengers berthed adjacent to a nuclear power plant.

The floating industrial exhibit *Savannah* showcased American art, science and industry, inside and out. The ship had seven holds and six decks: Navigation/Bridge, Boat, Promenade, A, B and C. D deck didn't run the length of the ship. Public spaces dominated on the Promenade and A decks, except the dining room, which was on B deck. Officers were quartered on the Boat Deck. The main lounge had a spacious and elegant feel with multiple sitting areas in mixed colors and upholstery types. It doubled as a theater. Even the National Park Service made a special loan to the ship: two circular coffee tables, at opposite ends, sliced from a tree found in Arizona's Petrified Forest National Park.

The promenade had a non-skid covering in shades of blue and green. The 30-inch portholes had polarized glass and easily rotated with a single finger to adjust the brightness. The veranda was

■ *Compare and contrast how Jack Healy's rendering (above) for* Savannah*'s lounge differs from the layout as it appears in this 1964 American Export Lines brochure. – Geo. Sharp Collection, SSHSA Archives and Author's Collection.*

■ *(Above and below) A typical stateroom aboard* Savannah. *– Author's Collection.*

■ *(Below)* Savannah*'s distinctive lobby is the height of modern design. – Author's Collection.*

a modern space with a dance floor in the middle that was constructed of brass circumscribed in translucent white vinyl tile. Table tops had illumination. Behind the bar, and doubling as a wine rack, a colored, honeycombed, stainless steel sculpture mimicked the chart of nuclides. Seemingly stark during the day, in the evening it became dramatic. Glass panels gave a wonderful view looking aft over the pool and out to sea.

The 30 staterooms held a total passenger capacity of 60 and were located on A deck. There were 15 on each side, all outboard with virtually a mirrored layout. Twenty-six of the staterooms contained sofa beds. Only four rooms were dedicated to single passengers. The barber shop, with two chairs and beauty lounge, were forward on this deck to starboard. The hospital, located between the staterooms, contained radiation monitoring apparatus. Deck A also contained the lobby, entered via a thwartship passageway. The chief purser's office, chief steward's office and pursers' workroom flanked the lobby, which could be a formal reception area. A conference room was on the port side adjacent to the chief purser's office. Five elevators served the crew and passengers. All the staterooms and officers' quarters featured color TV, unusual in 1962.

Aft of the main lounge to starboard, a writing room and library faced the promenade. An abstract sculpture titled Atomic Freedom, made of steel and concrete, was a point of focus. A tall metal sculpture by Jean Woodham featured prominently in the main stairwell.

Down below on B deck, the large dining room could seat 75; passengers could dine simultaneously with dignitaries, visitors and guests. Diners found it comfortable and modern, more than luxurious. Red chairs and the white tablecloths contrasted beautifully with the muted blue overhead, on the bulkheads and in the carpet. Behind the captain's table was a large white,

futuristic, wall sculpture by Pierre Bourdelle titled Fission.

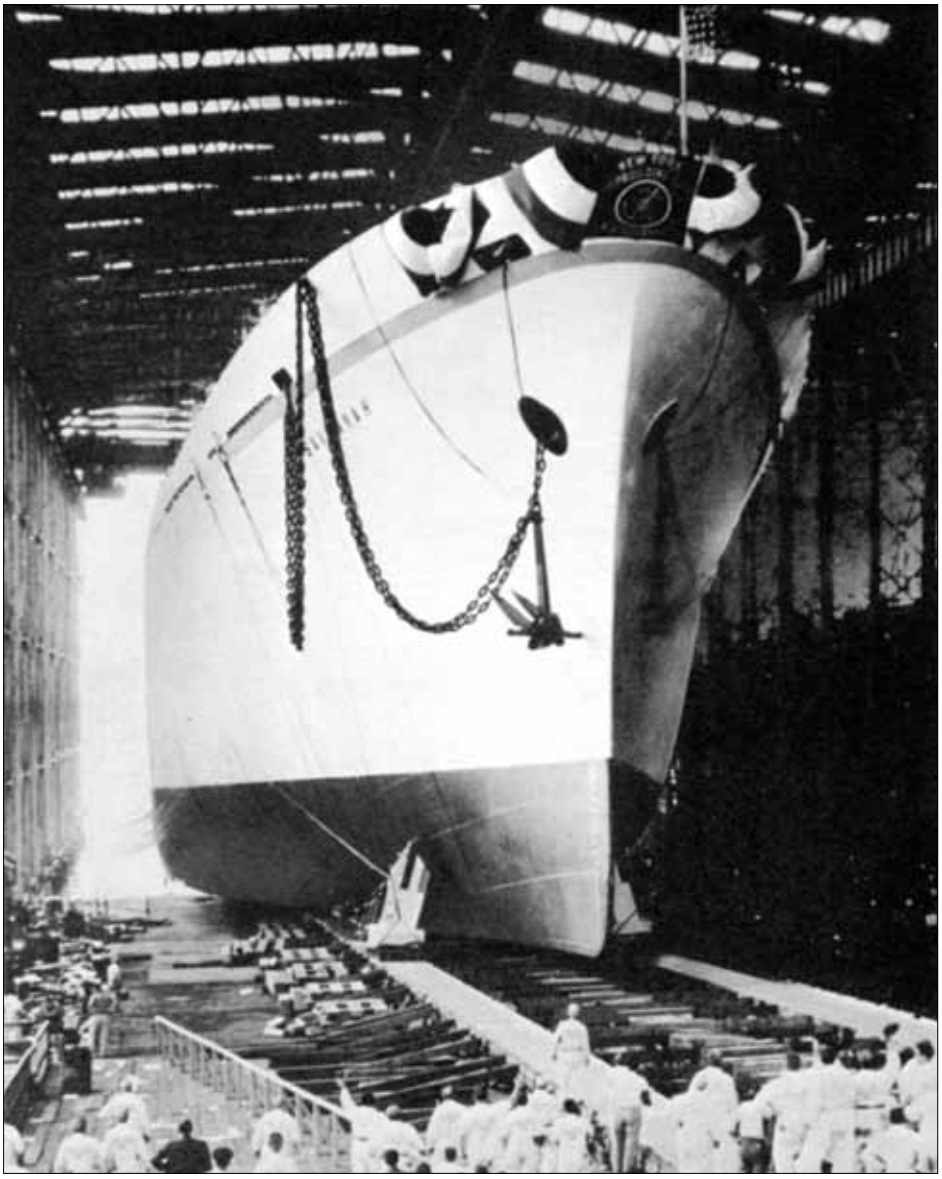
At the opposite end, diners saw a gold-plated model of the original *Savannah*, framed in glass. All the china, napery and cutlery were specifically designed for the ship. The main galley, forward, had easy access to the dining room. Down on C deck was the reactor control room. A unique viewing glass above the engine room allowed passengers and visitors unobstructed views of the engine room and control panel for the reactor operations.

NEW YORK SHIPBUILDING CORPORATION

By any measure, the New York Shipbuilding Corporation has to be considered one of the most important of the 20th century. Founded in 1899 by Henry Morse, New York Shipbuilding was in Camden, across the Delaware River from Philadelphia. Morse had chosen the name because he expected to build the ships on Staten Island. When he couldn't obtain the land, he moved his yard to New Jersey but retained the incorporated name.

New York Shipbuilding had covered slipways that provided some security in addition to protection from the elements. Originally, *Savannah* was to be completed in late 1960. But shipyard delays, problems and extra costs mounted.

■ *(Above)* Savannah*'s modern veranda lounge and dance floor. (Below)* Savannah *at her launching from a covered drydock at New York Shipbuilding's Camden, New Jersey, shipyard. – Author's Collection.*



Unfortunately, the shipyard came to bankruptcy just five years after the *Savannah* delivery.

***Savannah* had** a homeport at Galveston, Texas, along with the Nuclear Servicing Vessel *Atomic Servant*. Todd Shipyards handled the necessary work, with employees having specialized training to support the ship.

MAIDEN VOYAGE

For all of the design, expense, construction, expectations and publicity, *Savannah*'s career was remarkable short – she served for less than eight years. She was christened July 21, 1959, and testing of the reactor systems was completed in October 1961. Two months later saw the first low-power chain reaction. *Savannah* moved to Yorktown, Virginia, under her own diesel power for full-power testing and sea trials. In early March, the reactor became critical. A successful three-day sea trial started on March 23, 1962; reports indicated a fuel consumption of just a tablespoon.

States Marine Lines had been named as operators of the ship in 1958. The early announcement allowed plenty of time to designate officers for training and obtain qualifications to operate the ship. States Marine Lines was founded in 1931 and chartered vessels instead of buying them. After World War II, the line began extensive purchases, taking advantage of the Maritime Commission sale to liquidate excess tonnage. The *Savannah* was delivered to States Marine May 1, 1962, followed by a short trip to

The sleek Savannah *dockside at New York. – Braun Bros. Collection, SSHSA Archives.*

Savannah, Georgia, in August 1962.

The ambitious maiden voyage of five months was unique for a new ship; ships crossing the Atlantic had a maiden voyage of less than one week. The *Savannah* departed her namesake city, postmarking mail on August 27, 1962. Passing through the Panama Canal in mid-September, she headed up the west coast to Seattle, arriving October 1 and remaining for three weeks at the 1962 World's Fair, called Century 21.

***Savannah* could hardly** have expected a better debut to a large public audience. The 600-foot space needle (as tall as the ship length), the monorail and the dramatic ship of the future seemed poised to leap into the 21st century. Fifty-five years later, all three exhibits have stood the test of time.

