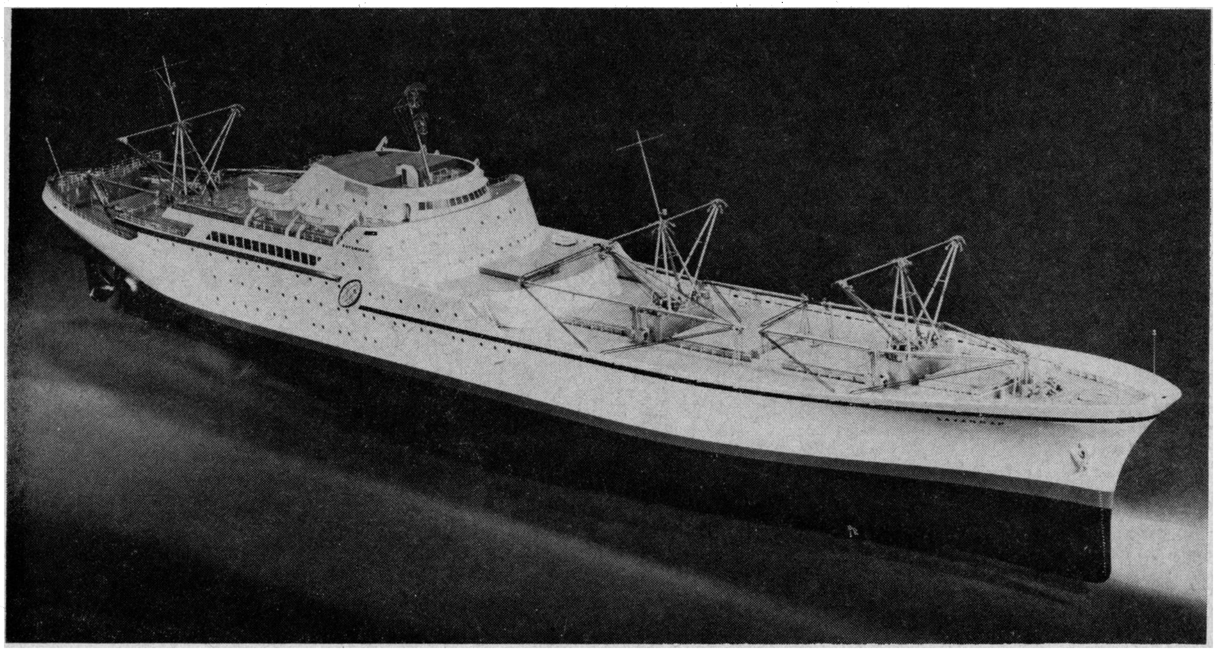


Safety on the Nuclear Ship Savannah

RICHARD P. GODWIN, B.S., PRESTON P. EDDY, B.S., and RALPH K. LONGAKER, M.S.

THE LAUNCHING of the *NS Savannah* in July 1959 signaled a major advance in the peaceful application of nuclear energy. Following outfitting, tests, and sea trials, the *Savannah* is expected to enter the sealanes of the world during 1960, powered by a nuclear reactor which will not require refueling for 2 to 3 years. Safety, both nuclear and marine, has been the keynote throughout the project in design and construction and in planning the vessel's operating program.

Mr. Godwin is assistant director for maritime reactors in the Division of Reactor Development, Atomic Energy Commission, and nuclear projects officer for the Maritime Administration, Department of Commerce. Mr. Eddy is project manager in charge of design, engineering, and construction for the NS Savannah. Mr. Longaker, a sanitary engineer with the Special Projects Branch, Division of Radiological Health, Public Health Service, is now on detail as Public Health Service liaison to the Maritime Administration-Atomic Energy Commission nuclear-powered ships projects.

