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Russia's Nuclear Icebreaker Fleet

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Nuclear icebreakers remain important for the economic survival of Russia's Arctic regions and are a central element of the Northern Sea Route development strategy. Reactor life extension activities are critical to sustaining the nuclear fleet, as several of the currently operated nuclear icebreakers are reaching the end of design service life. Russia is also finishing a new icebreaker and is planning to build additional nuclear ships within the next 10–15 years. Nuclear icebreaker reactors are fueled with highly-enriched uranium (HEU), which has to be reliably protected against theft and diversion.

NORTHERN SEA ROUTE

Soviet nuclear icebreaker technology was a spinoff of the nuclear submarine program. It was a useful demonstration of the civilian benefits of nuclear propulsion. It also was seen as an important element of the national strategy to develop Russia's Arctic regions, a vast stretch of land rich in natural resources.

Historically, the development of the Russian Arctic has been closely linked to the development of the Northern Sea Route (in Russian, Severny Morskoi Put' or Sevmorput'), which was established by the Soviet Union in the 1930s. The route connects Russia's Atlantic and Pacific ports and has been in regular use since World War II. It is open for navigation from June to November and relies on extensive infrastructure, including the fleet of icebreakers and ice-class cargo ships, aerial reconnaissance, meteorological stations, navigational aids, and port facilities. The route is a lifeline for many Arctic settlements that have their fuel, food and other resources brought to them by ships. The sea route is also used to move products of the mining, chemical, and wood-processing industries in the Arctic regions of Siberia to Murmansk and other major ports with access to national and international transportation networks.

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The volume of cargo transported via the Northern Sea Route peaked at 7 million tons in 1987 and then declined to 1.5 million tons in the late 1990s.[1] The Russian government seeks to increase the volume to some 10 million tons per year by 2008–2010.[2] To a significant extent, these expectations are linked to the beginning of oil and gas production in the Barents Sea. The exploitable reserves in the Arctic coastal regions and sea shelf of Russia and in Western Siberia are estimated at the equivalent of many billions of barrels of oil.

While Russia's economic needs are believed to be the most important factor in developing the Northern Sea Route, it is also expected to become a major international transoceanic shipping line between the ports in Europe and North America on one hand and the Far East and South East Asia on the other. Taking this route could reduce trip length radically: the distance between Yokohama and Hamburg, for example, is 40 percent shorter via this route compared to routing through the Suez Canal.[3] International shipments between European countries and China, Japan and Thailand commenced in 1991 when Russia announced that it had met conditions for international navigation along the Northern Sea Route. Eventually fees for using the Route could generate on the order of $200 million annually for the Russian economy.[4]

NUCLEAR ICEBREAKERS

The nuclear icebreaker fleet, operated by the Murmansk Shipping Company (MSC) for the Ministry of Transportation, services the western section of the route extending from Murmansk to River Lena as well as river ports on major Siberian rivers. The Arctica-class icebreakers can open passages through 1.5–2 m thick ice, which is sufficient to make possible year-round navigation in the region.[5] The shallow water ships—two Taimyr-class icebreakers and the Sevmorput'-class cargo vessel—are designed to visit river ports and, generally, are not suitable for leading sea convoys. One of the fleet's major responsibilities is to serve the Norilsk Nickel combine, a giant facility, which produces copper and nickel concentrates. The icebreakers assure the delivery of the concentrates from the Arctic port of Dudinka to Murmansk for subsequent processing at the Severonikel facility.[6] The eastern section of the route is serviced by the Eastern Shipping Company, which operates diesel icebreakers. When the ice is thick, the nuclear icebreakers help the Eastern Shipping Company keep the route open.

The advantage of using nuclear icebreakers is their greater power and ice-breaking ability. Unlike diesel icebreakers, they also can operate for extended periods without refueling. (On several occasions, nuclear icebreakers have remained at sea for nearly 400 days.) Because of their high maintenance and operational costs, however, the operation of the nuclear fleet has not been profitable in recent years.[7] Profitability is expected to improve with the hoped-for increase in cargo volume.

