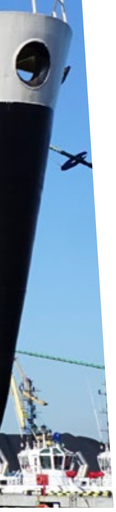
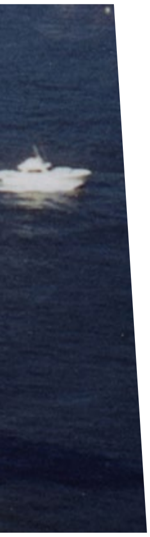
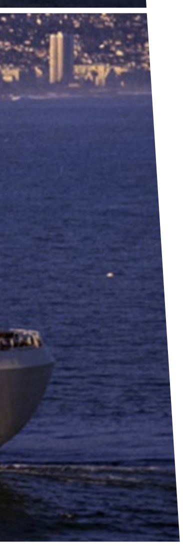
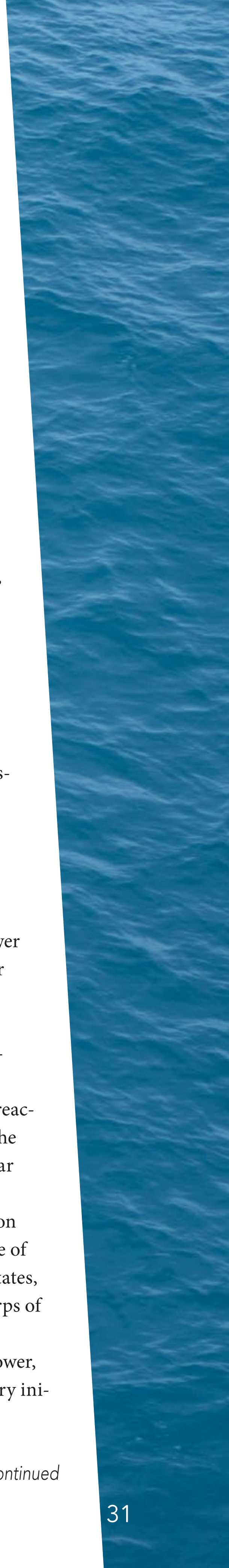

ЛЕНИН
LENIN


CORPS OF ENGINEERS
U.S. ARMY



The history and future of civilian nuclear power afloat

By Gail H. Marcus and Steven M. Mirsky

In the early days of the development of nuclear power, a broad range of nuclear technologies and applications were explored. Among these developments were the use of nuclear propulsion for ships, both military and civilian, as well as a floating nuclear power plant. While the use of nuclear power for naval vessels, including submarines and surface ships, continued, most of the civilian uses of nuclear power on the water were ultimately terminated.

Recently, however, there has been a resurgence of interest in both floating nuclear power plants and the use of nuclear propulsion in the civilian sector. The renewed interest makes this a particularly timely moment to recount the initial developments in this area. Some of the early civilian nuclear vessels were discussed in two sessions during the June 2021 ANS Annual Meeting, "NS *Savannah* History" and "History of Non-Naval Nuclear Ship Power." This article draws on the presentations from those sessions, the second of which was cochaired by the authors, as well as on other studies of the history of nuclear power.

Background

The use of nuclear power for ship propulsion was envisioned from the earliest days of nuclear power development and proceeded in parallel with the development of some of the first land-based nuclear power stations. In fact, the launching of the USS *Nautilus*, the world's first nuclear-powered submarine, on January 17, 1955, followed the first electricity supplied to a transmission grid (in the Soviet Union on June 27, 1954) by only a few months, and preceded the first electricity supplied to a transmission grid in the United States (in Arco, Idaho, on July 17, 1955), also by only a few months.

As is widely known, Admiral Rickover's selection of a pressurized water moderated and cooled reactor for the *Nautilus* heavily influenced the technology later used for full-scale nuclear reactors in the United States and elsewhere. Perhaps less widely known is that the first surface vessel to use nuclear power was a Soviet civilian icebreaker, the NS *Lenin*, which began operation in 1959.

While the histories of the civilian and military vessels overlap, this article will focus primarily on the civilian side, both on the use of nuclear power for the *Lenin* and other icebreakers, and the use of nuclear power for cargo and passenger ships, particularly the NS *Savannah*, built in the United States, and the NS *Otto Hahn*, built in Germany. This article will also cover the *Sturgis*, a U.S. Army Corps of Engineers barge that became the first vessel to provide power to places ashore.

