Marine Nuclear Power: 1939 – 2018

Part 3B: Russia - Surface Ships & Non-propulsion Marine Nuclear Applications

Peter Lobner

July 2018

Foreword

In 2015, I compiled the first edition of this resource document to support a presentation I made in August 2015 to The Lyncean Group of San Diego (www.lynceans.org) commemorating the 60th anniversary of the world's first "underway on nuclear power" by *USS Nautilus* on 17 January 1955. That presentation to the Lyncean Group, *"60 years of Marine Nuclear Power: 1955 – 2015,"* was my attempt to tell a complex story, starting from the early origins of the US Navy's interest in marine nuclear propulsion in 1939, resetting the clock on 17 January 1955 with *USS Nautilus*' historic first voyage, and then tracing the development and exploitation of marine nuclear power over the next 60 years in a remarkable variety of military and civilian vessels created by eight nations.

In July 2018, I finished a complete update of the resource document and changed the title to, *"Marine Nuclear Power: 1939 – 2018."* What you have here is *Part 3B: Russia - Surface Ships & Non-propulsion Marine Nuclear Applications*. The other parts are:

- *Part 1: Introduction*
- *Part 2A: United States - Submarines*
- *Part 2B: United States - Surface Ships*
- *Part 3A: Russia - Submarines*
- *Part 4: Europe & Canada*
- *Part 5: China, India, Japan and Other Nations*
- *Part 6: Arctic Operations*

Foreword

This resource document was compiled from unclassified, open sources in the public domain. I acknowledge the great amount of work done by others who have published material in print or posted information on the internet pertaining to international marine nuclear propulsion programs, naval and civilian nuclear powered vessels, naval weapons systems, and other marine nuclear applications. My resource document contains a great deal of graphics from many sources. Throughout the document, I have identified all of the sources for these graphics.

If you have any comments or wish to identify errors in this document, please send me an e-mail to: PL31416@cox.net.

I hope you find this informative, useful, and different from any other single document on this subject.

Best regards,

Peter Lobner
July 2018

Marine Nuclear Power: 1939 – 2018
Part 3B: Russia – Surface Ships & more

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Marine Nuclear Power: 1939 – 2018

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- Russian nuclear vessel design, construction & life-cycle infrastructure
- Russian naval nuclear infrastructure
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Russian nuclear-powered surface ships

- Surface ship reactors
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Surface ship reactors

Russian surface ship reactors

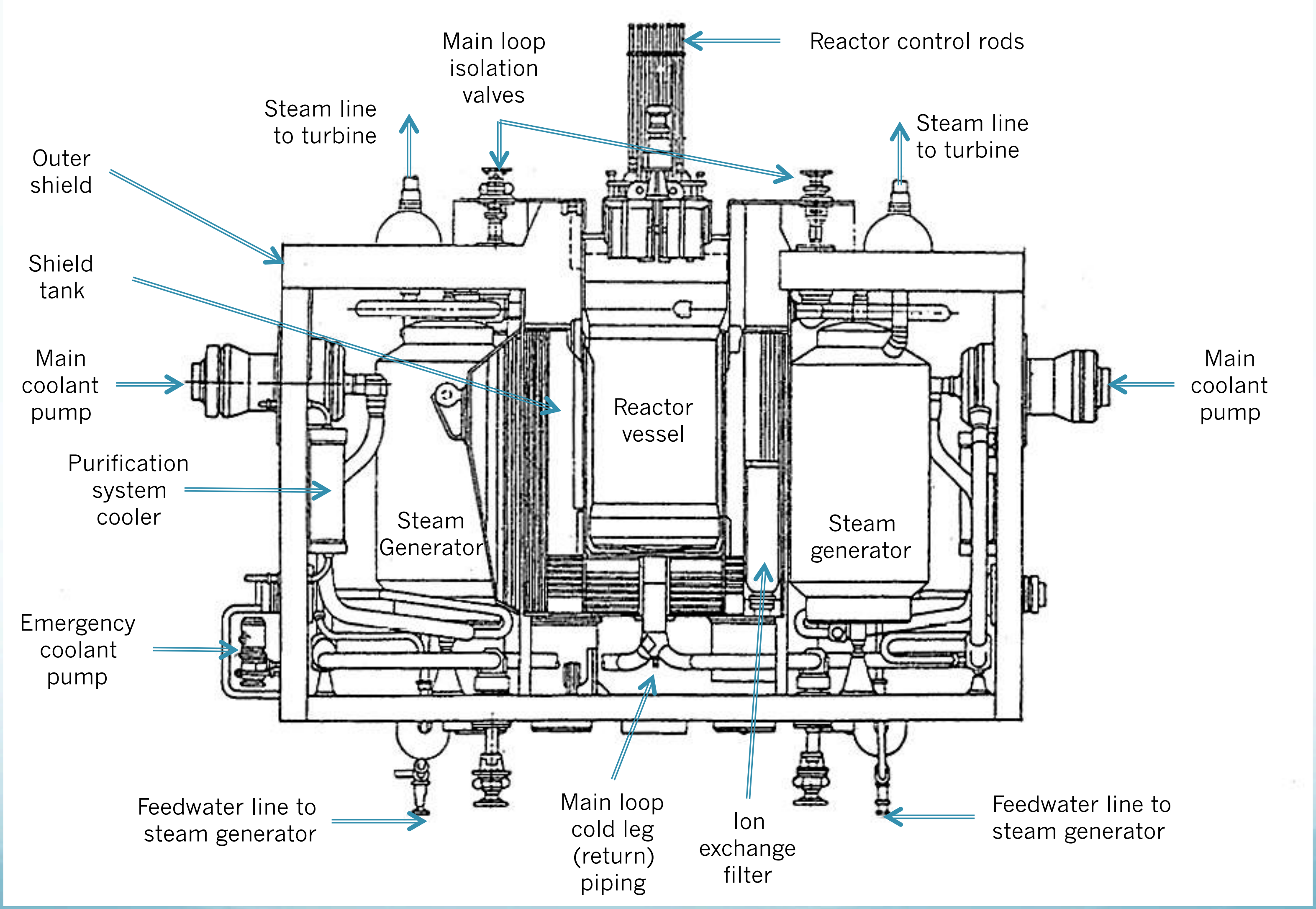
Reactor system	Reactors	Design bureau	Power (MWt)	Initial ops	Application
OK-150	3 x PWR	Afrikantov	90	1959	• *Lenin* icebreaker, original reactor plant. • Powered the world's 1st nuclear surface ship.
OK-900	2 x PWR	Afrikantov	159	1970	• *Lenin* icebreaker, replacement reactor plant. • Modular PWR design.
OK-900A	2 x PWR	Afrikantov	171	1975	• Six Arktika-class deep-water icebreakers. • Also was the basis for the KLT-40, the KN-3 naval reactor and the OK-650 series of submarine reactors.
KLT-40	KLT-40	Afrikantov	135	1988	• 1 x KLT-40 powers *Sevmorput* LASH icebreaking cargo ship. • Derived from the OK-900A.
KLT-40M	KLT-40M	Afrikantov	171	1989	• 1 x KLT-40M powers each of two Taymyr-class icebreakers. • Derived from the OK-900A.
KLT-40S	KLT-40S	Afrikantov	150	2015 expected	• 2 x KLT-40S are installed on the floating nuclear power plant *Akademik Lomonozov*. Not used for propulsion.
RITM-200	RITM-200	Afrikantov	175	2020 Expected	• 2 x RITM-200 PWRs power the LK-60-class "universal" icebreakers.
KN-3	2 x VM-16 PWRs	Afrikantov	300 (est)	1980	• Usually described as a Combined Nuclear and Steam (CONAS) plant. Used on four Project 1144.2 Orlan (Kirov)-class CGNs, and likely intended for the Project 1143.7 Ulyanovsk-class aircraft carrier. • Sometimes referred to as an OK-900B, which supports other evidence that KN-3 is based on OKBM Afrikantov's OK-900A modular PWR plant used on the Arktika-class icebreakers.
OK-900 variant	2 x PWR	Afrikantov	171 (est)	1989	• One Project 1941 (Titan) "Ural" command, control & communications ship. • Similar to the Arktika-class icebreaker OK-900A nuclear reactors.