The ship posted mail at the unique Space Needle post office October 14, 1962. Departing Seattle on the last day of the fair, the trip home included San Francisco in mid-November and Long Beach/Los Angeles on November 28. *Savannah* celebrated Christmas in Hawaii, returning to the mainland at Astoria, Oregon; the actual port visit came at Portland alongside the Willamette River. The last stop along the West Coast was San Diego on January 16. *Savannah* finally reached Galveston a month later, arriving February 5. The ship covered 29,649 miles, equivalent to a trip around the world at the equator. Unfortunately, the engineering department found most of the return disagreeable.

A PUBLIC HUMILIATION

***LIFE* magazine covered *Savannah* labor** problems in the June 14, 1963, issue. A 30-paragraph story titled "Atom Powered Ship is a National Disgrace" denigrated the ship, her builders and her owners and operators.

Labor and pay issues boiled over during the stop in Los Angeles. The 29 engineers resigned, citing pay inequities between States Marine deck officers and the engineers. Labor arbitrators had ruled in favor of the deck officers, who received higher pay than similar ranks in the engineering department. States Marine ultimately convinced the crew of their moral obligation to sail the ship to Hawaii and back to the Galveston homeport. Negotiations might be easier there, the company said, and perhaps an equitable settlement would be reached.

Arriving at the homeport in early February 1963, the engineers walked off the ship, and vitriol between all parties continued. The take-home pay for the two groups was the same, but the engineers were working a seven-day week at sea, thereby enjoying considerable overtime. The government threatened to blacklist and brand the reactor crew as a security risk. The engineers felt that they held a winning hand because of the extent of their training, which meant that they couldn't be readily replaced.

The situation reached the highest levels of government, including the Department of Labor, House of Representatives, Department of Commerce and Atomic Energy Commission (AEC). As negotiations stalled, MARAD, embarrassed by the debacle and watching the ship sit idle, terminated the States Marine contract in late May 1963. Internal governmental discussion preceded the termination and included recommendations for a new manager, American Export-Isbrandtsen, reported July 23, 1963.

AMERICAN EXPORT OPERATIONS

In July 1963, American Export/Isbrandtsen took over operation for $1 and scrambled to find a qualified team. Founded in 1919, American Export had a long-established reputation and was well known between the wars for operation of the four aces: *Excalibur*, *Exochorda*, *Exeter* and *Excambion*. During the war, a series of modified C3 ships made up the bulk of their fleet. Passenger liners *Independence* and *Constitution* joined the fleet in 1951. In October 1960, the firm Isbrandtsen bought a controlling interest in American Export and, after approval by MARAD in 1962, became officially known as American Export-Isbrandtsen Lines in 1964.

American Export had no nuclear-trained engineers with the appropriate qualifications. The *Savannah* would continue to suffer the indignity of lay-up as a qualified crew could be mustered. The AEC anticipated 10 or 12 months to train new engineers, but the Secretary of Commerce predicted four to six months. AEC estimates proved more accurate, and *Savannah* wouldn't depart for Europe until over a year after reaching Galveston.

On April 27, 1965, American Export established a subsidiary for the *Savannah* operation, the First Atomic Ship Transport (FAST). Deck and engineering officers agreed to the same pay scale as other American Export-Isbrandtsen crews. Nuclear training began in earnest at the Merchant Marine Academy on September 3, 1963. Officers began arriving in Galveston in early December for onboard training. Finally, *Savannah* left Galveston, arriving in New York June 2, 1964.

As the new manager began sailing *Savannah*, the bloom had come off the rose in the United States, but European ports still anticipated her arrival. On June 8, 1964, she finally made her first Atlantic crossing. She reached Bremerhaven, Germany, 10 days later then shifted to Hamburg on June 23. German interest in the ship proved high. Ironically, her arrival in Germany coincided with the launching of the nuclear-powered *Otto Hahn*, Germany's *Savannah* equivalent. The Hamburg shipyard of Kieler Howaldtswerke had laid her keel on August 31, 1963, as hull number 1103.

***Savannah* sailed** to Dublin, arriving July 2, and then to Southampton, July 7 through 12. She returned to New York on July 20. Soon at sea again, she visited Portland, Maine on August 7 and Pier 84 in New York City on September 21. The successful Atlantic voyage proved the American Export management decision sound.

Passengers traveling in the ship found a confusing array of pricing. Other than the transatlantic voyages, the ship wasn't on a regular route, and passage charges were one-time only. From the last U.S. port to ports in Europe, the price was $550 per person for two in a three-person cabin, and another $425 would carry a car across the Atlantic. Barcelona to Naples could be booked for $125 per person for three persons in a cabin. The ship hosted open houses at virtually every port visit, and she offered some overnight visits to nearby ports in the United States. There was even an overnight trip from New York to Philadelphia for $50. Most passengers wanted the privilege of riding a nuclear ship, and the *Savannah* was the only one.

MARAD awarded a three-year charter to FAST on May 20, 1965. Red tape and bureaucratic difficulties delayed the award for a nuclear reactor operating license. Some technical problems needed attention, including replacement of all four main coolant pumps. The first commercial trip went to Europe August 20 through October 9. With her cargo spaces filled, *Savannah* worked the ports of Bilbao, Rotterdam, Antwerp, Bremerhaven and Le Havre. At the end of November came an initial Mediterranean voyage, with a return January 1966.

After the European visits, American Export-Isbrandtsen kept the ship "profitable," but with generous governmental subsidies. Expenses proved more than the line expected. Passenger operations had been discontinued, which meant a reduction of 25 crew members, most in the purser's department. *Savannah* continued as a freighter, with a passenger capacity of 12, similar to the 1962 *Export Builder* and her sisters. The crew moved

Fireboats and small craft welcome Savannah *into port. – Author's Collection.*

■ *The glamorous, gleaming white* Savannah *overshadows the typical freighter docked across the way at 33rd Street, Brooklyn, NY, October 31, 1964. – Braun Bros. Collection, SSHSA Archives.*

■ *Superstructure details of NS* Savannah *at 44th Street Pier on North River, April 6, 1968. – Braun Bros. Collection, SSHSA Archives.*

into the passenger staterooms, but the ship still maintained the huge taxpayer subsidies. The expense of crewing the engineering department, plus the multitude of AEC reactor operation regulations, continued to raise the operating expenses. Many people forgot that *Savannah* was never expected to make money for the operators.

The 1968 budget included provisions to remove the *Savannah* subsidy and revoke the FAST contract a year early. Arguments on both sides revealed that the ship in operation proved highly successful, with reactor availability 99.7 percent during all commercial trips. Cargo holds recorded 94 percent full eastbound and westbound. Revenue exceeded FAST expectations, and the House Appropriations Committee reversed its budget projections, granting an additional $3.5 million for fiscal year 1968.

ALL STOP – FINISHED WITH ENGINES

Following the budget decision in 1967, *Savannah* looked finished by the fall of 1968. A call to save her went out. The ship had been operating for only six years, nearly one-and-a-half years pierside. Even after 332,000 miles, the original core still had life, so the decision was made to continue. After a partial refueling and element rearrangement, she left for the Orient. There was even some talk of conversion to a container ship, but that would be expensive and not worth the effort.

Returning to Galveston in July 1970, *Savannah* shut down for the final time. Reactor operations were over and she passed back to MARAD, which laid her up in Galveston for 10 years, after which an attempt was made to bring her to her namesake port. Regrettably, city politicians were indifferent and squabbled among themselves. The majority of the city residents were dismayed when the spruced-up *Savannah* went to Patriots Point Museum at Charleston, South Carolina, where the still-beautiful ship shared the limelight with the destroyer *Laffey*, carrier *Yorktown*, submarine *Clamagore* and Coast Guard cutter *Ingham*.

Calculations indicate that *Savannah* steamed 470,000 miles and used 137 pounds of nuclear fuel. She visited 77

Forward deck of N.S Savannah, Brooklyn, New York, October 31, 1964. – *Braun Bros. Collection, SSHSA Archives.*

ports in 25 countries and hosted 1.3 million visitors. In 1982, 20 years after delivery, interest in the ship seemed confined to an older generation. Finally, and long overdue, *Savannah* became a National Historic Landmark in 1991. By 1993, the 30-year-old ship needed major attention. After a 1994 dry-docking, she moved to the Merchant Marine Reserve. Today, *Savannah* is under a long-term lay-up contract with Canton Marine Terminals in Baltimore.

***Savannah* is a testament** to the optimism in the United States. She proved worthy of the initial $50 million investment. She proved that building and operating a commercial nuclear ship at sea was uneconomical. The ship publicly demonstrated the difference between "atomic bomb" and "nuclear power." She showed that disposal of nuclear waste had difficulties that weren't completely resolved. Her operations clearly proved the safety and dependability of nuclear power. The ports facilities needed to support the ship were inadequate. Both sailing and in-port expenses were more than the top estimates, discounting heavily any ability to make money without subsidy. She identified the expenses, duration of construction and risk versus reward for shipbuilders.

***Savannah* clearly** demonstrated the pitfalls in educating and paying highly trained, unionized employees. The difficulty in dry-docking and shortcomings in emergency repair facilities have been identified. The arrangement of port visits proved comprehensive and revealed that some countries had misgivings about hosting a nuclear ship pierside for cargo operations, or even at anchor.

***Savannah*, far from** being a national disgrace, has rightly achieved legendary status. When she returned to MARAD, the price of fuel averaged 35 cents per gallon; today the price is ten times that. Would that have made a difference in the decision to continue with nuclear ships? Probably not. Only the Navy can exploit the advantages of nuclear power and handle the associated pitfalls.