To date, the use of nuclear power on civilian ships, either for propulsion or to provide shore power, has been limited, but there continues to be interest in these concepts, and some recent exploratory initiatives will be outlined.

Continued

Nuclear icebreaker *Lenin*.
(Photo: © Snfokin2006 | Dreamstime.com)

Lenin

The first nuclear-powered surface ship

Early on, the Soviets, who had significant operations in the Arctic, realized that nuclear icebreakers would be more powerful than the existing diesel-powered icebreakers. In addition, conventional icebreakers used a great deal of fuel and thus needed frequent refueling, which was difficult in remote Arctic areas and limited their operations. Therefore, the Soviets started thinking about nuclear-powered ship propulsion as early as the late 1940s. Due to other priorities, however, it took over a decade before the first nuclear-powered icebreaker, the NS *Lenin*, went into operation.

The *Lenin* employed three reactors that were specifically designed to power ships. The first reactors installed on the *Lenin* were OK-150 90-MWt pressurized water reactors that used 5 percent enriched uranium in the form of ceramic uranium-dioxide fuel elements. Different cladding materials were used over time. The ship was run by three electrically driven propellers totaling 44,000 horsepower (32.4 MW).

The *Lenin* was launched on December 5, 1957. It was put into operation in 1959 and made its first Arctic voyage in 1960. The voyage lasted three months and 10 days. The ship could reach speeds of 18 km/hr in open water. During its 30-year lifetime, it made 26 trips to the Arctic, traveling over 500,000 nautical miles through ice and towing over 3,700 ships. In 1977–1978, it achieved a milestone of 390 days for one trip.

Although the details cannot be confirmed, it appears that there were two serious accidents involving the OK-150 reactors. According to some accounts, the first accident occurred in February 1965. Following a shutdown for refueling, the coolant was removed from one of the reactors before the spent fuel had been removed. As a result, about 60 percent of the fuel elements melted inside the reactor. This was discovered when the fuel elements were being unloaded for storage and disposal. The fuel, control grid, and control rods were removed and replaced.

The second accident occurred in 1967 and involved a leak in the cooling piping system. The crew had to break through the concrete and metal biological shielding with sledgehammers to find the leak, and once it was found, the damage could not be repaired. There are some reports that this accident resulted in approximately 30 fatalities.

Following the second incident, the three reactors were replaced by two OK-900 reactors in 1970. The new 171-MWt reactors used 90 percent enriched uranium in the form of metallic uranium-zirconium fuel elements. The ship continued to operate until 1989.

Today, the *Lenin* has been decommissioned and turned into a museum based in Murmansk, but Russia continues to operate other civilian nuclear-powered ships. Russia remains the only country in the world to operate civilian nuclear-powered icebreakers in the Arctic. In addition to a fleet of seven Arctic icebreakers, it operates two icebreakers designed for use on rivers. One of the *Lenin*'s successor icebreakers, the *Arktika*, which began operation in 1975, was the first surface ship to reach the North Pole.

Continued

Savannah

America's cargo and passenger demonstration ship

Following his groundbreaking "Atoms for Peace" speech before the United Nations on December 8, 1953, President Eisenhower in 1955 proposed the design and construction of a nuclear-powered merchant ship. With congressional approval in 1956, the cargo and passenger merchant ship NS *Savannah* was completed, tested, and delivered for sea service in 1962. The purpose of the *Savannah* was to demonstrate the application of nuclear technology to merchant ships with all its new concomitant regulations, standards, training, operations, and design features.

The *Savannah* was a single-screw, all-steel cargo and passenger ship with a length of 595 feet and a full load weight of 22,000 tons. Power was provided by a Babcock & Wilcox–designed two-loop, 80-MWt PWR that used low-enriched uranium dioxide pellets in 304 stainless steel–clad fuel rods.

The entire nuclear steam supply system was surrounded by a 40,000 cubic foot steel containment vessel and an integral ship collision protection structure. The *Savannah* could carry 110 crew members and 60 passengers and had a cruising speed of 21 knots.

Between 1962 and 1965, the *Savannah* operated in a passenger/cargo demonstration phase, traveling 90,000 nautical miles, hosting 1.4 million visitors, carrying 848 passengers, and visiting 28 U.S. and 18 foreign ports in 13 nations. The *Savannah* then continued its cargo demonstration phase from 1965 to 1971, at which time it was deactivated. By 1971, the *Savannah* had traveled over 450,000 miles and visited 32 U.S. and 45 international ports in 26 nations. The one refueling in 1968 required only four fresh fuel assemblies in the 32-assembly core. The energy derived from the fission of 163 pounds of uranium over its nine-year operating life was estimated to be the equivalent to the energy from the combustion of 29 million gallons of fuel oil.