OK-150
Loop-type PWR

- Reactor plant developed by Russian Special Design Bureau for Mechanical Engineering (OKBM) Afrikantov.
  - 3 x 90 MWt loop-type PWRs
- Primary system for each reactor consisted of 2 primary coolant loops:
  - Each coolant loop had 1 x steam generator, 2 x main coolant pumps (one operating, one in standby), 1 x emergency coolant pump (in standby), main loop isolation valves, and a water purification loop with cooler and ion exchange filter.
  - Primary system cold loop (return) piping connects to the bottom of the reactor vessel.
  - The Volume compensation system (4 x pressurizer tanks) performed the function of a pressurizer.
- Reactor:
  - Fuel: 5% enriched uranium in ceramic uranium dioxide (UO_2) fuel, with various cladding (Zr, stainless steel, Zr-Nb alloy).
    - Fuel load: 85 Kg (187.4 pounds)
    - Core life was 18 - 20,000 MWd (Megawatt-days), 200 – 222 full-power days, for the first core.
  - Core dimensions: 1.58 m (5.18 feet) high by 1 m (3.28 feet) diameter
- In “single-loop” mode (one primary loop out of service), the reactor was allowed to operate at up to 50 MWt with 1 x main coolant pump + the emergency coolant pump operating.
- Application: Used only on the icebreaker Lenin.

OK-150

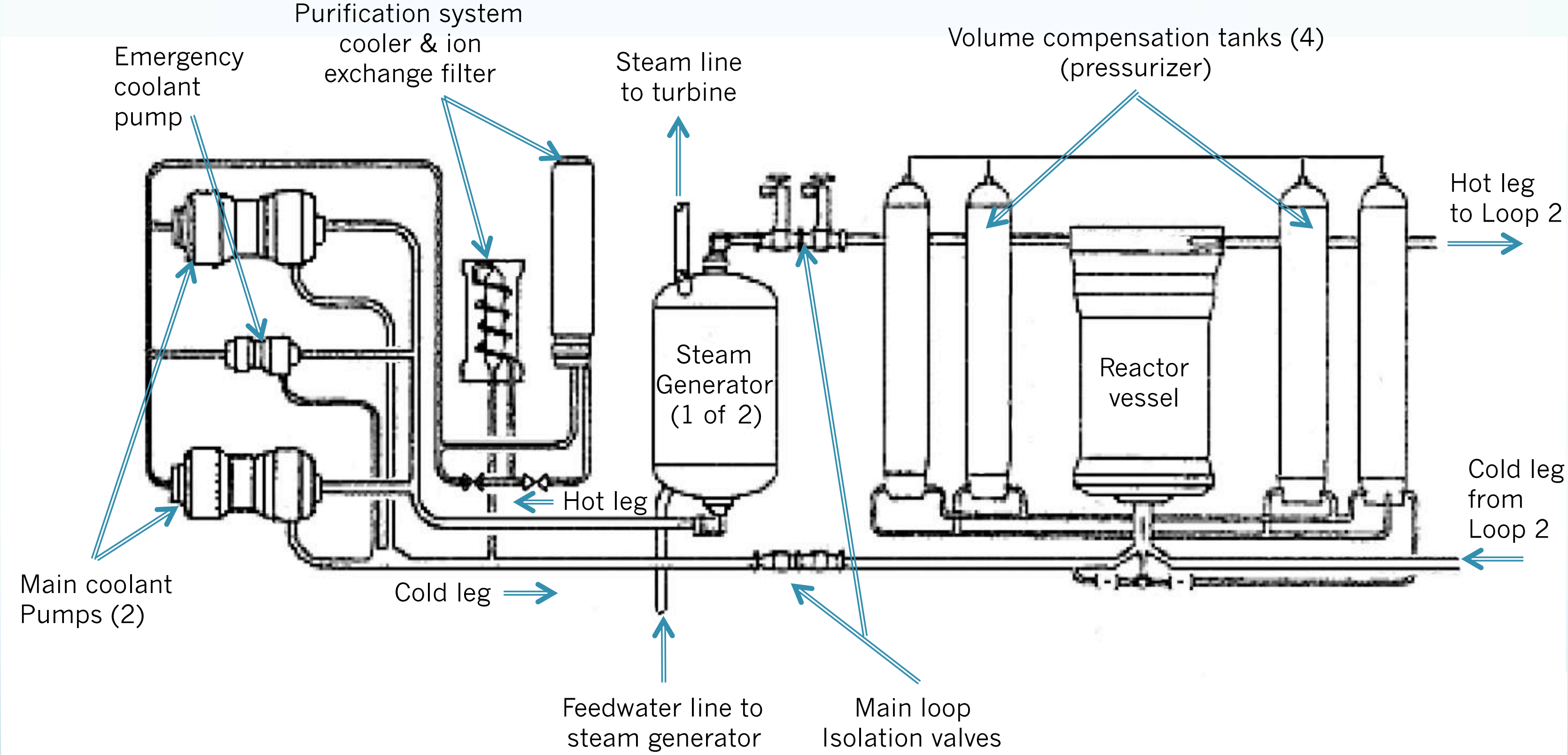
Typical of three reactor units on icebreaker *Lenin*



Source: adapted from atomicpowerreview.blogspot.com

OK-150

Process flow diagram for one of two primary loops for a single reactor on icebreaker *Lenin*



Adapted from Nordic Nuclear Safety, research report NKS-138

OK-900 and variants

Modular PWRs

- Developed by Special Design Bureau for Mechanical Engineering (OKBM) Afrikantov.
- Each modular PWR has 4 primary system "loops". Pipe-inside-pipe (co-axial) load-bearing "loop" piping connects the top of the reactor vessel to each of four steam generators and main coolant pumps.
- A recently declassified 1983 CIA report* described the OK-900 as "the 'workhorse' of the Soviet Navy," and identified three types of OK-900 reactor cores: the HEU-fueled VM-14-5/02 and VM-14-5/03 cores, and the LEU-fueled VM-149/M core.
  - The VM-14-5/02 HEU core: 180 MWt
    - Core diameter is 1.5 meters; active length is 0.9 meter; triangular fuel lattice
    - Two types of fuel pins: "heavy" fuel pins contain uranium at 45% enrichment and "light" fuel pins contain uranium at 30% enrichment. The fuel pins are assembled into fuel elements. Fuel pin external diameter is 7 mm.
    - Total core load is about 197 kg of U-235. Gadolinium is used as a burnable poison.
  - The VM-14-5/03 HEU core: 171 MWt
    - Dimensions of the core are the same as the VM-14-5/02 core, but the number of fuel pins and enrichment are different. This was the first core to use reprocessed uranium.
    - The "heavy" pins contain uranium at 68.6% enrichment; the "light" pins contain uranium at 55.6% enrichment; total core load is about 270 kg of U-235. Burnable poison is used.
    - This core has been cycled 20,000 times in the 20% - 100% power range with an amplitude of ± 25% at a rate of change of 1%/second. This likely represents an icebreaker duty cycle.
    - Design core burnup was about 2.6 x 10^6 Megawatt-hours; about 15,205 equivalent full-power hours (EFPH) or 634 full-power days @ 171 MWt.

* Intelligence Information Special Report, "Design and Performance of Soviet Naval Nuclear Reactors," Central Intelligence Agency, 11 January 1983, declassified and approved for release 16 June 2017

OK-900 and variants

Modular PWRs

- The VM-149M LEU core: 100 MWt
  - Core diameter is 1.21 meters; active length is 0.91 meter; triangular fuel lattice
  - The "light" pins contain uranium at 5% enrichment; the "heavy" pins contain uranium at 6.5% enrichment; total core load is about 109 kg of U-235. Burnable poison is used in the core.
  - Design core burnup was about 1.0 x 10^6 Megawatt-hours; about 10,000 equivalent full-power hours (EFPH) or 417 full-power days @ 100 MWt.
  - This core may have been a preliminary version for an LEU core for the KLT-40 marine reactor.
- The Orlan (Kirov) guided missile cruiser core: a modified VM-14-5/03 HEU core
  - Fuel pin and active core length were increased from 0.9 meter to 1.1 meter
  - Core power level is greater than that of a standard OK-900.