Nuclear icebreakers remain a central element of the Northern Sea Route development strategy.[8] The near-term plan (see below) is to extend the life of the operating ships by up to 10 years and to complete the construction of a new icebreaker, which, as of 2002, was 70-percent built. By 2014, four new-generation 60-MWe single-reactor icebreakers (to be designed collaboratively by the nuclear industry, the Marine Fleet's Central Research Institute, and the Krylov Institute) are to be brought on line to replace some of the older ships. These icebreakers would be able both to conduct convoy operations on the high seas and to work in shallow waters and in rivers. A nuclear super-icebreaker with a capacity of 110 MWe is planned to enter operation by 2017. It would be able to go through 3–3.5 m of ice, and its main mission would be to lead convoys from Europe to the Pacific on a year-round basis. Implementation of these plans will depend on the availability of funding.

NUCLEAR ICEBREAKER TECHNOLOGY

The USSR's first icebreaker *Lenin* was put into operation in 1959 and operated until 1966 with three reactors. In 1970, the icebreaker was retrofitted with two OK-900 reactors. In 1989, after 11 refuelings and its reactors having produced 1460 MW-years of thermal energy, the icebreaker was finally retired.

Elements of the OK-900 reactor and associated turbine technology (commonly referred to as the KLT-40 reactor technology) have been used in every commercial nuclear-powered ship built after *Lenin*.[9] In 1974, the Baltiiskiy Zavod shipyard in St. Petersburg completed the *Arktika* icebreaker, designed by the Iceberg Design Bureau. It was the lead unit of 54-MWe Arktika-class icebreaker ships powered by two OK-900A reactors each (see Table 1). The fifth and last vessel of this class, the *50 Years of Victory* icebreaker, was expected to enter the operation in 2006.[10]

In 1988, Baltiiskiy Zavod, in cooperation with Wartsila Marine Shipyard in Finland, built a 29.4 MWe container ship *Sevmorput*.' The conventional portion of the ship was built in Finland while the reactor and turbine equipment was installed at the Baltiiskiy Zavod plant in St. Petersburg. The ship is powered by a single KLT-40 reactor, representing the latest generation of icebreaker reactors. The KLT-40 reactor is based on the OK-900A design but also includes additional safety features. Finally, to extend the operational range of the icebreaker fleet to important river ports on major Siberian rivers, Russian ship-designers, also in cooperation with Finnish shipbuilders, developed and built a reduced-draft Taimyr-class icebreaker. Two 32.5-MWe single reactor ships were built and placed in operation in 1989 and 1990. They use a single modified KLT-40M reactor each.

Under current conditions of limited funding, perhaps the highest priority for the Murmansk shipping company is life extension for its aging icebreaker

Table 1: Nuclear-powered civilian ships in Russia.

Icebreaker	Startup	Estimated retirement/ retirement with life extension	Projected retirement according to 2000 Russian estimates[a]
Lenin 1959–67—three OK-150 reactors 1970–89—two OK-900 reactors	1959	1989 (retired)	na
Arktika-class icebreakers (2 OK-900A reactors each)			
Arktika	1974	2007/2010	2001
Sibir	1977	not in operation since 1992; full retirement if no funding	1992
Rossiya	1985	2004/2014	2011
Sovetski Soyuz	1989	2009/2019	2015
Yamal	1992	2012/2022	2018
50 Years of Victory	2006 (planned)	2026/2036	na
Container ship (single KLT-40 reactor)			
Sevmorput'	1988	2003/2013	2014
Taimyr-class river icebreakers (single KLT-40M reactor)			
Taimyr	1989	2004/2014	2015
Vaygach	1990	2005/2015	2016

[a]V. Makarov, B. Pologikh, Ya. Khlopkin, F. Mitenkov, Yu. Panov, V. Polynichev, O. Yakovlev, "The Experience of Designing and Operation of Civilian Ship Reactor Units," *Atomnaia Energia* (September 2000): 179-189.

fleet. Icebreaker life expectancy depends on operational tempo, ice conditions, maintenance and other factors. The expected service life is 100,000 full power hours, which corresponds to about 20 years of ship operation.[11] For single-reactor ships, the life is expected to be shorter and, in Table 1, it is assumed to be approximately 15 years.[12] Service life of major reactor components is limited mainly by metal stresses due to thermal cycling and by metal corrosion.