***Savannah* remains** a beautiful, elegant and unique ship, a National Historic Landmark. She is, surely, one of the most significant ships built during the 20th century. ⚓

About the Author

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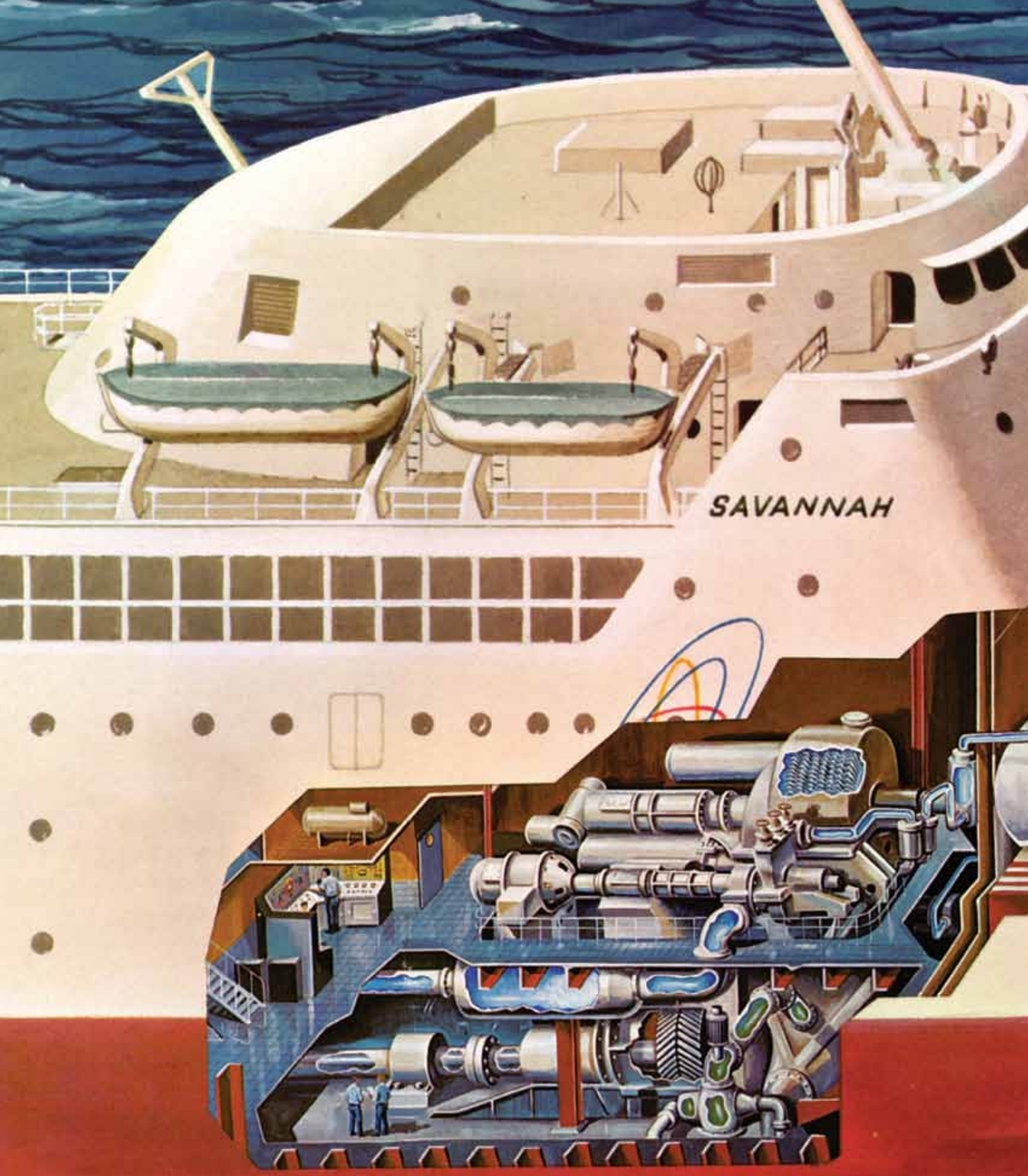
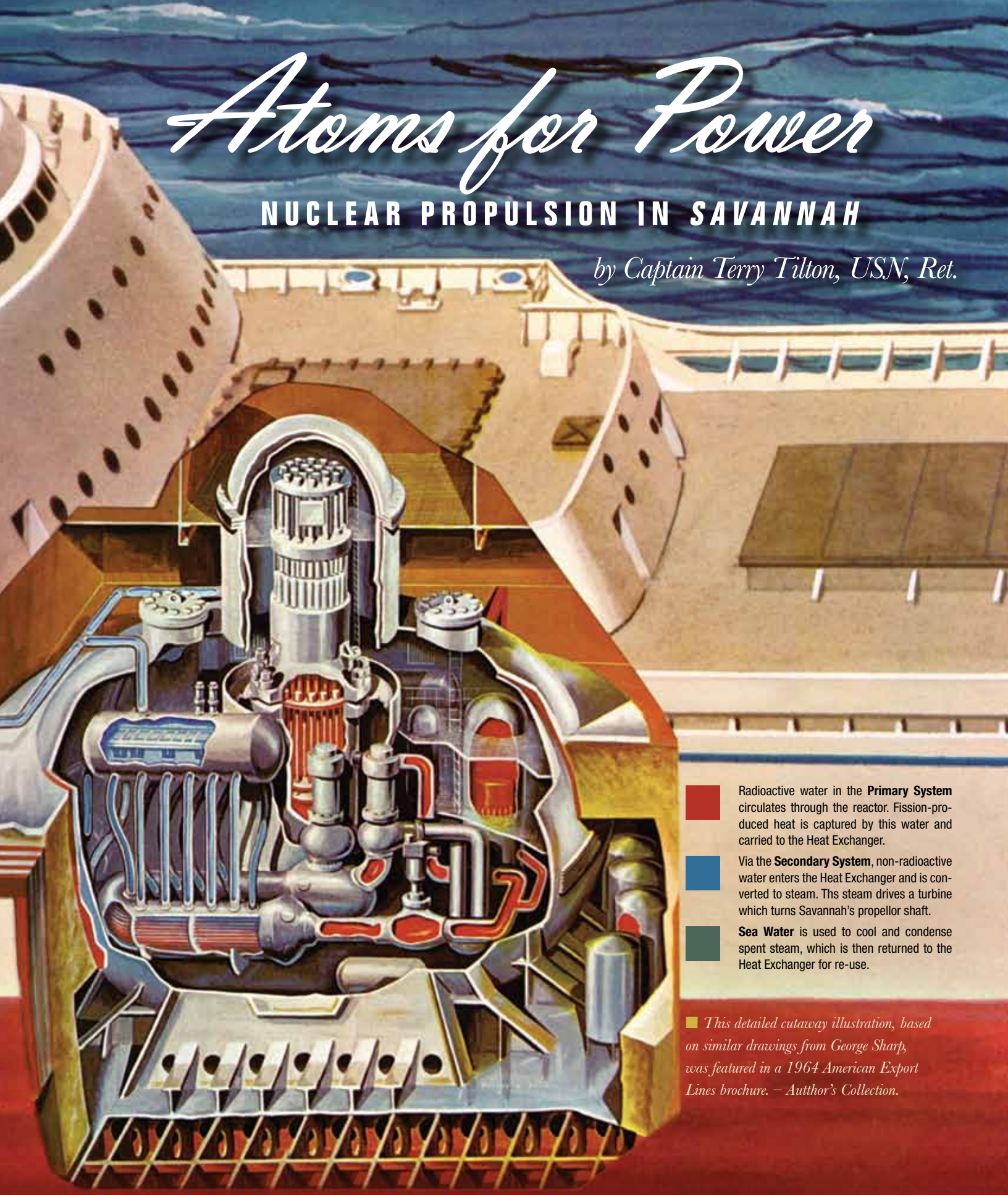
SSHSA board member, a ship enthusiast for 50 years, has deck and engineering experience on steam, diesel, nuclear and gas turbine ships. A graduate of the U.S. Naval Academy, he has been underway on 200 ships and commanded the USS Peoria *during Operation Desert Storm. He and his wife, Mary Pat, reside in San Diego, California.*


SAVANNAH

Atoms for Power

NUCLEAR PROPULSION IN *SAVANNAH*

by Captain Terry Tilton, USN, Ret.