- A containment structure encloses the OK-900 nuclear steam supply system:
  - A release of radioactive material from the primary system is contained.
  - The containment is designed to flood if the vessel sinks, thereby maintaining structural integrity and the containment function.

OK-900 and variants

Modular PWRs

- Applications:
  - OK-900 with 2 x 159 MWt PWRs was installed on icebreaker *Lenin*, replacing the original OK-150 nuclear power plant.
  - OK-900A with 2 x 171 MWt PWRs are installed in all six Arktika-class deep-water icebreakers, with improved versions in the last three ships in the class.
  - An OK-900A variant with 2 x 171 MWt PWRs was installed on the Project 1941 *Ural* command ship.
  - KN-3 propulsion plant comprised of 2 x PWRs integrated into auxiliary steam boilers in a CONAS arrangement on the Orlan (Kirov)-class guided missile cruisers. The PWRs are an OK-900A variant with longer fuel elements capable of operating at higher power.
  - The submarine reactor designated OK-650 and used on almost all Russian 3rd-generation nuclear submarines, is believed to be a variant of the OK-900A modular PWR with the NSSS rearranged and modified to fit into the submarine hull.
  - The KLT-40 is based on the OK-900A, with enough NSSS hardware similarity to allow two OK-900A steam generators to be removed from a retired Arktika-class icebreaker and installed in a KLT-40 NSSS on the Taymyr-class icebreaker.