The nuclear-powered ship is the second *Savannah* to make maritime history. One hundred and forty years ago, a 320-ton wooden ship with all sails set on her three masts and belching smoke from a funnel amidship, commenced an epoch-making voyage from Savannah, Ga., to Liverpool, England. She was the *SS Savannah*, the first vessel to use steam on a transatlantic crossing. The 29-day voyage was successful even though only enough coal and wood could be carried to permit about 80 hours of steaming. Captain Moses Rogers, skipper of the vessel, stopped briefly at Kinsdale, Ireland, to replenish his fuel supply so that he could make a spectacular arrival by steaming up the Mersey River to Liverpool under power. However, the watch in the coastal station at Cape Clear on Ireland's southern tip sighted the *Savannah* with smoke coming from her stack and concluded she was on fire.

The British revenue cutter *Kite* was sent to her relief. To the surprise of the cutter's crew, the *Savannah*, without a sail set, outdistanced them completely. It was not until after the exasperated crew of the *Kite* had fired a shot across the bow of the American vessel that she stopped and gratified their curiosity.

Thus, the *SS Savannah* ushered in the steam age in ocean travel. Today another *Savannah*, bearing the designation "NS," will usher in the atomic age.

Development

On April 25, 1955, President Eisenhower first suggested the construction of a nuclear-powered merchant ship which, visiting the ports of the world, would demonstrate to people everywhere the peacetime use of nuclear energy, harnessed for the improvement of human living.

The following year, Congress passed legislation which made construction of the ship possible, and on October 15, 1956, the program was initiated. A joint group, drawing its members from the Maritime Administration of the Department of Commerce and from the Atomic Energy Commission, was established to administer the program.

Shortly thereafter, the U.S. Coast Guard, the Public Health Service, and other Federal agencies began to assist the nuclear merchant ship program through assignment of liaison personnel and active participants to technical committees dealing with questions and problems which had no precedent. In addition, the Atomic Energy Commission's Advisory Committee on Reactor Safeguards independently reviewed reactor construction and operating procedures with a view toward the safety of the ship's crew and passengers and the public.

The *NS Savannah* was launched on July 21, 1959. Before the beginning of the comprehensive test program, she will require approximately 7 months of dockside outfitting. Sea trials are scheduled to start during the spring of 1960. To staff the vessel, two groups of specially selected licensed merchant marine officers are being trained in a 15-month course which includes classroom work in reactor theory, operation of the *Savannah* reactor console simulator, and practical experience at other reactor sites such as those at Hanford, Wash., and Arco, Idaho.