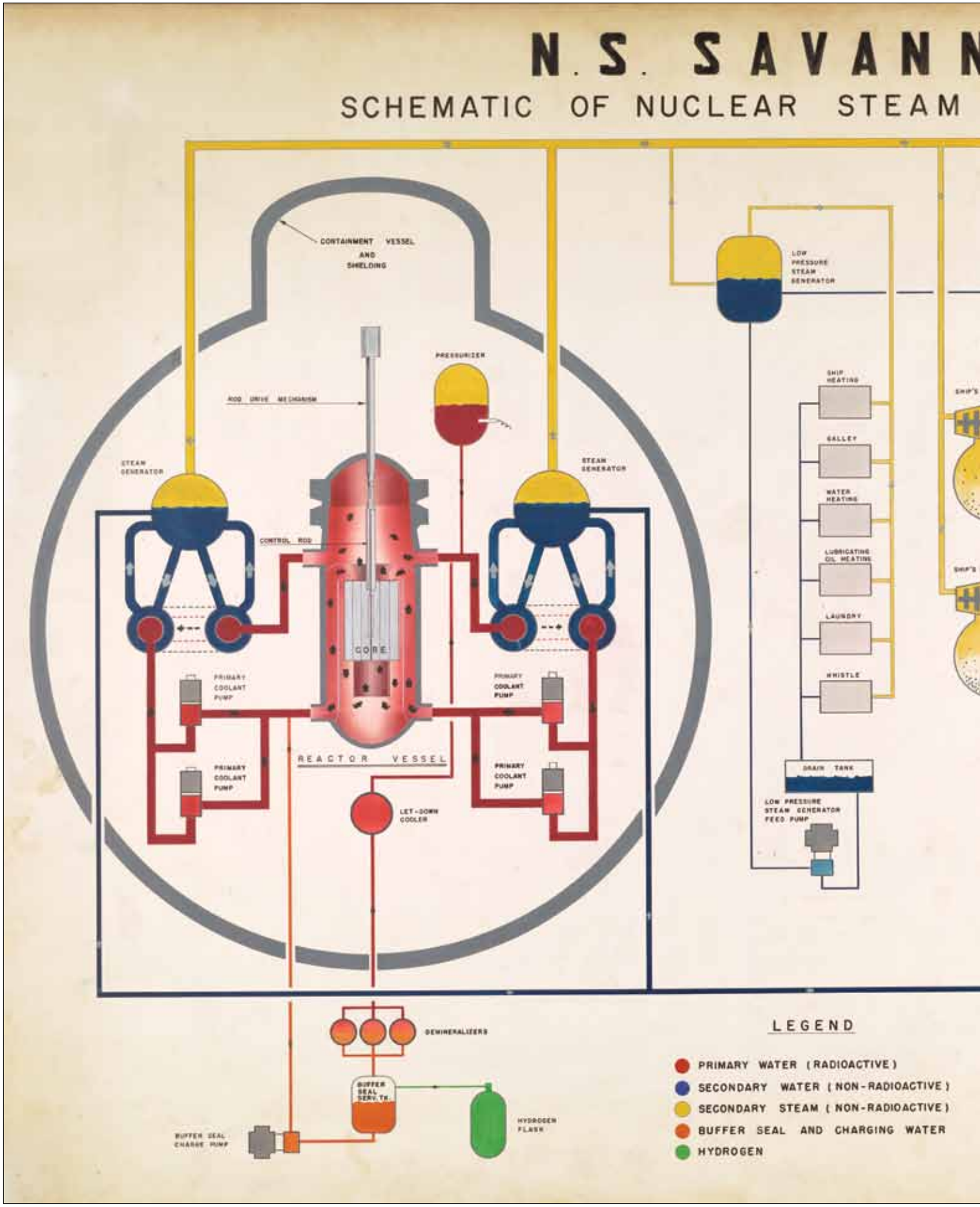


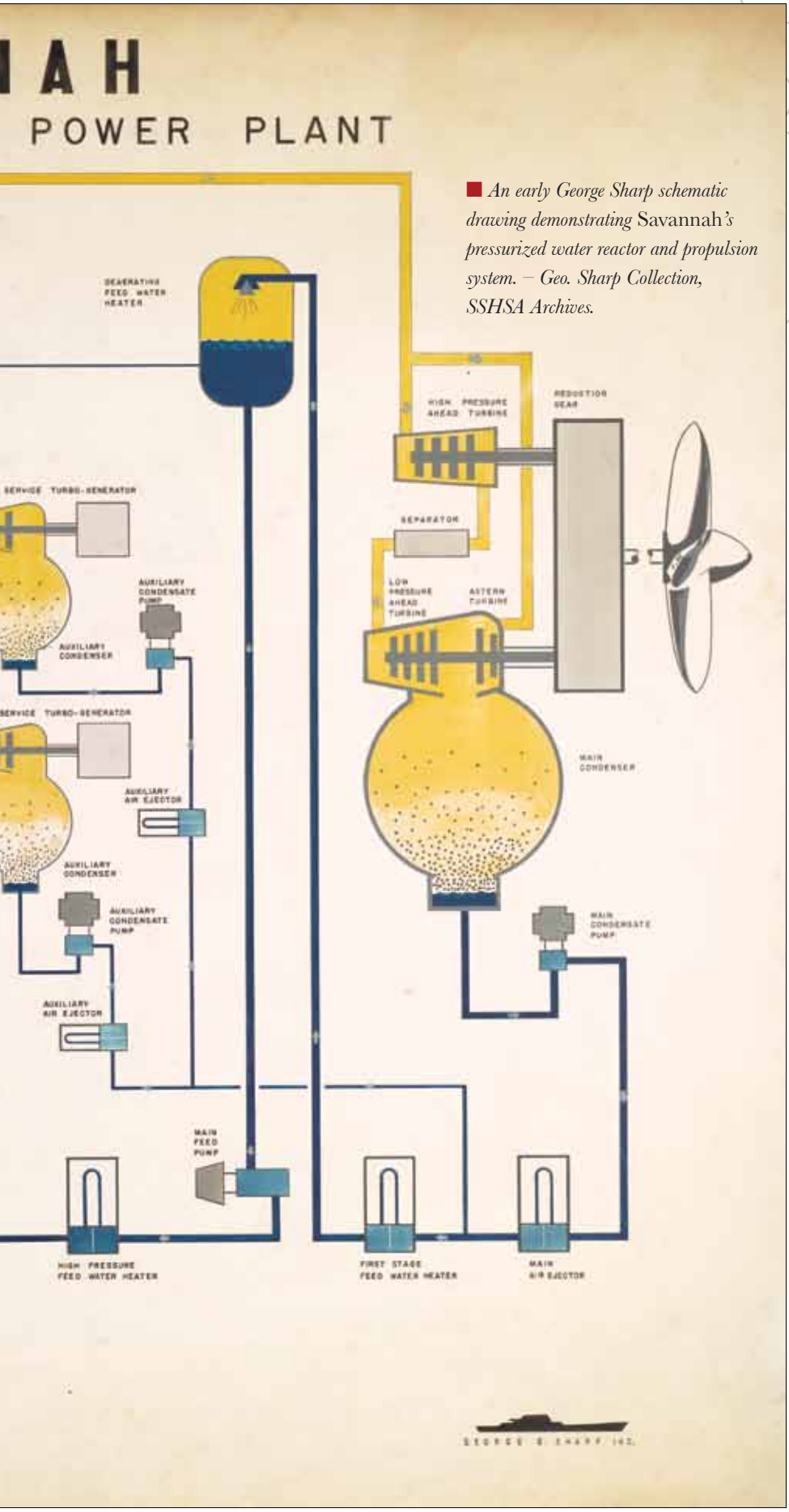
Radioactive water in the **Primary System** circulates through the reactor. Fission-produced heat is captured by this water and carried to the Heat Exchanger.

Via the **Secondary System**, non-radioactive water enters the Heat Exchanger and is converted to steam. Ths steam drives a turbine which turns Savannah's propellor shaft.

Sea Water is used to cool and condense spent steam, which is then returned to the Heat Exchanger for re-use.

This detailed cutaway illustration, based on similar drawings from George Sharp, was featured in a 1964 American Export Lines brochure. – Autthor's Collection.


N.S. SAVANN
SCHEMATIC OF NUCLEAR STEAM
CONTAINMENT VESSEL AND SHIELDING
PRESSURIZER
ROD DRIVE MECHANISM
STEAM GENERATOR
STEAM GENERATOR
CONTROL ROD
CORE
PRIMARY COOLANT PUMP
PRIMARY COOLANT PUMP
PRIMARY COOLANT PUMP
PRIMARY COOLANT PUMP
REACTOR VESSEL
LET-DOWN COOLER
LOW PRESSURE STEAM GENERATOR
SHIP HEATING
GALLEY
WATER HEATING
LUBRICATING OIL HEATING
LAUNDRY
WHISTLE
DRAIN TANK
LOW PRESSURE STEAM GENERATOR FEED PUMP
DEMINERALIZERS
BUFFER SEAL SERV. TK.
HYDROGEN FLASK
BUFFER SEAL CHARGE PUMP
LEGEND
PRIMARY WATER (RADIOACTIVE)
SECONDARY WATER (NON-RADIOACTIVE)
SECONDARY STEAM (NON-RADIOACTIVE)
BUFFER SEAL AND CHARGING WATER
HYDROGEN



■ *An early George Sharp schematic drawing demonstrating* Savannah*'s pressurized water reactor and propulsion system. – Geo. Sharp Collection, SSHSA Archives.*

THE VENTURE INTO NUCLEAR SHIPBUILDING may have been the most innovative step in the 150-year history of the U.S. Merchant Marine. Nuclear power promised to revolutionize the maritime industry, the technical equivalent of the 19th-century change from wind power to steam-powered machinery. There were bold expectations of nuclear-powered submarines and surface ships crossing the oceans at high speed.