OK-900

Model of installation of one reactor on *Lenin*

Volume compensation

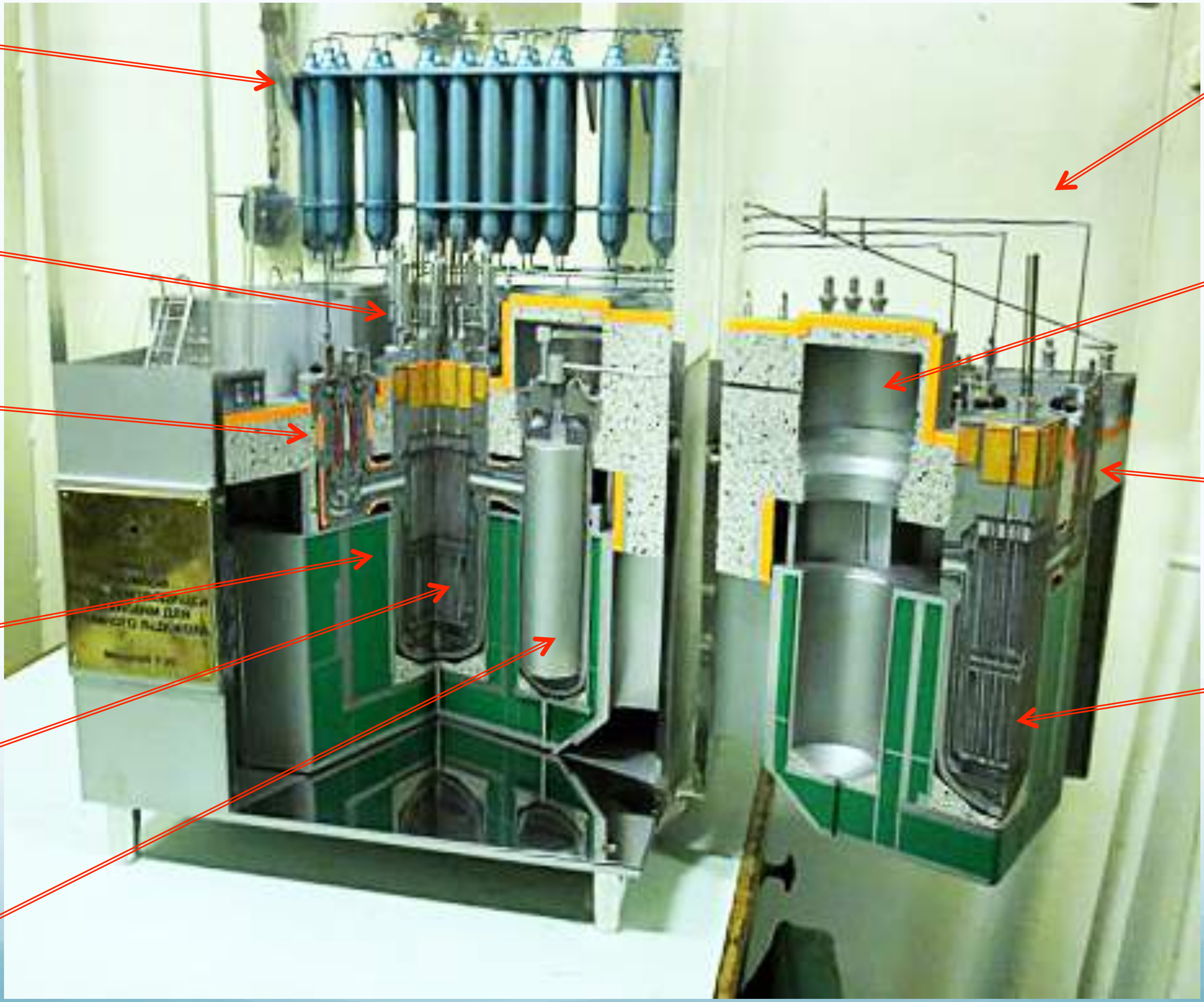
Control rod drives

Modular main coolant pump

Shield tank

Reactor

Modular steam generator



This piece of the model has been rotated 180°

Cavity for modular steam generator

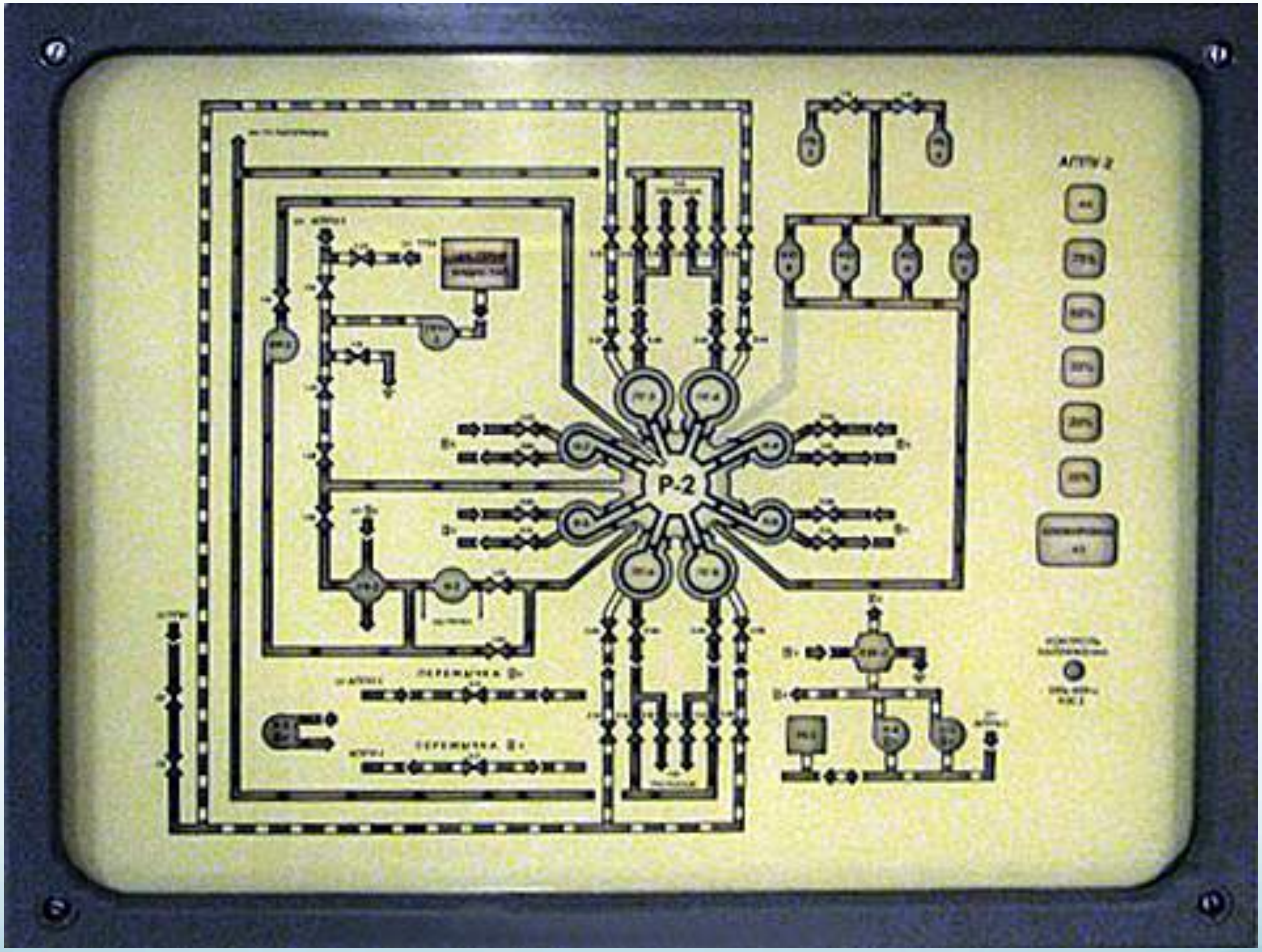
Modular main coolant pump

Reactor

Source: https://leninicebreaker.wordpress.com

OK-900 status panel

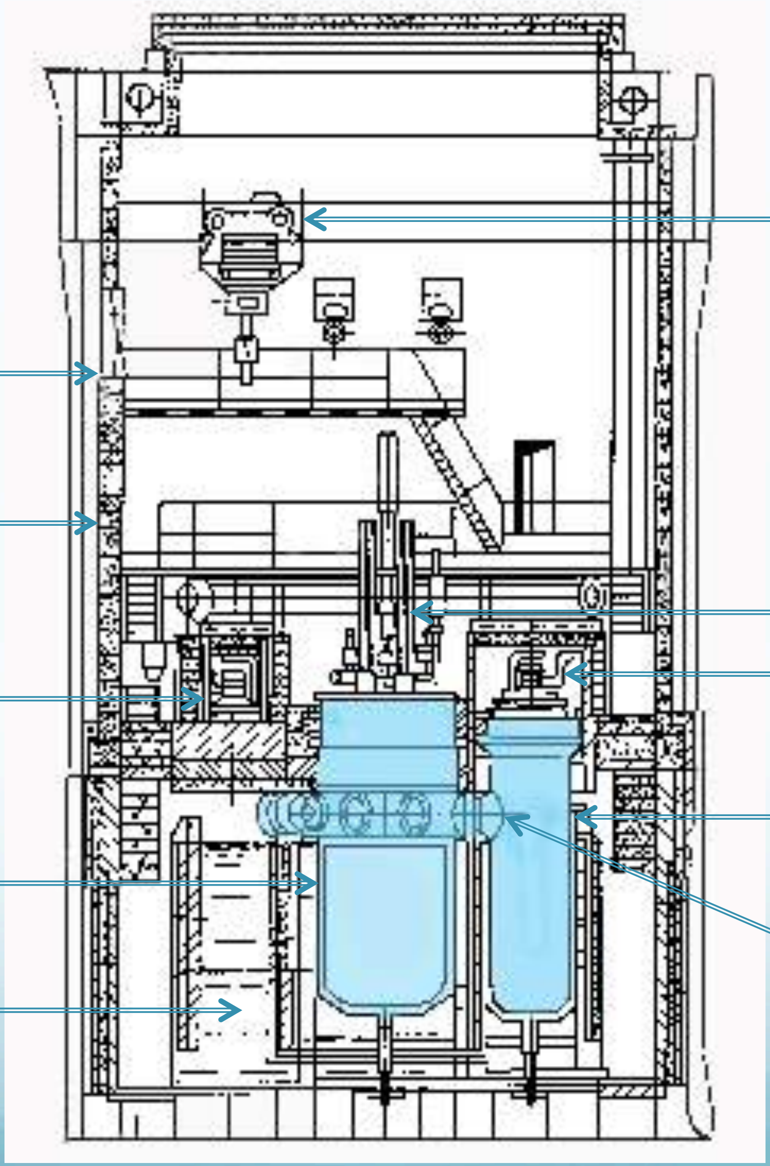
As installed on *Lenin*



Source: adapted from Arctic Expo Center – Icebreaker Lenin

OK-900A

As installed in Arktika-class icebreakers



Source: adapted from spb.org.ru/bellona/

KLT-40 and variants

Modular PWRs

- This modular PWR was developed by Russian Special Design Bureau for Mechanical Engineering (OKBM) Afrikantov
- KLT-40 is essentially the same modular PWR design as the OK-900A with a different reactor core. Containment structure is similar to OK-900, with additional pressure suppression features.
- Fuel: Enriched uranium in U-Zr alloy with Zr cladding
- Core dimensions: about 1.0 m (3.28 ft) high by 1.21 m (3.97 ft) diameter
- Applications:
  - KLT-40, rated at 135 MWt
    - 1 x KLT-40 is used for propulsion of the *Sevmorput* icebreaking cargo ship.
    - Entered service in 1988.
    - Fuel enrichment is believed to be in the 30 – 40% U-235 range.
    - Core life is reported to be 62,000 to 68,000 MW-days (460 – 503 full-power days)
    - After completing an overhaul in 2017, Sevmorput's NSSS was cleared for 175,000 hours of operation.
  - KLT-40M, rated at 171 MWt
    - 1 x KLT-40M is used for propulsion of two Taymyr-class icebreakers.
    - Entered service in 1989.
    - Fuel enrichment is believed to be in the 30 – 40% U-235 range.
    - In 2016, the KLT-40M on the Taymyr's NSSS was cleared for 200,000 hours of operation.
  - KLT-40S, rated at 150 MWt with an LEU core, is intended for non-propulsion applications

KLT-40

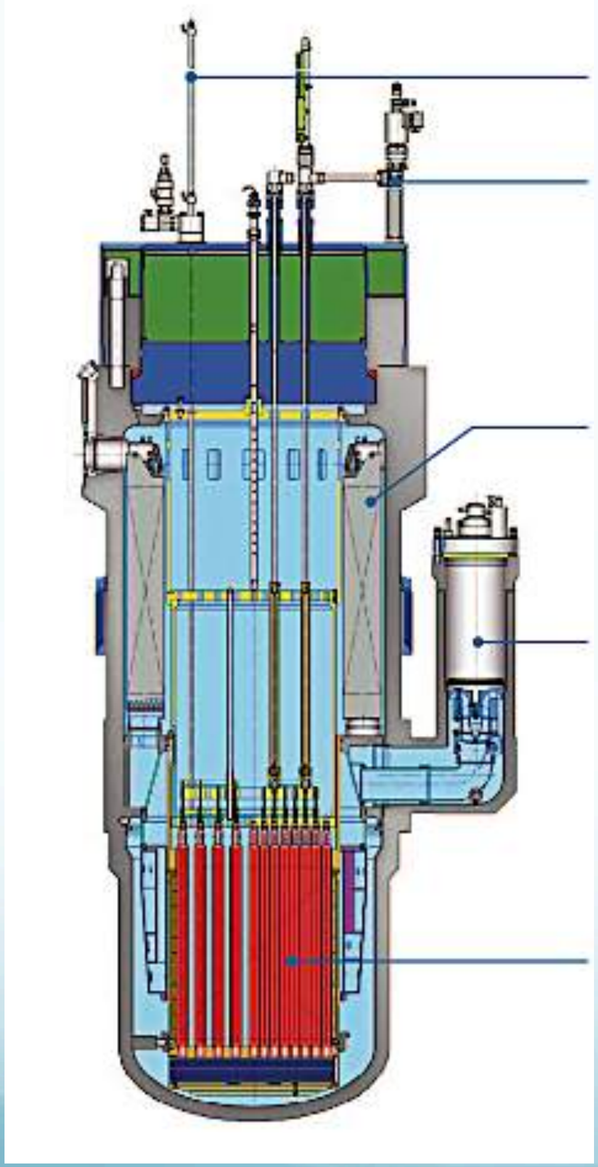
Basic configuration of the modular PWR

Source: OKBM Afrikantov

RITM-200
Integral PWR

- Reactor developed by OKBM Afrikantov.
- PWR, integral reactor plant (integrated steam generating unit, SGU) rated @ 175 MWt.
- Very compact, with 12 steam generator units (cassettes) internal to the reactor vessel and minimum primary system piping outside the reactor vessel; mainly for connections to the four variable speed primary coolant pumps.
- Safety is enhanced by:
  - The large water volume and high heat capacity within the reactor vessel
  - External systems connect to the top part of the SGU
  - Adequate primary system natural circulation for shutdown reactor core cooling
  - External accumulators provide primary makeup water when needed
  - The entire SGU is enclosed within a containment structure and a safety enclosure
- Reactor uses metal-ceramic (cermet) fuel enriched to less than 20% U-235.
- Reactor core life is 75,000 equivalent full power hours (EFPH); core service life is 12 years.
- Service life for RITM equipment is 20 years for replaceable components and 40 years for permanent components.