Since its deactivation, the *Savannah* has been docked in Galveston, Texas; Savannah, Ga.; Charleston, S.C.; Norfolk, Va.; and Newport News, Va., and now is berthed in Baltimore, Md., where it is being decommissioned and decontaminated. The NS *Savannah* was designated a National Historic Landmark on July 17, 1991.

The decision to deactivate the *Savannah* was influenced by cutbacks in funding for the merchant nuclear ship program as more funding was directed to support the Vietnam War. Without financial support from the federal government, the merchant ship industry was not willing to accept the perceived risks of nuclear-powered ships.

During its nine years of operation, the *Savannah* fulfilled its mission to demonstrate the dependability and safety of nuclear-powered commercial ships and won the acceptance of nuclear ships at international ports. The NS *Savannah* remains a shining example of the Atoms for Peace program. Public tours of the *Savannah* (which have been suspended due to COVID) offer a unique opportunity for nuclear marine power education and a chance to motivate a resurgence of interest in nuclear civilian ships for the 21st century.

Continued

The nuclear ship *Savannah* on its way to the World's Fair in Seattle, Wash., in 1962. (Photo: Atomic Energy Commission/ U.S. National Archives and Records Administration)

Otto Hahn

Germany's unique integrated PWR design

In 1960, West Germany began planning for a trade and research cargo ship to test the viability of civilian nuclear power. The 26,000-ton ore carrier cargo-passenger ship, named the NS *Otto Hahn*, began operation in 1968 under power from a 38-MWt PWR. The reactor, designed by Babcock & Wilcox Germany, was the first integrated PWR, with its helical coil steam generator design, pressurizer, and reactor core all located inside the reactor pressure vessel. Two external reactor coolant pumps circulated coolant through the integral module. Separate shielded spent fuel storage was also included in the design. This design concept, called the consolidated nuclear steam generator, was developed in 1962 by Babcock & Wilcox under AEC contract.

The reactor core had 12 fuel elements with 2,810 fuel rods containing LEU encapsulated in zircaloy-4 cladding. The *Otto Hahn* had a crew of 63 and could accommodate up to 35 research personnel. One unique aspect was the installation of a prototypical experimental reverse osmosis seawater desalination module that used the nuclear power–generated electricity.

After four years of operation over 250,000 nautical miles and the fission of 48.4 pounds of uranium-235, the reactor was refueled. In 1979, the reactor was deactivated and removed after having propelled the *Otto Hahn* for a total of 650,000 nautical miles while visiting 33 ports in 22 nations and having transported 750,000 tons of cargo. Over 10 years of operation, power plant availability was almost 100 percent, including operations under a wide range of sea conditions and power maneuvers. Subsequently, the reactor was replaced with diesel power. The ship was renamed and converted to a container ship in 1982, and it continued operation until 2009.

In addition to the *Otto Hahn*, two other nuclear-powered cargo ships are historically notable: Japan's *Mutsu* and Russia's *Sevmorput*. The *Mutsu* was a 36-MWt 32 fuel assembly PWR that was launched and began testing at sea in 1974. A shielding design deficiency resulted in high neutron radiation dose, which, along with negative public reaction, resulted in subsequent redesign, modification, and eventual decommissioning in 1992. The *Sevmorput* is a currently operating cargo container ship powered by a 135-MWt four-loop PWR. It is designed to carry up to 1,328 containers and is qualified to travel through the sea with ice present. It began operation in 1988 but was laid up for several years due to light demand for its services, and the possibility of converting the ship for other purposes was considered. Finally, after refitting and refueling, it returned to its cargo mission in 2016.

NS *Otto Hahn* near Cape Town, South Africa. (Photo: Hereon)

Undated photo of floating nuclear power plant *Sturgis* operating in the Panama Canal Zone. (Photo: U.S. Army Corps of Engineers)

Sturgis

A floating nuclear power plant

The *Sturgis* differs from the other ships discussed in this article because it did not use nuclear power—or any other onboard power source—for propulsion. Instead, another vessel was required to tow the *Sturgis* to any new location. The *Sturgis* was designed as a source of power in coastal areas, particularly for remote locations with seasonally or otherwise limited accessibility.