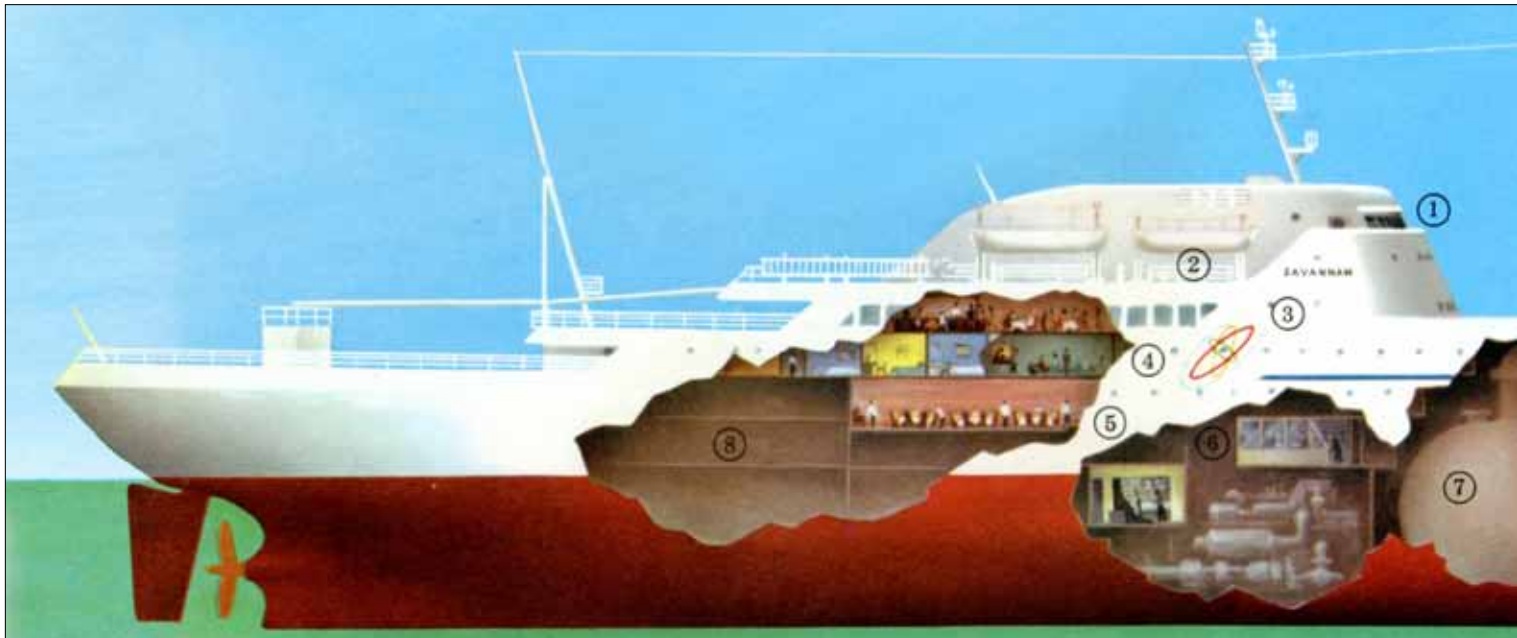
WHILE THEY'RE HUGELY DIFFERENT, there are some commonalities between the generation of steam in a reactor and in a conventional boiler. The reactor core is analogous to the boiler furnace. Boiler combustion gasses correspond with the primary coolant in a nuclear reactor. The water tubes and steam drum in a boiler have a function similar to that of the reactor heat exchanger.

ATOMS FOR PEACE

IT WOULD SURPRISE NO ONE THAT A SHIP, having plenty of space for the reactor and associated machinery, should be the first form of transportation to demonstrate nuclear viability. But other forms of transportation were considered for nuclear engines. Henry Ford II directed considerable research toward an atomic-powered car that would contain a reactor small enough to fit into the car's trunk. This proposed automobile, the Ford Nucleon, made it to a sophisticated 3/8 scale (6.5 feet long) model. Later, Ford displayed a futuristic automobile with possible nuclear power at the same Century 21 World's Fair attended by *Savannah*.

A NUCLEAR-POWERED locomotive named X12 became the subject of a 54-page paper by General Motors, General Electric and Westinghouse. Patents had been granted; the proposal described the feasibility of a reactor driving motors totaling 7,000 horsepower. This unit had an overall cost that was over twice that of a four-unit diesel electric locomotive.

NUCLEAR-POWERED AIRCRAFT advanced further. Both the United States and USSR had significant investment in the project. The U.S. research began in 1951, even before the



STEP ABOARD THE *Savannah*

1. Navigating bridge deck. *Pilot house, chart room, radio room, instruments.*
2. Boat deck. *Officer accommodations.*
3. Promenade deck. *Public lounge, veranda and cocktail bar. "Walk around" terrace has colorful ceramic tile floor, gives unobstructed view of the sea through windows 30 inches high. Veranda opens through sliding glass doors onto a swimming pool. Dance floor surrounded by tables with illuminated tops.*
4. "A" deck. *Main lobby. Offices for purser,*

nuclear-powered submarine. The United States converted a B-36 to carry a reactor-powered engine. The plane, named *Crusader*, made over 40 test flights with a reactor onboard, even though the nuclear plant never actually powered the engines. Two airplane reactors are on display at the Idaho National Laboratory in Arco.

NUCLEAR THEORY HISTORY: $E=mc^2$

During Operation Sea Orbit, on June 18, 1964, a famous photo was taken of sailors spelling out $E=mc^2$ on the nuclear-powered *Enterprise*. The photo enthralled readers of the February 1965 *National Geographic*. The famous equation was published in 1905 by Albert Einstein.

The concept of atoms dates back to Greek scholars 2,500 years ago. John Dalton, an English schoolteacher, was the father of modern atomic theory. He determined that elements consist of atoms of different sizes. Using quantitative analysis, he recorded a table of atomic weights, a forerunner to the periodic chart of the elements.

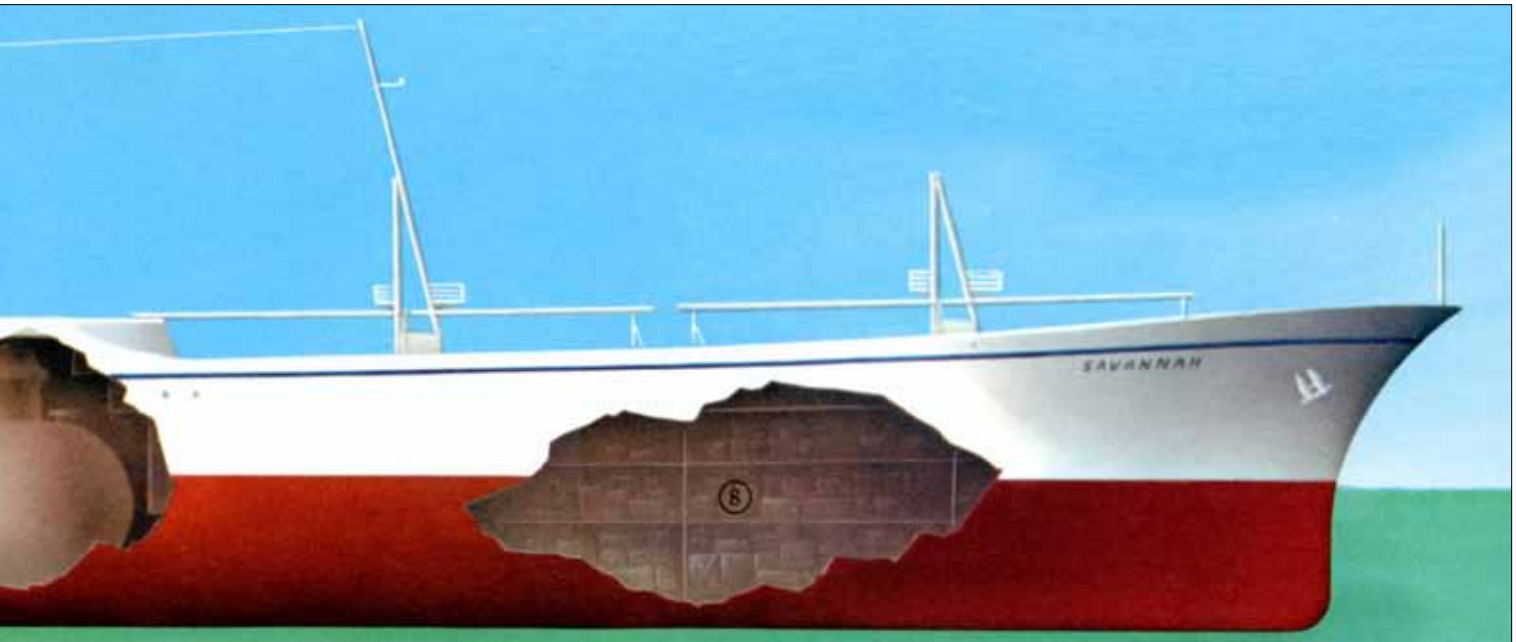
Scientists in atomic theory used his work as a basis for further exploration. And in 1913, H. G. Wells' fictional account *World Set Free* related a story of European war where nuclear-powered planes dropped nuclear bombs.

Enrico Fermi met with the top-level Navy technical community in March 1939 and described the possibility of uranium-235 generating heat to propel ships and submarines. A detailed discussion of nuclear power at sea came from a dissertation by Admiral Harold G. Bowen on November 13, 1939: "Memorandum on Sub-Atomic Power Sources for Submarine Propulsion." The first splitting of the element uranium came on December 17, 1938. Thirty months later, the Maude Committee Report in the United Kingdom predicted the possibility of nuclear-powered ships by 1945.

In 1942, nearly all efforts in atomic research concentrated on the manufacture of an atomic bomb. Nuclear power at sea would have to wait. Scientists at the University of Chicago recorded the first self-sustaining nuclear reaction on December 2, 1942. In 1944 the Manhattan Project predicted an atomic bomb success within a year.

After the atom had been successfully demonstrated in an

■ *Loaded into steel tubes, 682,240 pellets packed enough power to drive* Savannah *300,000 miles. They offer no radiation hazard until activated. – Author's Collection.*



steward, doctor and nurse. Dispensary. Air-conditioned staterooms and suites to accommodate 60 persons.

5. **"B" deck.** *Dining room seating 75 people. Sculptured mural provides dramatic background at one end; opposite is a golden model of the original* Savannah *suspended in a glass panel.*
6. **"C" deck.** *Reactor control room viewing gallery. Service and storage areas.*
7. **Reactor area.**
8. **Holds.** *The* Savannah*'s seven cargo holds accommodate 9,400 tons of freight in aproximately 746,200 cubic feet of cargo space.*

explosion, research accelerated in using it for propulsion. By 1949 Westinghouse, operating on a budget provided by the Navy and the Atomic Energy Commission, constructed a land-based prototype reactor in Idaho. There the pressurized water reactor proved the best choice for a nuclear submarine.