RITM-200



Source, both graphics: OKBM Afrikantov

RITM-200

Integral PWR

- Steam generators in the integral primary system originally were to be supplied by Turboatom, a Ukrainian company based in Kharkiv. The current war in eastern Ukraine required that a Russian manufacturer be qualified to deliver the steam generators.
- The main production operations for manufacturing RITM-200 are conducted near Moscow at the Zio-Podolsk Plant (together with OKBM Afrikantov, they are both parts of Atomenergomash). The manufacturing cycle takes about 2.5 years. The process of adding anticorrosive plating to the inside of the to the reactor vessel requires about eight months, during which time about 10 tons of anti-corrosive material is welded onto the reactor vessel.
- Applications:
  - RITM-200
    - 2 x RITM-200 integral PWRs, each rated at 175 MWt, will be installed in the new generation LK-60Ya icebreakers being built now, yielding 60 MW propulsion power.
    - Refueling interval is expected to be 7 years over a planned 40 year service life.
  - RITM-200B
    - Power uprated to 209 MWt, intended for icebreaker applications.
  - RITM-200M
    - Developed for non-propulsion applications as an ‘Optimized Floating Power Unit,” (OFPU) for use on non-self-propelled floating nuclear power plants (FNPP).
  - Other potential applications include land-based industrial and power plant applications.

Manufacturing RITM-200 vessels

for Project 22220 (LK-60Ya) nuclear icebreakers

Above: Integral reactor vessel for *Sibr* before adding primary pump housings Source: Atomenergomash

Right: Integral reactor vessel for 2nd reactor on *Arktika*, with primary pump housings installed. Source: Rosatom

Right: Completed RITM-200 integral reactor vessel weighs about 180 tons. Source: Atomenergomash

RITM-400
Integral PWR

- Reactor being developed by OKBM Afrikantov, derived from the RITM-200 design.
- PWR, integral reactor plant (integrated steam generating unit, SGU) rated @ 315 MWt.
- Expected service life: 40 years
- Application:
  - 2 x RITM-400 integral PWRs, each rated at 315 MWt, are expected to be installed in the new generation LK-110Ya Leader-class polar icebreakers, yielding about 120 MW (160,922 shp) propulsion power.
  - LK-110Ya icebreakers are expected to enter service in the mid-to-late 2020s.

KN-3

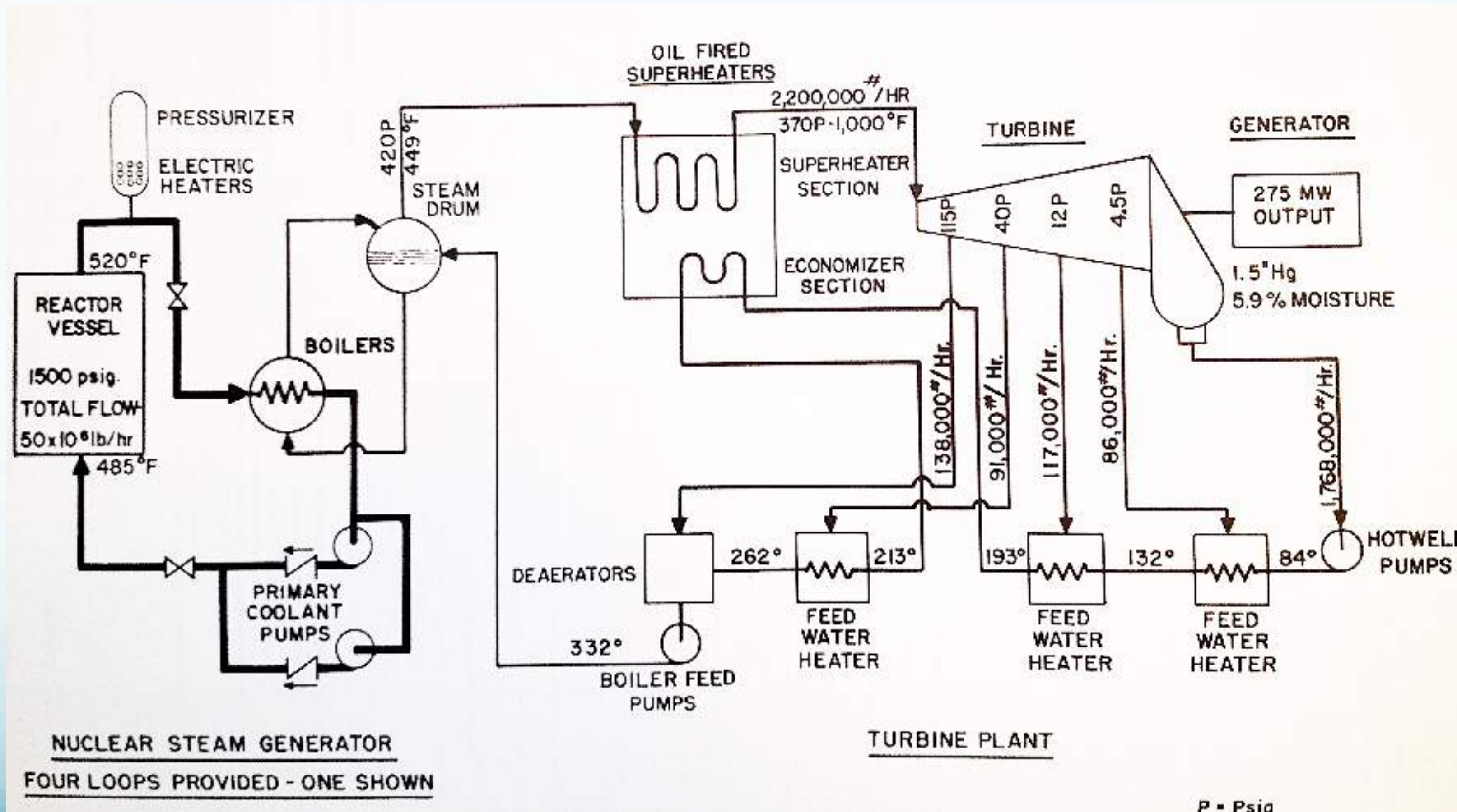
Combined Nuclear and Steam (CONAS) plant

- The KN-3 is described in several sources as a CONAS propulsion system that consists of 2 x PWRs each rated at about 300 MWt and 2 x oil-fired auxiliary boilers each rated at 115 t/h steam capacity (at unspecified steam conditions).
  - A recently declassified 1983 CIA report* indicates that these reactors are a variant of the OK-900A icebreaker reactors designed by OKBM Afrikantov.
  - The CIA report* refers to the reactors in the KN-3 propulsion systems as having modified VM-14-5/03 cores with longer fuel elements (1.1 meters vs. 0.9 meters) and a higher power rating than the standard icebreaker VM-14-5/03 reactor cores.
  - Other sources have referred to these reactors as "VM-16" and "OK-900B."
- The KN-3 with CONAS is used on Project 1144.2 Orlan (Kirov)-class guided missile cruisers.
  - Reported total propulsion power is 140,000 shp. The auxiliary boilers can operate independently to drive the ship at lower speed (max. 14 - 17 kts) with one or both of the reactors shutdown.
- Details of how the KN-3 CONAS system operates are not known. Two alternatives are tandem or parallel operation of the reactor plant and the oil-fired steam plant.
- Tandem operation of the reactor plant and the auxiliary boilers:
  - The reactor plants operate in tandem with auxiliary boilers that superheat the steam going to the turbines, and together they yield the combined propulsion power output needed for high-speed cruise: 140,000 shp.
  - If this process description is correct, then the turbines would be designed for superheated steam conditions. This may preclude operation without the auxiliary boilers, which are needed to superheat the saturated steam delivered by the nuclear power plants.