Reactor and ship designers are investigating the feasibility of extending reactor service life from 100,000 hours to 150,000 hours, corresponding roughly to 10 additional years of icebreaker operation. Currently, life extension activities, involving a safety analysis of the reactor and propulsion system and component replacement, are being conducted on the icebreaker *Arktika*. *Arktika* has operated for 142,000 hours; its life is being extended to 175,000 hours. Experts believe that life extension to 200,000 hours (corresponding to 30–35 years of service) is feasible.[13]

With a life-extension program in place, most ships in the fleet could operate until approximately 2010–15. Without life-extension, approximately half of the currently operating icebreakers would reach the end of their service lives during the next several years.

In October–November 2002, the Russian government decided to focus federal budgetary resources on the completion of the new icebreaker, *50 Years of*

Victory. Funding for life extension activities is to be borne by the icebreaker operating company. To implement this strategy, the MSC is expected to raise icebreaker service fees.

NUCLEAR FUEL CYCLE AND HEU SECURITY

A significant fraction of the icebreaker fuel is believed to be weapon-grade uranium. For example, according to ship designers, the KLT-40 reactor, installed on the *Sevmorput'* icebreaker, is fueled with 90-percent enriched uranium,[14] whereas, according to U.S. national laboratory and MSC personnel, "[T]he [icebreaker] fuel is U235 of 20%–90% enrichment with 60% average enrichment."[15] Most icebreaker fuel is of the cermet type in which uranium oxide particles are dispersed in an aluminum matrix. Exceptions are approximately 20 cores of 90-percent enriched, zirconium-clad, uranium-zirconium fuel produced for the Arktika-class icebreakers. The uranium-zirconium fuel, however, is no longer manufactured, and the existing stocks have probably already been exhausted.[16]

Naval reactor fuel is fabricated by the Machine-Building Plant in Electrostal. The fabrication probably involves coextrusion of fuel "meat" and cladding. Fresh fuel is sent by rail to the Atomflot base in Murmansk and is stored prior to refueling on board the *Imandra* service ship which is moored at the base.[17]

Nuclear icebreakers are refueled at the Atomflot base every three to seven years. Spent fuel is initially (for approximately six months) stored on board the refueling ship *Imandra*. After six months of storage on *Imandra*, spent fuel is transferred to another Atomflot service ship, *Lotta*.

After one to three years of storage, uranium-aluminum spent fuel is shipped to the Mayak complex in Ozersk (formerly Chelyabinsk-65), where it is reprocessed in the naval fuel line of the RT-1 reprocessing complex. (The RT-1 plant is currently not capable of reprocessing uranium-zirconium fuel.) The concentration of uranium-235 in the residual uranium remains fairly high. This uranium is mixed as uranyl-hydrate solution ($UO_2(NO_3)26H_2O$) with reprocessed uranium recovered from VVER-440 fuel and the mixture is manufactured into fuel for RBMK-type power reactors.

On average, the MSC conducts one to two refuelings per year. Assuming that one core contains 150 kg of ^{235}U, the average flow of ^{235}U in high-enriched uranium through the icebreaker-fleet fuel cycle is 150–300 kg per year.

The HEU fuel of nuclear icebreakers requires protection against theft and diversion during fabrication, transport to the Atomflot facility, and temporary storage on the *Imandra* prior to reactor loading. Nuclear-powered ships, particularly the shallow-water *Taimyr*, *Vaigach*, and *Sevmorput'* vessels, which operate primarily in rivers, also require protection against sabotage. Since 1996, upgrading the security of nuclear icebreaker fleet fuel-storage facilities has been a focus of an international cooperative effort, which has involved several

Russian agencies (primarily the Murmansk Shipping Company, Ministry of Transportation, Kurchatov Institute, and Ministry of Internal Affairs), the U.S. Department of Energy's nuclear Material Protection, Control, and Accounting (MPC&A) program, the Swedish Nuclear Power Inspectorate, the Norwegian Radiation Protection Authority, and the U.K. Office of Civil Nuclear Security.[18]