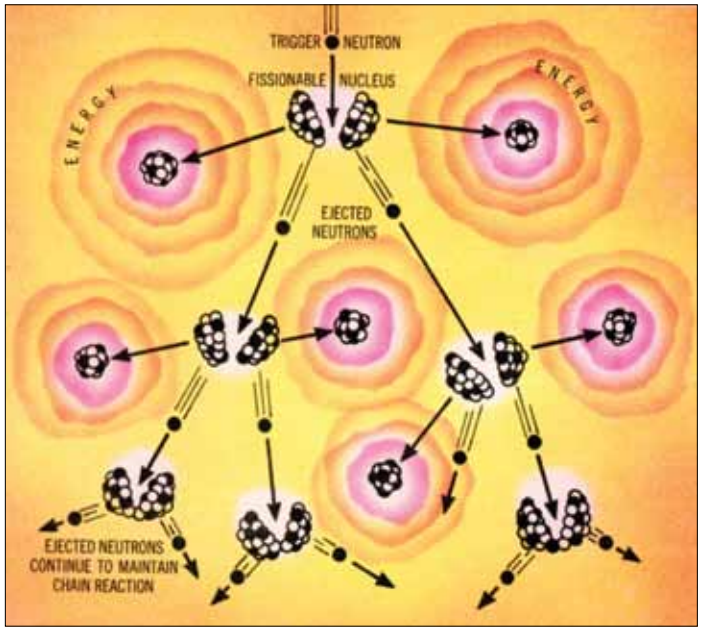
URANIUM

Uranium was discovered in 1789, identified by Martin Heinrich Klaproth in Czechoslovakia. It's nature's heaviest element, number 92 on the periodic table, with a density greater than that of lead. Henri Becquerel discovered that radium was radioactive when he left it adjacent to photographic film and it created a cloudy image. Splitting the uranium nucleus generates heat, the product useful for propulsion. A single pound of uranium has been compared to 1,500 tons of coal.

Uranium can be found in several different rocks, and it's available throughout the Colorado Plateau and South Dakota. At the time of the *Savannah* reactor development, uranium wasn't particularly plentiful, and a search for uranium began in earnest. Through the 1950s, prospectors searched far and wide, reminiscent of the gold rush a hundred years earlier. Rich deposits were found in Canada. Towns with names such as Uranium City and Port Radium sprouted. Amateurs deluged the Atomic Energy Commission for information regarding the search, so the government published a booklet, "Prospecting for Uranium," for just 55 cents. Today the element is plentiful in Kazakhstan, Canada and Australia; production is about 40,000 tons per year.

FISSION

The unique power plant in *Savannah* is described as "atomic" or "nuclear." A uranium nucleus consists of positively charged protons and uncharged neutrons, with electrons orbiting around them. Uranium-235 has 143 neutrons, 92 protons and 92 electrons; uranium-238 has an additional three neutrons. This seemingly insignificant difference prevents uranium-238 from undergoing the same fission process as U-235. The strength of the bond between the neutrons and protons is almost unimaginable. During construction of the reactor for the submarine *Nautilus*, it was said that if a piano wire had the same strength as the U-235 atom, it could support a battleship.



■ *A nuclear fission reaction. In* Savannah *the energy produced is used to generate steam to drive a turbine propulsion system. – Author's Collection.*

BABCOCK & WILCOX

After funding was provided for the *Savannah* in 1956, an appropriate reactor had to be developed to demonstrate the feasibility of nuclear-powered merchant ships. The Atomic Energy Commission and Department of Commerce funded the project and developed bid specifications. Babcock & Wilcox won the contract with a low bid of $9.9 million, a bid designed so that B&W could leap into the field ahead of its competitors. B&W had been involved with atomic energy contracts since 1944. The company obtained the contract for the first two nuclear submarines, *Nautilus* and *Seawolf*, one with a pressurized water reactor and the second with a liquid metal-cooled reactor.

B&W, established in 1868, was esteemed for its naval and marine work, especially in steam generation. The company's innovations enabled greater steam pressure and temperature. The oldest known B&W product, an 1869 boiler and steam engine, is located in the Henry Ford museum in Dearborn, Michigan.

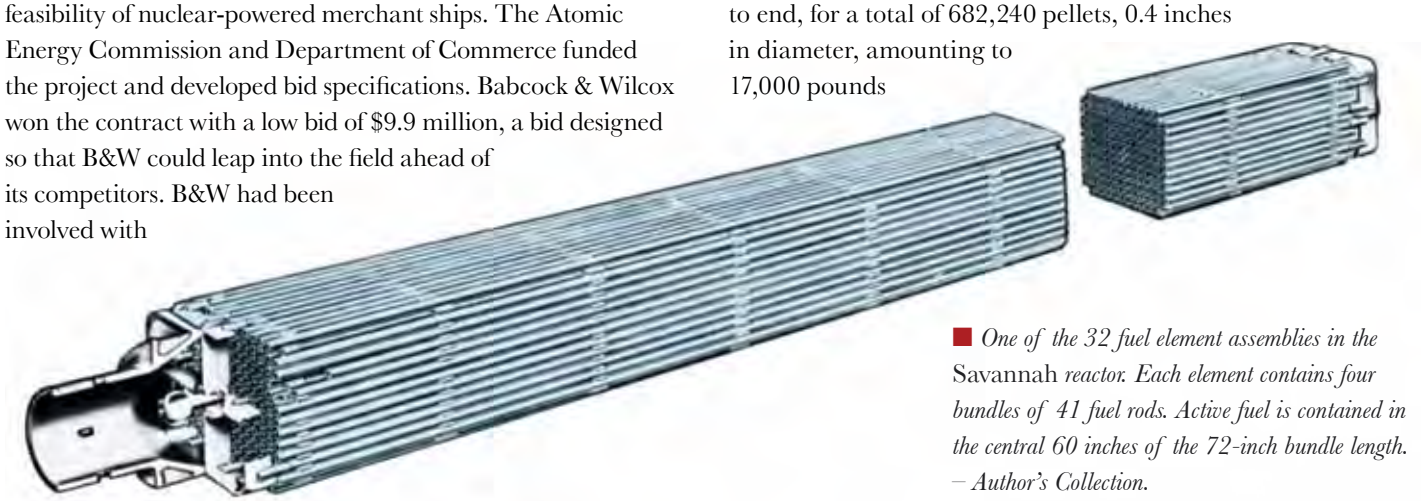
After a rash of boiler explosions, B&W invented a safety boiler and, in 1875, the first water tube boilers. Virtually all of the 2,700 liberty ships carried B&W boilers. The eight boilers for the *United States* were all designed or built by B&W. Of the fleet steaming into Tokyo Bay in 1945, B&W had constructed the boilers of all the aircraft carriers, 99 percent of the destroyers and 80 percent of the battleships. The *Baltimore*-class heavy cruisers had main battery gun mounts built by B&W.

REACTOR CONSTRUCTION

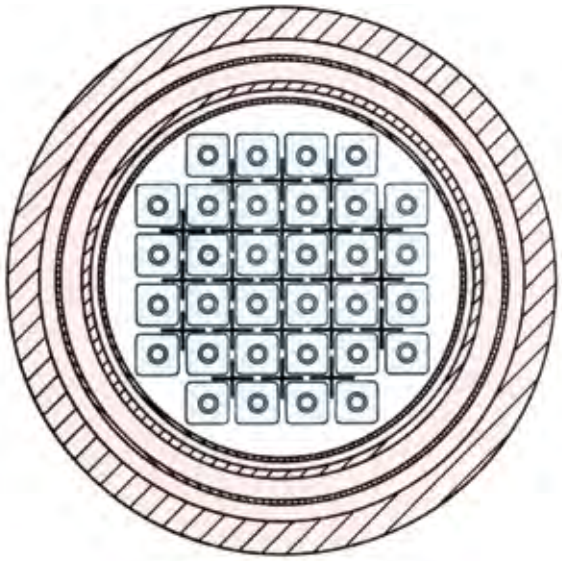
As in the first nuclear submarine, *Nautilus*, the reactor type in *Savannah* is a Pressurized Water Reactor (PWR.) Nuclear plants developed for sea must be able to withstand shock, vibration, flooding and collision. Beyond the contract for design and construction of the propulsion plant, B&W was responsible for supervising the reactor installation at New York Shipbuilding and took part in the testing. This contract, with ancillary equipment, amounted to approximately half of the construction costs.

The nuclear reactor on *Savannah* rests within a containment vessel. A cylinder-shaped cage containing the reactor core is 5 feet in diameter and 5.5 feet high, almost circular. There are 32 uranium fuel elements, measuring 6 feet tall by 8 inches square. Each of the 32 elements holds 164 fuel rods, in four bundles of 41 rods. Each of the 5,248 rods measures about half an inch in overall diameter, with a maximum length of 88 inches; the fuel-filled section has a length of 66 inches. The lower end of each element terminates in a stub that wedges itself into a grid plate. About a quarter of each element area is a coolant passage.

Within each rod, 130 uranium fuel pellets are placed end to end, for a total of 682,240 pellets, 0.4 inches in diameter, amounting to 17,000 pounds



■ *One of the 32 fuel element assemblies in the* Savannah *reactor. Each element contains four bundles of 41 fuel rods. Active fuel is contained in the central 60 inches of the 72-inch bundle length. – Author's Collection.*



■ *Top view of the reactor core showing the arrangement of fuel elements and control rods. Rods are in heavy black. – Author's Collection.*

of uranium, of which only 725 pounds is uranium-235. The remaining enrichment comes from its non-fissionable partner, uranium-238. The three passes of pressurized water through the reactor core absorb the heat from the nuclear fission and, ironically, encourage the chain reaction sustainability.