* Intelligence Information Special Report, "Design and Performance of Soviet Naval Nuclear Reactors," Central Intelligence Agency, 11 January 1983, declassified and approved for release 16 June 2017

Example PWR combined nuclear and steam (CONAS) process

Example of tandem operation with oil-fired superheat



This is the process flow diagram for the CONAS system at the original Indian Point nuclear power plant.

Source: atomicpowerreview.blogspot.com, reproduced from "Power Reactors 1959" published by ASME

KN-3

Combined Nuclear and Steam (CONAS) plant

- Parallel operation of the reactor plant and the auxiliary boilers:
  - Speculation exists that the auxiliary boilers actually operate in parallel with the reactor plants and both deliver saturated steam to turbines that are designed for those steam conditions.
  - Two 300 MWt reactor plants should be able to deliver a total of about 115,000 shp via main turbines that are designed for saturated steam conditions.
  - The balance of propulsion power would be provided by the two auxiliary boilers. This would be a minimum of 25,000 shaft horsepower for Project 1144.2 Orlan (Kirov)-class CGNs.
- The KN-3 has been incorrectly attributed in several sources as the propulsion plant for the Project 1941 *Ural* command ship. However, a Russian report prepared in connection with dismantling the *Ural* disclosed that the *Ural's* reactor plant is very similar to the OK-900A reactor installations on Arktika-class nuclear icebreakers.
- KN-3 may have been the intended propulsion system for the Project 1143.7 Ulyanovsk-class aircraft carrier, which was being developed in the late 1980s.

Refueling Afrikantov marine and naval reactors

- Since the 1960s, OKBM Afrikantov has been developing, manufacturing and delivering nuclear fuel handling equipment for refueling and repairing marine and naval reactors.
- **For naval reactor plants:** The refueling equipment performs the following functions: seal, unseal and dismount reactor pressure vessel heads, discharge the nuclear fuel, charge fresh nuclear fuel and perform other process operations.
- **For icebreaker reactor plants:** To optimize fuel handling for the KLT-40 and KLT-40M marine reactors, special devices were developed and delivered to provide compact stowage and transportation of spent nuclear fuel.
- **For a Floating Power Unit (FPU):** The KLT-40S reactor refueling complex for the FPU *Akademik Lomonosov* was developed to ensure correct operation of the nuclear fuel handling path, starting from fresh fuel loading and ending up with preparing the spent fuel overpacks and solid radwaste canisters for unloading.
- **For new LK-60Ya multi-purpose icebreakers**: Afrikantov designed and manufactured the first core loading equipment and a refueling complex for the RITM-200 reactor. The refueling complex performs the entire scope of fuel handling activities in the course of operation of multi-purpose nuclear icebreakers, starting with opening the reactor, discharging spent fuel assemblies, inserting new fuel assemblies into the reactor core, and then installing all other reactor equipment required prior reclosing the reactor.

Refueling complex for a KLT-40 reactor on the floating power unit *Akademik Lomonosov.* Source: OKBM Afrikantov, http://www.okbm.nnov.ru/english/equipment

Nuclear-powered icebreakers

Northern Sea Route

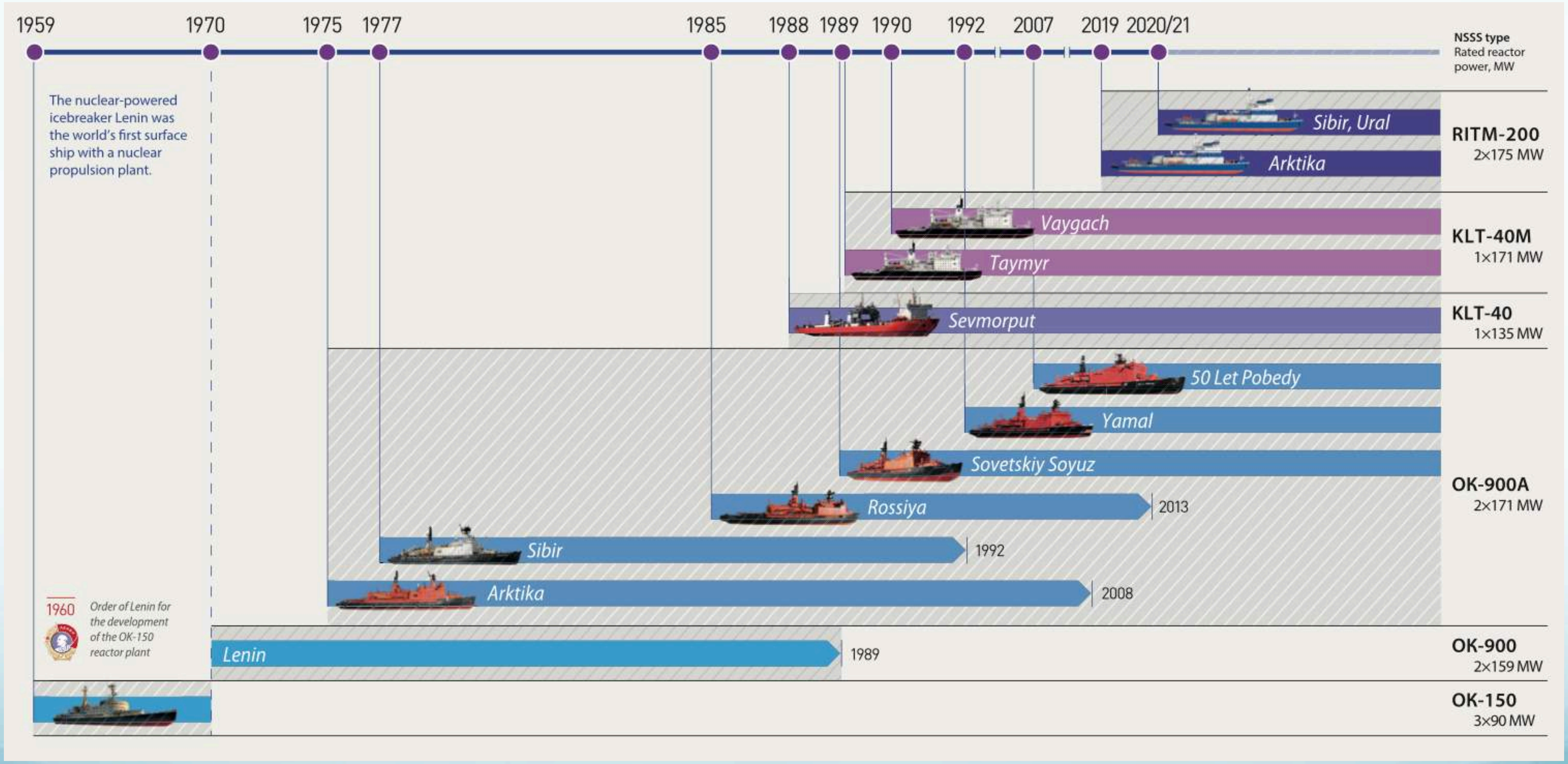
Source: ArcticEcon.wordpress.com

- Northern Sea Route, also known as Northeast Passage, is a water route along the northern coast of Russia, between the Atlantic and Pacific oceans.
- First traversed by Nils A. E. Nordenskjold of Sweden in 1878-79.
- Regular use of this route was first established in the 1930s by the USSR.
- This route enables shipping to support Russian cities and industrial infrastructure along the north coast and cuts the distance between Russian Atlantic and Pacific ports in half, relative to routes through the Suez Canal.
- A fleet of Russian icebreakers, aided by aerial reconnaissance and by radio weather stations, keeps the entire Northern Sea Route navigable from June to October, and the route from Murmansk to Dudnika open all year.