When the *Sturgis* was built, the Army already operated several land-based nuclear reactors, but the ship boasted the largest of the Army's reactors, as well as the only floating reactor. It was built by the U.S. Army in the 1960s and may originally have been intended for deployment in Vietnam. The Army used a mothballed Liberty ship, the SS *Charles H. Cugle*, as its platform. Starting in January 1963, the ship was converted to a barge by removing its propulsion equipment, and a 45-MWt, 10-MWe, LEU pressurized water reactor was installed. It was renamed the Sturgis Floating Nuclear Power Plant, or alternatively, MH-1A (standing for mobile, high-powered, first-of-a-kind, field installation).

The *Sturgis* reached initial criticality on January 24, 1967, at Fort Belvoir, Va., where it supplied power to the base. In 1968, it was towed to Gatun Lake in the Panama Canal Zone. At the time, Panama was experiencing a severe drought. Normally, water from Gatun Lake was used both for operating the locks and for the Gatun Hydroelectric Station. However, the drought had lowered the level of the lake, so there was insufficient water for both tasks. Using the *Sturgis* to supply electric power allowed all the water in Gatun Lake to be used for canal operations. The *Sturgis* operated there from 1968 to 1975. During the Vietnam War, the additional power supplied to the region by the *Sturgis* reactor enabled the passage of several thousand U.S. military ships through the canal on their way to Vietnam.

By 1975, the MH-1A reactor was in need of an overhaul. However, the Army considered it impractical to keep the one-of-a-kind facility in operation, and in late 1976–early 1977 the *Sturgis* was towed back to the United States for decommissioning. Off the coast of South Carolina, it suffered storm damage and had to divert to the Sunny Point Military Terminal on the Cape Fear River for temporary repairs. It then continued on to Fort Belvoir, where the reactor was deactivated and defueled, and the barge was transferred to the James River Reserve Fleet. By 2015, the levels of radioactive contamination had decayed enough to allow for final disposition of the vessel. It was towed to Galveston, Texas, where the remaining contaminated material was removed and hauled to a hazardous materials disposal site, and the rest of the vessel was cut up and scrapped.

Until two years ago, the *Sturgis* was the world's only floating nuclear power plant ever to have operated. In December 2019, the Russian 70-MWe *Akademik Lomonosov* floating barge nuclear power plant started providing power in the port of Pevek, Chukotka, Russia. The concept of having a power plant that can be moved from place to place as needed or located offshore has long been considered attractive, and in recent years, there has been renewed interest in possible new floating plants.