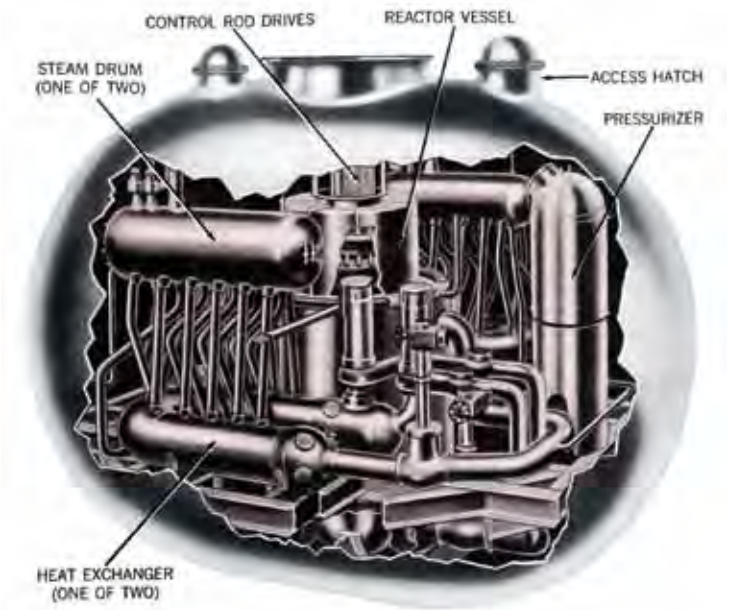
The core cage rests in a reactor vessel 26 feet high, with an 8-foot internal diameter; the cage is only 20 percent of the overall height. The extra height beyond the core itself is mostly because of the 6-foot control rods, plus the vertical control mechanism, flow baffle assembly and grid plates above and below the elements. The walls are 6.5 inches thick and can withstand 2,000 psi and temperatures of 650°F. Interior walls are cladded with quarter-inch stainless steel for corrosion resistance. The reactor vessel, without the core, equals the approximate weight of the two boilers on the Mariner-class ships.

While the 32 elements remain stationary, 21 mechanical, cruciform-shaped control rods surround the element bundles. Each element is adjacent to at least one control rod. These rods are constructed of boron stainless steel, a neutron-absorbing material with a high melting point that controls the sustainability of the reaction. The vertical movement of these rods is concisely controlled, and the complex system has multiple power sources for safety. Safety locks ensure that the rods remain in the lowest position in the event of a ship capsize.

When the rods are in the lowest position, for a "shut down," nuclear fission is prevented. The control rods are lifted with an electric motor driving a hydraulic pump. Maximum steam generation and equivalent top speed occur when the control rods are at their highest. The primary coolant makes three passes through the core, picking up heat from the 620°F fuel-rod surfaces.

The initial *Savannah* element fueling was completed on November 29, 1961, five months before the ship was delivered to the Maritime Commission. The 32 elements required approximately an hour each to install, and the entire process didn't begin until dummy, dry-run training was successfully completed.

CONTAINMENT SHELL



Cutaway drawing of containment vessel with components of nuclear power plant shown. Vessel is sealed at all times during plant operation and is well protected on all sides. – Author's Collection.

Forward of the engine room at the second deck is the containment vessel, not to be confused with the reactor core vessel. The shape is somewhat oval, 50.5 feet long and 35 feet in diameter, with a 13-foot extension above the basic cylinder, necessary to house the control rod drive shafts and allow access for refueling. The larger shell contains the equipment for the entire primary pressurized water loop: primary coolant pumps, valves, steam generators (boilers), monitoring equipment, steam drums, pressurizer and ancillary piping. Approximately 100 tons of nickel alloy steel is used in the reactor, vessel and containment shell. This shell protects the crew and ship should the most dramatic catastrophe occur. A surprising total of 82 penetrations exist for piping, electrical cables, pneumatic lines and accesses. The amount and complexity of equipment within the shell necessitated construction of a full-size exact replica, constructed mostly of wood.

Extensive shielding surrounds the containment shell. The carbon steel walls are 2-3/8 inches thick and can contain internal pressures up to 186 psi, accommodating any complete rupture of the cooling fluid. The fission process produces significant gamma rays, and a primary function of the shell is to contain the radiation. External to the containment shell is a 33-inch layer of water, then a layer of lead. Continuing outboard, there's a combination of lead and 125 tons of polyethylene on the upper level and concrete around the lower level.

In the worst case, a broadside collision at sea (determined to be not credible), the opposing ship would need to penetrate 17 feet of structural reinforcement, a heavy collision bulkhead, two feet of laminated redwood and steel collision mat, plus four feet of concrete in order to reach the containment shell. The total weight of the reactor core, shielding, equipment and containment shell equals 2,500 tons, the displacement of a loaded World War II destroyer. This weight forward of the superstructure necessitates considerable strengthening of the basic Mariner-ship hull.

STEAM GENERATION

The *Savannah* PWR is one of several types of naval reactors. Water under extreme pressure boils at a much higher temperature than 212°F at sea level. In the *Savannah,* the water is under extremely high pressure, 1,750 psi, giving a boiling point of 530°F. This pressurized water is maintained by powerful pumps and a pressurizer within a water loop of piping with no opening or mixing with other mediums. This high-pressure loop remains a nearly constant water temperature throughout – an average of about 508°F, never reaching steam conditions – entirely within the containment shell, passing through the reactor. This primary loop of piping absorbs the heat generated by the fission process. The pressurized water at 520°F is then force-fed into the tubes on the primary side of the heat exchanger (steam generator), in the bottom unit, passing heat to the exchanger, and exits the exchanger at 495°F.

The motive force circulating the primary water loop through the reactor and steam generator is maintained by four massive coolant pumps. These Allis Chalmers pumps and motors were the upright type and each consumed 250 horsepower to run at full speed, consuming 1.5 percent of the reactor power to operate. The pumps had electrical windings for both high and low speed. Each pump had a flow rate of 5,000 gallons per minute. On line together, the pumps could empty an average swimming pool in 30 seconds.

Secondary water from the turbines and condenser is forced into the same bottom unit at a lower temperature than the primary water. This water surrounds the 520°F primary loop in the tubes and flashes into steam, which is collected in the upper steam drum. There are two steam generators, each one completely isolated from the other in case of mechanical difficulty. Since the temperature difference between the primary water inlet and outlet is a mere 25°F, the *Savannah* heat exchangers have been designed for a large primary water flow rate. The U-shaped tube has a 5-foot diameter.

Once it gives up heat to generate steam, the pressurized water passes through the reactor again, continuing the loop. Steam leaves at the top of this steam generator through 8.5-inch-diameter piping and moves to the engine room main turbines and the turbo-generators. The ship can maintain approximately 14 knots on just one steam generator. With a lower load (less speed) on the main turbines, steam pressure

is higher than the full-speed, 475-psi pressure. The volume of steam produced, 125,000 lbs/hour, almost doubled that of the two B&W boilers on the Mariner ships. The additional volume mitigated the large differences in steam pressure conditions. The *Savannah* had a conservative power plant because, for her purpose, the highest reactor development wasn't required.

What's remarkable about the steam conditions is that the pressure and temperature of the steam are so unremarkable. The specifications of the steam system seem quite regressive to the turbine/boiler technology of the era. The final ship built by the U.S. Maritime Commission (No. 2918) in 1951, the unique *Schuyler Otis Bland*, tested boiler efficiency with a turbine inlet pressure of 875 psi and temperature of 900°F. The 1952-built Mariner ships had 600 psi at 875°F.

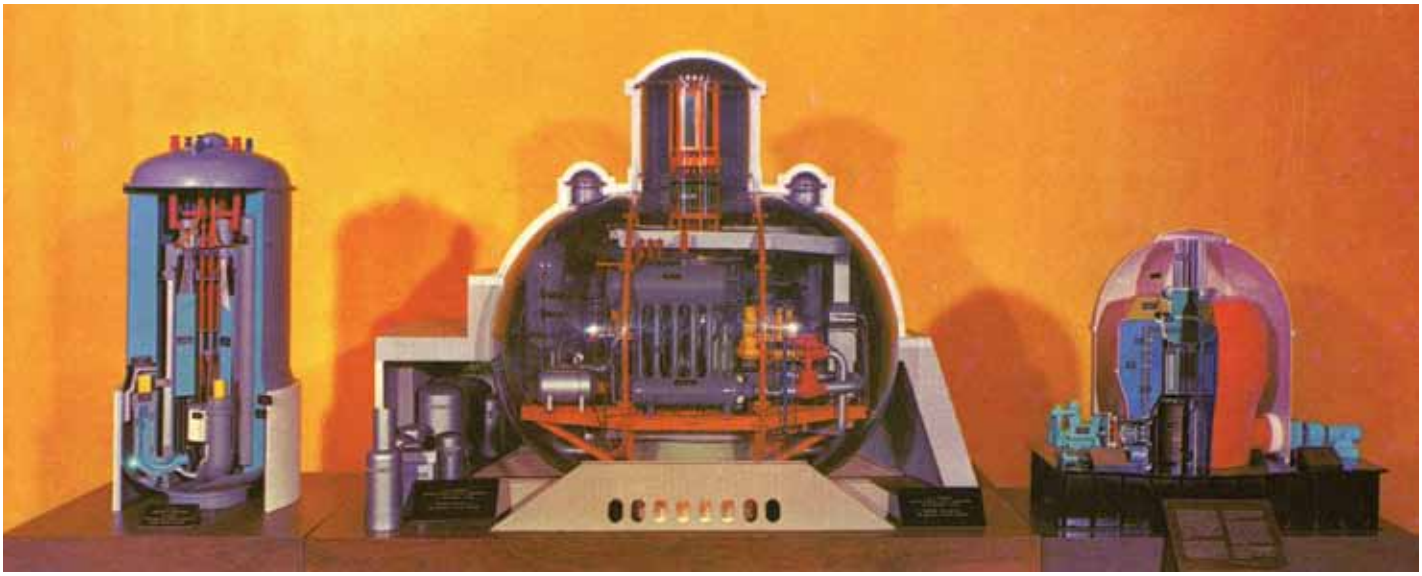
TURBINES AND GEARING

The *Savannah* engine room has a watertight bulkhead separating the engines and reactor compartment. This 60-foot-long machinery room contains steam turbines, reduction gear, turbo generators, the condenser, auxiliary diesel generators, package boiler and supporting equipment. After leaving the steam generation within the containment shell, the "low-quality," saturated steam enters the engine room and high-pressure turbine at 460 psi and 475°F. Simultaneously, steam has to be split for the turbo generators.