The Russian nuclear icebreaker fleet operator

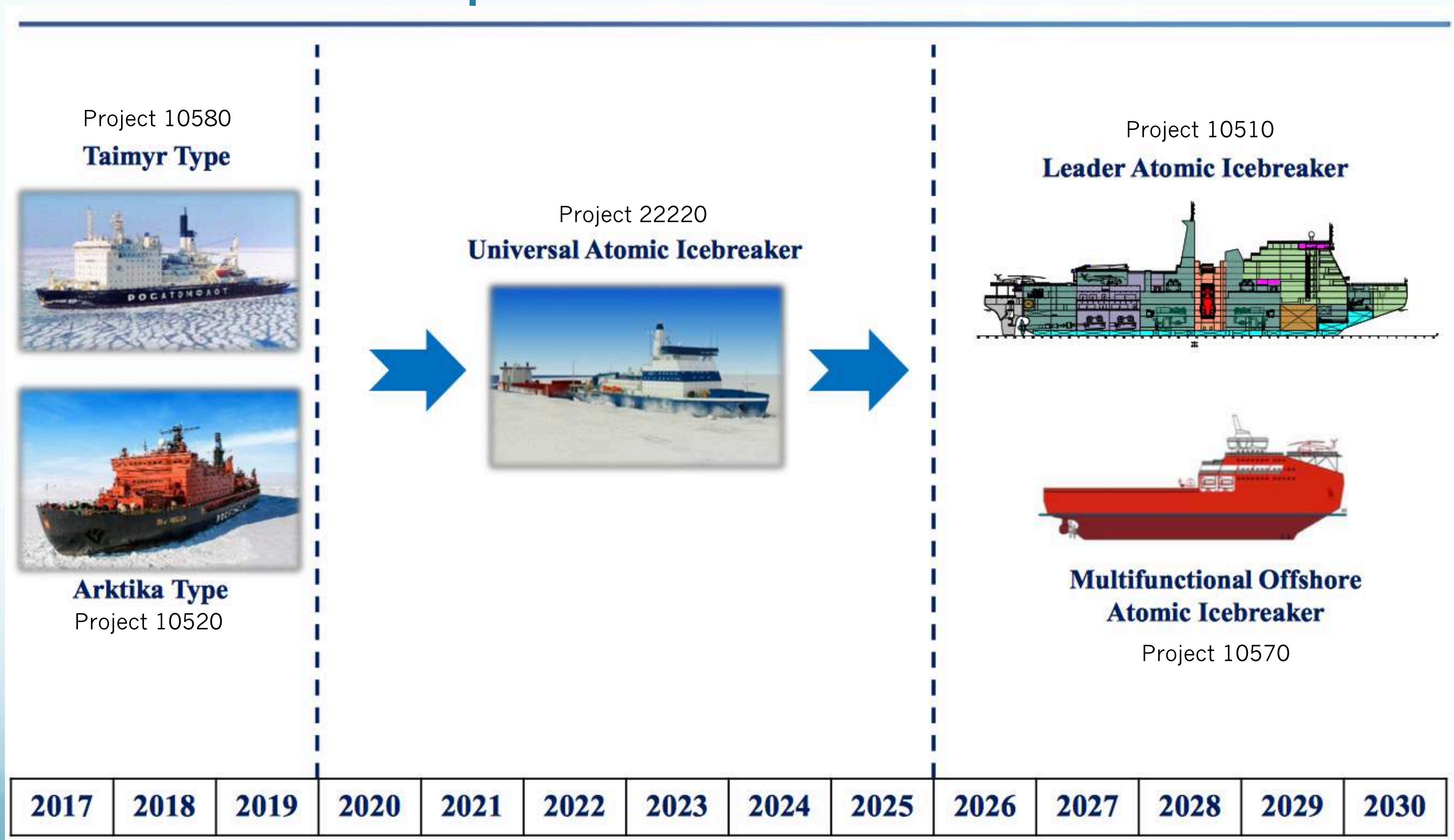
- The nuclear icebreaker fleet is under the administration of Rosatomflot, based about two km north of Murmansk.
- The nuclear icebreaker fleet is supplemented by many diesel-powered icebreakers and various types of ice-breaking cargo and utility ships.
- Icebreakers guide convoys of ships and tow other vessels if needed. The wide beam of the icebreaker cuts an ice channel wider than the following ships.
- Murmansk Shipping Company (MSC): 1959 – 2008
  - MSC managed and operated the state-owned Russian nuclear icebreaker fleet since *Lenin* was introduced in 1959. In 1998 the icebreaker fleet was transferred to MSC.
  - MSC was the only Russian marine company operating in the Arctic all year around.
  - The company had a monopoly on the strategic market for icebreaker assistance in the Arctic.
  - MSC delivered cargo for various oil and mining companies and delivered goods to remote Russian cities in the Arctic region.
  - The nuclear icebreakers were serviced at the Atomflot base just north of Murmansk.
  - MSC was 25% owned by the Russian state.
- ROSATOMFLOT (Atomflot): 2008 – present
  - In 2008, Atomflot replaced MSC as the manager and owner of the Russian icebreaker fleet. At that time, only two of the nuclear icebreakers, *Yamal* (commissioned in 1992) *and 50 Let Pobedy* (commissioned in 2007) were not in need of overhauls.
  - Atomflot is a Russian state nuclear corporation and a member of ROSATOM Group.

Russian nuclear-powered icebreakers



Source: http://www.okbm.nnov.ru/images/pdf/ritm-200_extended_en_web.pdf

ROSATOM long-range plans for nuclear-powered icebreakers



Source: ROSATOMFLOT, “Development of Atomic Icebreaking Fleet and Support for Arctic Projects,” 2017