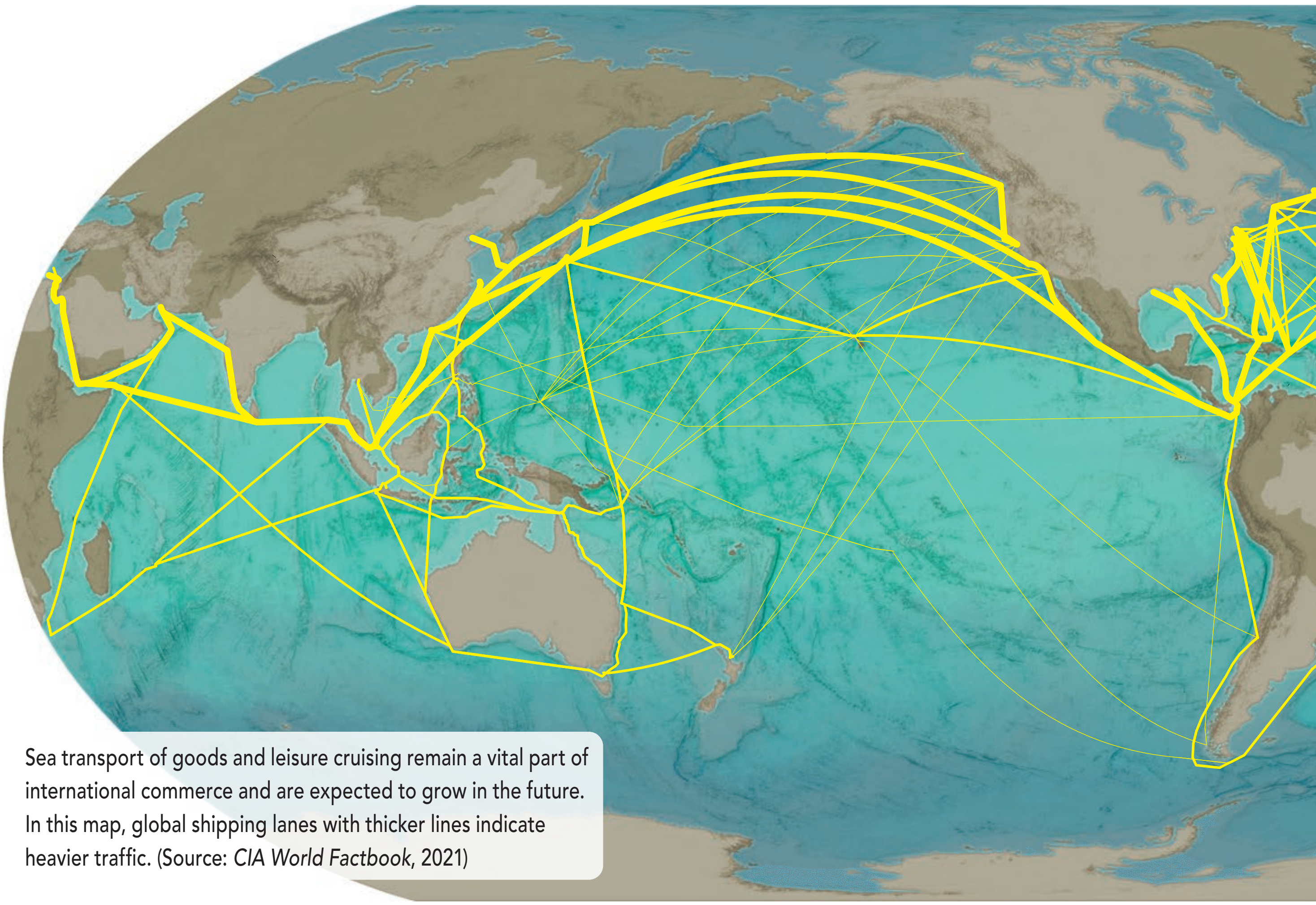
Continued

Looking ahead to the next generation of nuclear ships

Commercial shipping currently uses oil, diesel fuel, and propane for propulsion and onboard electric power. The combustion of these fuels emits carbon dioxide, methane, sulfur oxides, black carbon particulates, and nitrogen oxides, which are identified as greenhouse gases, acid rain progenitors, and sources of respiratory illness. Commercial shipping currently accounts for about 3 percent of all anthropogenic greenhouse gas emissions but is projected to account for as much as 17 percent by 2050. The use of these fuels has also resulted in liquid releases to the sea environment due to accidents (e.g., the *Exxon Valdez*). Alternative fuels, such as carbon-free hydrogen, biofuels, and ammonia, are being evaluated to reduce environmental impacts, but the production, distribution, storage, and use of these fuels pose logistic and economic challenges to meet the future needs of the commercial shipping industry.

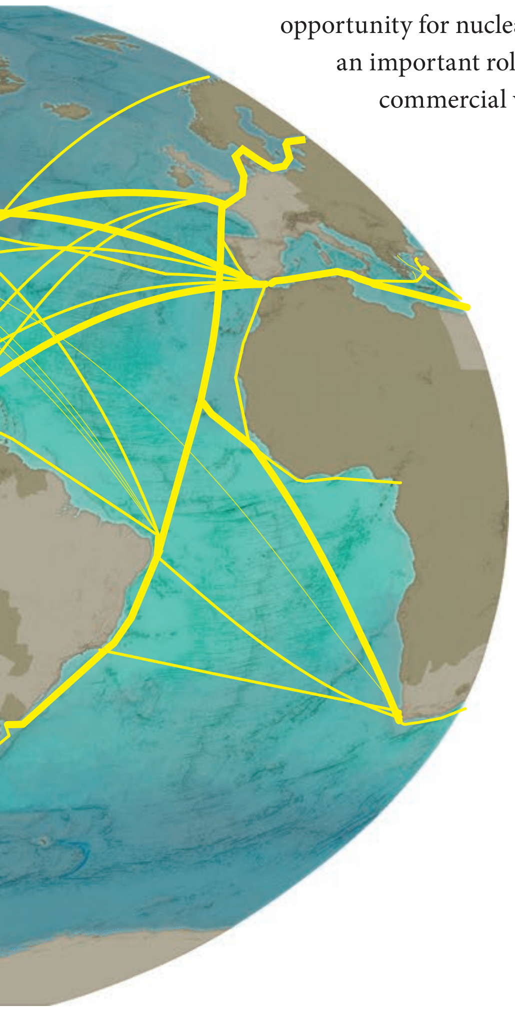
Nuclear-powered commercial shipping has an international design and operational history going back more than 60 years, as this article illustrates. Including nuclear naval ships, more than 12,000 reactor years of marine propulsion operating experience have been accumulated. Nuclear energy offers unique advantages for powering commercial ships, including (1) no operational and accidental air pollutants or liquid fuel emissions; (2) no need to refuel for years; (3) no combustible fuel fire hazards; (4) no need for large onboard and port fuel storage tanks; (5) high reliability; (6) reduced volume of the power system; (7) faster port turnaround times by eliminating the need to refuel; and (8) insensitivity to changes in fuel prices, because fuel is a very small fraction of the cost of producing power.