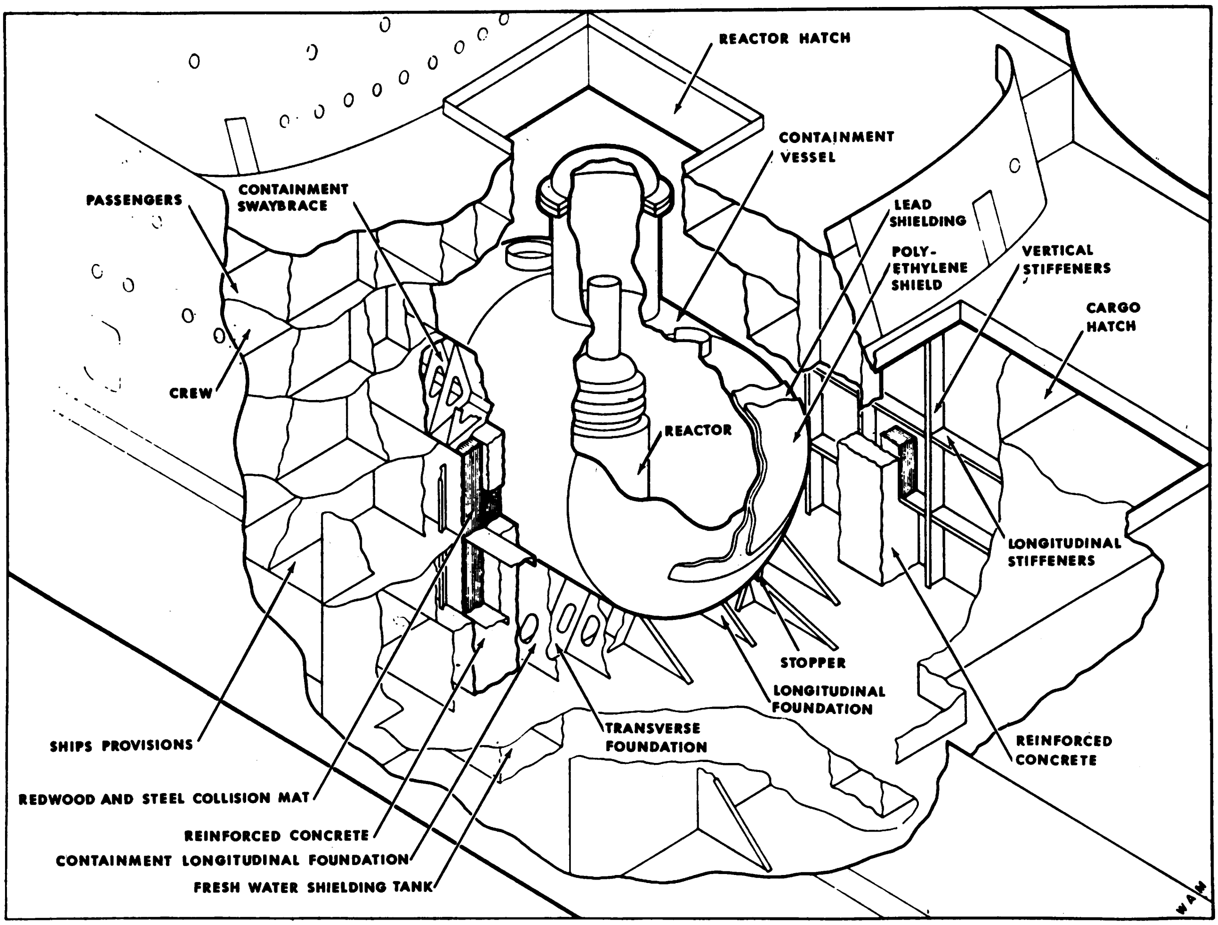
The *NS Savannah* is a combination passenger-cargo ship of the Mariner class. It is 595 feet long, has a 78-foot beam, and will have fully loaded displacement of 21,800 tons. The ship will have a sea speed of 20 knots and a cruising radius in excess of 100,000 miles. With a 124-man crew and additional space for observers and technicians, she will also be able to carry 60 passengers.

The nuclear plant, including the containment vessel, shielding, and propulsion machinery are located amidship (see chart). The propulsion power will be provided by a pressurized water reactor operating at approximately 1,750 pounds per square inch at an average temperature of 508° F. The slightly enriched (4.4 percent) uranium oxide core is in the form of a cylinder 62 inches in diameter and 66 inches high. Reactor control is provided by 21 boron stainless steel control rods inserted in channels between the 32 symmetrically arranged fuel elements. The first core has been designed for a maximum power level of 69 megawatts and is expected to produce approximately 52,200 "megawatt-days." In other words, it will have an operating lifetime of about 3 years' normal operation without refueling.

Safety on Nuclear Merchant Ships

The principal problems in ship design introduced by nuclear propulsion are those related to safety, that is, protection of the environment from radioactive contamination. The safety of the ship, the personnel aboard, and the operating environment had to be and were considered for conditions without precedent.

Containment. One of the basic safety problems of a nuclear reactor is the control of fission products. To provide this control it was decided to install the entire reactor system and its major auxiliary components within a shielded containment vessel capable of confining the mechanical energy released in the event of a severe rupture of the "primary" portions of the



Amidship cross section of NS Savannah showing nuclear plant and shielding.

system. Thus, the containment vessel surrounds all of the primary system, preventing the escape of radioactive material and serving as structural protection for the reactor.