The focus of the U.S./Russian project has been on security upgrades for fresh fuel stocks on the *Imandra* ship.[19] The European countries have primarily contributed to safeguard improvements on the icebreaker ships, including *Sevmorput*,' *Arktika*, and *Yamal*.[20] Under the MPC&A program, the United States and Russia have also been working to improve security of nuclear shipments by upgrading railcar security. MPC&A work at the HEU fuel fabrication line of the Electrostal plant, however, has not begun, because of lack of access for U.S. personnel. (In addition to icebreaker fuel, the line produces nuclear submarine fuel whose design is classified by Russian law.)

NOTES AND REFERENCES

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2. V. Peresypkin, "The Strategy of Development," (http://segodnya.spb.rus.net/5-6-00eng/17_e.htm)

3. Claes Lykke Ragner *Northern Sea Route Cargo Flows and Infrastructure—Present State and Future Potential*, FNI Report (The Fridtjof Nansen Institute, 2000).

4. "Four questions for Sergey Frank," *New East Today* 3/4 (2000).

5. The maximum thickness of ice depends on numerous factors, including snow, which slows icebreakers down, and ice pressure due to wind. The last Arktica-class icebreaker—*50 Years of Victory*—will be capable of breaking 2.8 m thick ice. See: "Icebreaker Fleet," Baltiiskii Zavod web site (www.bz.ru/e031_002.htm).

6. "Russian Northern Sea Route not Hit by Cold: Shipping Firm," *Informare*, (February 18, 1999) (www.informare.it/news/review/1999/st0724.asp).

7. "Atomic ice-breakers unprofitable," Bellona web-site (May 23, 2002) (www.bellona.no/en/international/russia/icebreakers/15252.html#24915).

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9. V. Kovalenko, "Braving the Chill of the Market," *Nuclear Engineering International* (January 1993): 52–54.

10. "No Radiation from Ship Fire," *The St.Petersburg Times* (December 3, 2004) (www.sptimes.ru/index.php?action_id=2&story_id=2228).

11. V. Makarov et al., "The Experience of Designing and Operation of Civilian Ship Reactor Units," *Atomnaia Energia* (September 2000): 179–189.

12. A two-reactor ship often can sail using only one reactor at significant power. This effectively increases ship's life relative to single-reactor ships, which have to operate their reactor and associated turbine equipment continuously.

13. A. Korolev, "Life time for nuclear icebreakers prolonged," Bellona Web-site (May 22, 2000) (www.bellona.no/en/international/russia/icebreakers/16825.html).

14. Interview with representatives from the Krylov Institute, St. Petersburg, September 1992.

15. Michael O'Brien, "MPC&A Activities with Russian Icebreaker Fleet," presented at the 38th Institute of Nuclear Material Management's Annual Conference, Phoenix, AZ, July 20–24, 1997.

16. The choice of Zr-based fuel was originally made out of concern that Al-based fuel would leak or loose its structural integrity as had happened in some submarine reactors. Operational experience, however, has demonstrated adequate performance of Al-based fuels and the production of unreprocessable Zr-U fuel was terminated.

17. Michael O'Brien et al., "MPC&A Activities with Russian Icebreaker Fleet," Partnership for Nuclear Security (U.S. Department of Energy, September 1998).

18. Michael O'Brien et al., "MPC&A Activities with Russian Icebreaker Fleet," (U.S. Department of Energy, 1997); "Wilson: Latest UK Funding For Safe Russian Nuclear Clean-Up Only Tip Of The Iceberg," (U.K. Department of Trade and Industry, November 19, 2002) (www.dti.gov.uk/energy/nuclear/fsu/index.shtml).

19. Security enhancements at the ship *Imandra*, the Atomflot base, and some of the ships were implemented by 1998–99 following a vulnerability assessment conducted in the fall of 1996, and included access control, intrusion detection and assessment, computerized material accounting, and radio communications.

20. Anna Shuvalova, " U.K.-Russian Global Partnership Cooperation," *Yaderny Control* (3) (2004), 125–144.