***Savannah*'s steam turbines** are unique. DeLaval designed and manufactured both the turbines and the gearing. Again, like B&W, DeLaval was a superb choice for turbine manufacture. The company began building turbines and gears late in the 19th century and had a location just 30 miles upriver from Camden. *Savannah* turbines had some modifications compared to the 1960 counterparts; a lower entry pressure needs a larger high-pressure turbine. The two turbines (high- and low-pressure) had to develop equal torque on the reduction gearing for the best possible wear and efficiency. An astern turbine, located in the low-pressure casing, operated with 8,000 horsepower. The reduction gearing had the commonality of most naval steam-driven ships, including the Mariner class. A double reduction in speed is required due to the very high steam turbine speed compared to shaft speed. Nickel alloy steel was used in all pinions, high pressure quill shafts, turbine rotors and coupling sleeves.

ELECTRICAL PLANT

By virtue of her unique power plant with inherent radioactive properties, a nuclear-powered ship has some vulnerability should a complete failure of electrical power be experienced. Second in complexity only to the reactor itself, the electrical plant on *Savannah* deserves special attention. The level of complexity and sophistication is much more akin to the Navy nuclear surface cruisers than to any merchant ship. The total electrical generating capacity equals 4,800 kilowatts. This is equivalent to the battleship *South Dakota*, built at the same



■ *Experience with* Savannah*'s reactor (center model) promoted development of smaller, more powerful maritime reactors. – Author's Collection.*

shipyard. Again, as a comparison with the Mariner type, two turbo generators, each with 600 kW, have less output than a single one on *Savannah*. The Mariner became the first major freighter class to have alternating current instead of direct current, and *Savannah* followed this example.

On the upper platform, port side, two steam turbine electrical generators carried a 1,500-kW rating. As designed, the *Savannah* steam turbine generator provided power for the ship, easily handling all nominal requirements (about 2,300 kW) for the ship, crew, passengers and engineering plant. The electrical power protected the reactor against any catastrophe: fire, flood, collision, reactor emergency and any other imagined or unimagined difficulty.

These twin turbo generators had a pretty much standard design, operating on main steam pressure, the same as the propulsion turbines. The turbo generators operated in parallel, but normally at much less than full generating capacity. The generators turned at the same speed and frequency and were governed by the ship's electrical load. The dual steam generators in the containment vessel had an additional benefit: closing the main throttle valve immediately after reactor shutdown still gave sufficient steam pressure to continue turbo-generator use for up to about 15 minutes, depending on the load.

On the machinery space lower level there were two additional electrical generators with identical specifications. Mistakenly referred to as emergency diesels, they were more fittingly called auxiliary generators. B&W contracted with Cleveland Diesel, a division of General Motors, for two V-12, type 278A, 1,000-horsepower diesels, a two-stroke design with scavenging blower. The diesels drove two identical 750-kW generators. No corners could be cut on these *Savannah* diesels; without reactor steam, the protective pumps and equipment needed maximum reliability.

Both diesels had an automatic, loss-of-main-power startup ability and could pick up the rated load in less than 10 seconds. In case of a total loss of steam generation (reactor shutdown), the diesel generators' primary function covered all reactor safety, decay and heat removal. They also had sufficient electrical power for reactor startup after either a "normal" shutdown or SCRAM. The diesels could also provide additional electrical capacity during a non-emergency operation.

One downside to the diesel generator was its location in the engine room lower level. This low position left the two engines vulnerable to main-space high water level resulting from flooding or fire. Even if the ship lost both steam generative power and the two auxiliary diesel generators, a fifth power generator was located high on the navigation bridge deck in the dummy funnel. This smaller diesel provided a last resort of 300 kW, not even half that of a single auxiliary diesel. The 300-kW diesel powered an emergency switchboard that sent electrical energy to run reactor primary coolant pumps (with the low-speed windings only), plus emergency lighting. There would be no power for any passenger service.

Simultaneously, a battery bank provided sufficient electricity for about 30 minutes. This duration might seem short, but the 500-ampere rating gave power for emergency lighting, navigational running lights, smoke/fire detectors, fire door closure, general alarms, radiation monitoring instruments, wheel house alarms and gyro compass. A small auxiliary boiler generated ship service steam at 150 psi, 7,500 pounds per hour. The small boiler could handle just basic steam loads during a loss of reactor power.

Mariners are leery of new technology and want a backup plan in case of disaster. During the advent of steam engines, some doubted its reliability, and sails remained on ships for decades until the reciprocating engines proved their mettle. That feeling held about the nuclear plant on the *Savannah*. Accordingly, an electrical emergency "take home" motor had been designed into the propulsion plant on the reduction gear, high-pressure side. Following a reactor shutdown and stabilization, electrical

power needs could be minimized so that one of the two 750-kW auxiliary diesels could be mated with an electrical motor of the same rating and provide propulsive power. Parasitic losses aside, enough power remained for steerageway at 5 knots. This speed could be maintained for hours.

PRIMARY CONTROL ROOM

The *Savannah* engineers supervised the power plant from a control room located on the lower level, just aft of the main machinery space. Double-thick glass allowed visitors and passengers a view into the control room from the upper-level C deck. An astonishing array of 519 control and indicating items, including flow and level indicators, indicating annunciators, meters, pressure and conductivity indicators, push buttons, selector switches, motor-operated valves, temperature gauges and indicator lights had to be monitored. Television equipment allowed observation of the reactor plant inside the containment shell. The six-panel operating station, essential for reactor plant operation, main machinery spaces and electrical plant, proved more complex than that of any single-screw merchant ship.

In the case of a reactor emergency, a SCRAM switch could be found on the upper main control panel. According to legend, SCRAM usage dates back to the earliest days of nuclear science, when workers and scientists, in the case of a malfunction, had to "scram" out of immediate danger. Use of such switches is restricted to a major catastrophic event such as a piping rupture, main pump failure or other disastrous external difficulties with ship operation. This last-ditch shutdown consists of dumping huge quantities of neutron-absorbing material into the core (control rods) to stop the neutron flux in mere seconds.

ATOMIC SERVANT

Compounding the expense of the nuclear plant in *Savannah* was the need for a support barge. This non-propelled barge measured 129 feet long with a 36-foot beam, larger than the original *Savannah* of 1819. The *Atomic Servant* started out at Todd Shipyards in Houston as hull No. 255 and was delivered to MARAD in November 1960. The barge moved from Houston to Galveston to support the ship. Previously, only minimal facilities existed to handle the needs unique to a nuclear ship. The barge served primarily as storage for radioactive resin from the primary circuit filters and other wastes. The barge could be moved as appropriate to support the ship.

The *Atomic Servant* was essentially a single-deck barge with a laboratory below at one end. The operations center was on the highest level above the main deck. Any *Savannah* radioactive waste would be stored on the ship until it had access to *Atomic Servant*. A fuel pit was amidships, with a tank for liquid waste adjacent to it. Above the main deck, the barge had a supporting workshop. A crane with a reach of one-third the barge's length rested at the highest level.

The master control room could be viewed by visitors from a viewing gallery on "C" deck. – Author's Collection.

MERCHANT MARINE NUCLEAR POWER ENDS

The only U.S. nuclear-powered merchant ship met or exceeded expectations. The nuclear power plant had not been designed to demonstrate efficiency at high speed. She steamed 450,000 miles on 163 pounds of nuclear fuel, but any anticipated price reduction in reactor construction and maintenance didn't appear feasible. During *Savannah*'s career, the number of American-flagged merchant ships dipped to its lowest postwar levels, paralleling a steep decline in U.S. shipbuilding. In 1958, the United States failed to register in the top ten countries that built ships of over 2,000 tons. The shipyard that built *Savannah* went bankrupt in 1967.

The PWR has proved its mettle at sea. Admiral Rickover and his team demanded the machinery, training and exceedingly high-quality control standards that would safely sustain 60 years of nuclear power. The *Savannah* (and *Nautilus*) were expected to be the starting point for the path of nuclear-power technological advancements in both commercial and Navy applications. At the time of launching, the *Savannah* nuclear plant was expected to be obsolete prior to the maiden voyage, a rare historical event.

Sea-going reactor development has continued for 60 years since B&W built the *Savannah* PWR. Reactor power has dramatically increased as reactor size has diminished. Core life has been extended by five to seven times. At the *Savannah* delivery in 1962, the U.S. Navy had 26 nuclear submarines and another 30 under construction or contract. Every one of these had some type of pressurized water reactor (except *Seawolf,* which was later changed to a PWR). With 5,000 reactor-years and over 100 million steaming miles, there has never been a reactor accident. Twenty nuclear surface ships have been constructed with the PWR. This author is fortunate to have served on one of them. ⚓