The containment vessel, already installed in the ship, is a welded steel cylinder 2½ inches thick, 50 feet long, and 35 feet in diameter. It will be hermetically sealed at all times during plant operation. Television cameras within the vessel will enable the crew to observe conditions from the externally located control room while the reactor is operating. After shutdown of the plant, the containment vessel may be entered through an airlock for inspection and maintenance. Once operating reliability has been demonstrated on the *Savannah*, an expensive, heavy containment vessel of this type may not be necessary on other nuclear merchant ships.

Shielding. A most important feature of the *Savannah* is the radiation shielding. The main source of radiation during operation of the ship's power plant is the reactor itself. In addition, minute quantities of impurities and also traces of corrosion products remaining in the demineralized "light" water used as primary coolant will become activated while passing through the reactor. However, a bypass purification system will remove these activated materials automatically by ion-exchange methods.

The following conditions had to be met for areas accessible to passenger and crew:

- In all areas to which passengers have access, the radiation level will be less than that required to produce an integrated total body dosage of 0.5 rem per year. This is a conservative figure since it will be determined at the points of highest radiation, and the computations for the annual dosage will be based on the assumption that a person remained in these areas for an entire year. Allowing for movement aboard ship and taking distance from the reactor into account, the average exposure received by any passenger remaining aboard for a year would probably be less than 0.2 rem—comparable to levels which would be received on land from background and cosmic radiation. In determining these radiation levels, the average annual reactor power has been computed to be approximately 50 megawatts.

• In all areas where crew members have unlimited access, radiation levels will be less than 5 rem integrated dosage per year. This dose limit is in accordance with the guidelines of the International Commission on Radiation Protection and of the National Committee on Radiation Protection. Since the 5-rem area is relatively small and not in general use and since no crew member will be aboard the ship a full year, it is doubtful whether any crew member will receive an annual integrated dosage of more than 0.5 rem in a year.

• Only officers and crew of the engineering department will be allowed access to the controlled machinery spaces aft of the reactor compartment. Other ship personnel will not be permitted in these spaces except under specific authorization of the captain. The engineering crew will be limited to an integrated dosage well within the guidelines of the NCRP and ICRP and will, of course, be equipped with appropriate personnel dosimeters.

• A health and safety staff will continually analyze the environs of the ship to assess and minimize exposure to radiation and control potential hazards.

• Certain areas in the vicinity of the reactor will be denoted as "limited access areas" and will not normally be entered when the reactor is operating. Those areas located outboard of the reactor compartment include the fan room and lockers for storage. At full reactor power, a radiation level of 1 rem per 168-hour week will be the maximum permissible in these areas. They will remain locked at all times, and the captain's permission will be needed for controlled entry while the reactor is at full power.

• The entire secondary shield, surrounding and encasing the containment vessel will, when completed, weigh more than 1,600 tons. "Ordinary" concrete, in the form of a vertical 4-foot thick "skirt" extending up to the "equator" of the vessel, accounts for 1,600 tons, and the 14-inch layer of lead and polyethylene encasing the upper half of containment accounts for 500 long tons.

Waste management. The basic plan for the collection and handling of radioactive waste aboard the *Savannah* is predicated on complete retention of all solid, liquid, and high-activity gaseous wastes. Remotely handled and stored, these wastes will be held in special tanks for periodic dockside transfer. Ultimate disposal by licensed contractors will be based on procedures used for land-based reactor wastes.

Additional safeguards. The reactor system as well as the ship has been designed to minimize the effects of marine hazards such as storm, grounding, fire, flooding, and sinking. In some respects a nuclear ship may be safer than a "conventional" vessel. For example, the fire hazard in the *Savannah's* engine room is considerably less because of the general reduction in oil piping and hot surfaces and the absence of oil-fired boilers.

With respect to the effects of collision, a recently completed study of marine casualties has shown that on the basis of tonnage and speed not one ship in 95 percent of the world's merchant fleet could penetrate the hull of the *Savannah* to the depth of the laminated steel and redwood collision mats placed on the flanks of the containment vessel (see chart).