More than 60,000 commercial ships weighing more than 1,000 tons each currently operate worldwide. Sea transport of goods and leisure cruising remain a vital part of international commerce and are expected to grow in the future. There is a trend toward larger ships, as well as expectations of new Arctic sea routes between Asia, Europe, and North America. Since bulk cargo, oil tanker, and container ships accounted for 85 percent of all carbon dioxide emissions



Sea transport of goods and leisure cruising remain a vital part of international commerce and are expected to grow in the future. In this map, global shipping lanes with thicker lines indicate heavier traffic. (Source: *CIA World Factbook*, 2021) from commercial shipping in 2020, these three ship types would be the most likely to benefit from the use of nuclear power. In addition, the unique duty requirements for icebreakers, as evidenced from the numerous Russian vessels commissioned since the *Lenin* in 1959, point to another application of nuclear ship propulsion that may be adopted by other nations taking advantage of shorter Arctic routes.

There are some obstacles to civilian nuclear-powered ship deployment that must be acknowledged. These include the need to obtain regulatory certification by the ship's flag state, as well as visiting ports, and the requirement to demonstrate competitive economic operating costs, including the effect of decommissioning and decontamination at the end of life. Moreover, as in the case of all things using the adjective "nuclear," public outreach and acceptance of the safety case are critical for the successful growth of nuclear ship deployment. However, the confluence of environmental protection goals, the growing demand for larger and more commercial ships, and the attractiveness of Arctic sea routes offer an opportunity for nuclear power to play an important role in powering commercial vessels.



Gail H. Marcus is currently a consultant in nuclear power technology and policy. She previously served in senior management positions at the Nuclear Regulatory Commission, the Department of Energy, and the OECD Nuclear Energy Agency, and she is an ANS past president (2001–2002).

Steven M. Mirsky, PE (smirsky@nuscalepower.com), is a senior technical advisor with NuScale Power with over 45 years of nuclear industry management, engineering, and consulting experience, and is a member of the Board of the ANS Washington, D.C., Section.

The authors acknowledge Erhard Koehler, of the U.S. Maritime Administration, for the extensive documentation and background information he provided in support of this article.

References

Freire, Luciano Adair, and Delvonei Alves de Andrade, "Historic Survey on Nuclear Merchant Ships," *Nuclear Engineering and Design*, July 2015.

Historical Mitigation Report: Deactivated MH-1A Nuclear Power Reactor and Barge Sturgis, U.S. Army Corps of Engineers, July 2019.

"History of Non-Naval Nuclear Ship Power," technical session chaired by Gail H. Marcus and Steven M. Mirsky, presented on June 16, 2021, at the ANS Annual Meeting, ans.org/meetings/am2021/session/view-533/.

Marcus, Gail H., *Nuclear Firsts: Milestones on the Road to Nuclear Power Development*, American Nuclear Society, 2010.

"NS *Savannah* History," technical session chaired by John Kelly and Erhard W. Koehler, presented on June 14, 2021, at the ANS Annual Meeting, ans.org/meetings/am2021/session/view-532/.

NS Savannah *Updated Safety Analysis Report*, U.S. Department of Transportation, Maritime Administration, STS-004-002, Revision IV, April 20, 2007.

Olgaard, Povl L., *The Potential Threats from Russian Nuclear Ships*, Nordic Nuclear Safety Research, November 2001.

Project 10081 Sevmorput, GlobalSecurity.org, globalsecurity.org/military/world/russia/10081.htm.

Schroeder, E., W. Jager, and H.G. Schafstall, "Nuclear Merchant Ship Propulsion," International Conference on Nuclear Power and its Fuel Cycle, IAEA-CN-36/93, May 2–13, 1977.

Shropshire, David, Geoffrey Black, and Kathleen Araújo, *Global Market Analysis of Microreactors*, INL/EXT/21-63214, June 2021.