The probability of ships in the remaining 5 percent colliding with the *Savannah* and penetrating the containment vessel is currently being evaluated. Large ships generally operate at a reduced speed within and when approaching harbor areas. At these speeds, even the larger ship could not penetrate the containment vessel if it were to strike directly at the reactor compartment. As an illustration, citing the 1956 collision of the *Stockholm* and the *Andrea Doria*, it has been determined that the striking ship would have had to travel 1 to 4 knots faster than her maximum speed to penetrate the *Savannah* even to the collision mat.

If collision leading to eventual sinking should occur, the reactor would be "scrammed," that is, shut down automatically. Cooling of the reactor would be continued by the primary circulation pumps operating on emergency power as long as the ship was afloat. If the vessel were to sink in shallow water, the containment vessel would remain intact, and the exposed surface afforded by the vessel would be sufficient to dissipate residual "decay" heat by natural convection. However, if sinking were to occur in deeper water, where the submergence pressure might cause collapse of the containment vessel, automatic flooding valves would open to admit sea water into the vessel to equalize the internal and external pressure on the vessel. (As soon as the internal pressure was equalized, the check-type valves would automatically close.) The pressure equalization, by preventing rupture of the containment vessel, would keep the reactor system intact, thus preventing the escape of radioactive elements. Should an accident by any chance open the reactor core, the consequences would be influenced by the stage of the 3-year fuel cycle.

Potential

The construction of the *Savannah* has posed some new and unique problems. For most of them, satisfactory design and operating solutions have been found; the remainder are under study. Complete containment, retention of wastes, and other safeguards, both nuclear and nautical, have been incorporated to achieve maximum safety. The *Savannah's* experimental years of service may show that less stringent requirements will be necessary in the future.

During the past decade there has been an ever-increasing interest in the application of nuclear power in industry, both to conserve existing fuel resources and to provide an additional energy source. Today other maritime nations are actively conducting programs for the development of nuclear-powered merchant ships. The potential economic advantages of nuclear power over conventional fuels are great; among these are:

- Elimination of the space and weight requirements for fuel oil, resulting in increased cargo-carrying capacity.
- Longer range, making nuclear ships virtually independent of refueling time losses.
- Operation at speeds higher than those now economically feasible for ships powered by the "fossil fuels."

The *NS Savannah*, however, will not be and is not intended to be economically competitive with conventionally fueled merchantmen. Rather, this "first generation" nuclear-powered merchant vessel will be used to provide a baseline of practical construction and operating experience necessary for application to the design of "second" and "third generation" ships. These, in turn, may attain competitive status within the next decade. Thus, the *NS Savannah* is heralding the transition from fossils to fission, quite as her famous namesake crossed the threshold from sail to steam.

Impairments in the United States, July 1957–June 1958

About 24 million impairments, including chronic or permanent physical defects, existed among the civilian, noninstitutional population of the United States during the year beginning July 1, 1957. This figure, published in a report by the U.S. National Health Survey, Public Health Service, is derived from household interviews with a representative population sample and represents a rate of 141.4 impairments per 1,000 noninstitutionalized persons.

The report, "Impairments, by Type, Sex, and Age, United States, July 1957–June 1958," does not indicate the total number of persons with impairments (since many have more than one impairment) except for conditions such as visual, auditory, or speech defects, mental retardation, cerebral palsy, and absence of extremities.

Rates for specific impairments per 1,000 persons were 5.7 for inability to read ordinary newsprint even with glasses; 12.3 for less severe visual impairments; 0.6 for total deafness; and 33.9 for other hearing defects.

Conditions reported frequently were paralysis and other defects of the limbs, back, and trunk, and impaired speech.

Impairments caused by injury amounted to 33 percent of the total; 41.8 percent for males and 22.2 percent for females. Loss or defects of extremities had the highest proportions due to injuries, and speech defects and blindness, the least. Impairments increased from 52.9 per 1,000 persons at ages under 25 years to 615 at ages 75 and over. (Announcement of publication appears on p. 752.)