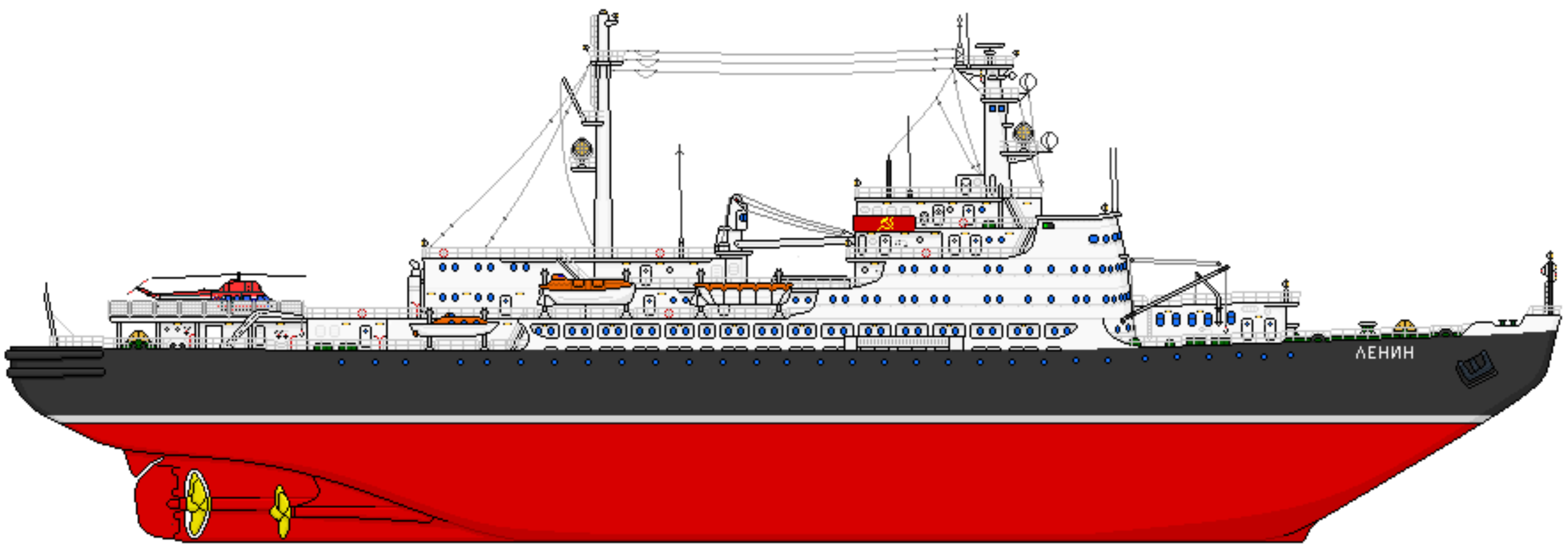
Russian nuclear-powered icebreakers

Project #	Class	# in Class	Length	Beam	Displacement (tons)	Reactor	Shaft hp	Max speed (kts)	Years delivered	Years in service
92M	Lenin	1	134 m (440 ft)	27.6 m (91 ft)	16,000	3 x OK-150 re-fit with 2 x OK-900	44,000	18	1959 with OK-150 1970 with OK-900	1959 - 1989
10520	Arktika	6	148 – 159 m (486 – 522 ft)	30 m (98 ft)	23,000 – 25,000	2 x OK-900A	69,700 (49 MW)	20.6	1975 - 2007	1975 – present, 4 retired
10580	Taymyr	2	149.7 m (491 ft)	28.9 m (94.7 ft)	20,790	1 x KLT-40M	43,600 (32.5 MW)	16.5	1989 - 90	1989 - present
10081	Sevmorput	1	260.3 m (854 ft)	32.2 m (105.6 ft)	61,880	1 x KLT-40	39,450 (29.4 MW)	20.8	1988	1988 - present
22220	LK-60 universal icebreaker	3 under contract	173.1 m (568 ft)	33.8 m (111 ft)	33,540	2 x RITM-200	80,460 (60 MW)	> 20	2019 expected 1st ship	
11510	Leader heavy icebreaker	Detailed design started in 2016	209 m (686 ft)	47.5 m (156 ft)	70,674	2 x RITM-400	160,900 (120 MW)	> 20	2026 expected 1st ship	
10570	Multi-function offshore icebreaker	Concept design done in 2016	152 m (499 ft)	31 m (102 ft)	20,700	Not specified	53,640 (40 MW)	> 20	2026 expected 1st ship	

Project 92M - *Lenin*

Russian nuclear-powered icebreaker & world's first nuclear-powered surface ship

Source: Lazer_one, http://www.shipbucket.com/drawings/2783



- Launched 5 Dec 1957 at the Baltic Shipyard, St. Petersburg, and completed in 1959. *Lenin* departed on its 1st voyage on 15 Sep 1959.
- Length: 134 m (440 ft); beam: 27.6 m (91 ft); displacement: 16,000 tonnes; max speed: 18 kts
- Designed to maintain 2 kts speed while breaking through 2 m (6.6 feet) of ice. This feat could not be matched by contemporary, large conventional icebreakers (typ. 10,000 ton, 20,000 shp ships)

Project 92M - *Lenin*

Russian nuclear-powered icebreaker & world's first nuclear-powered surface ship

- Original propulsion system:
  - 3 x OK-150 PWRs, each rated @ 90 MWt, driving 4 x steam turbine generators.
  - Normally two reactors were operating and one was in standby.
  - 44,000 hp (32.8 MW) DC electric motor propulsion system drove three shafts with fixed-pitch propellers.
  - Steam dumps around the main turbines allowed for rapid changes in propulsion power demand without requiring rapid load-following by the reactors.
  - Two diesel generator auxiliary electric power systems provided supplementary power and propulsion.
- First refueling occurred in 1963.
- Nuclear accidents occurred in 1965 and 1967.

Source: Arctic Expo Center – Icebreaker Lenin

- Replacement propulsion system:
  - After the 1967 accident, the OK-150 nuclear power plant was replaced by a two-reactor OK-900 nuclear plant; each reactor rated at 159 MWt.
  - Normally one reactor was operating and one was in standby.
  - Designed for 100,000 hours of reactor operation, with periodic refueling.

Project 92M - *Lenin*

Russian nuclear-powered icebreaker & world's first nuclear-powered surface ship

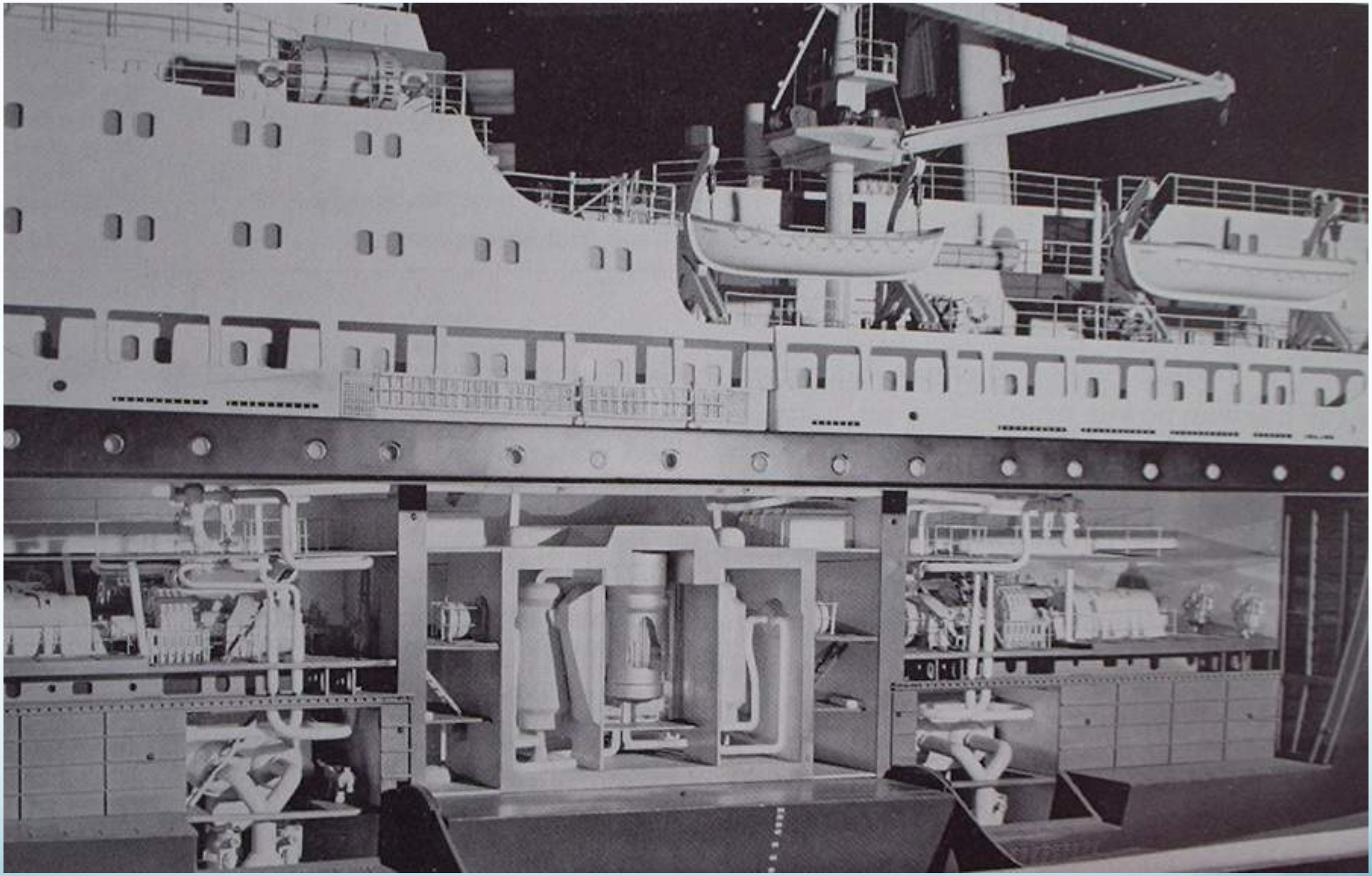
Above: *Lenin* museum ship. Source: Arctic Expo Center – Icebreaker Lenin

- *Lenin* returned to service in 1970 and operated until 1989 when it was decommissioned with a hull worn thin from ice friction.
  - Cruised 650,400 miles (1,046,717 km), 560,000 miles (901,233 km) in ice.
- Conversion to a museum ship in Murmansk was completed in 2005.

Left: OK-900A exhibit aboard *Lenin;* Right: *Lenin* museum ship dockside in Murmansk. Source, two photos: http://sarner.com/portfolio/lenin-ice-breaker/

OK-150 installed on *Lenin*

(one of three reactor units shown)



Note: The three reactors are installed side-by-side, amidships. One secondary plant with two steam turbine generators is located forward and the other is located aft of the reactor compartment.

Source: atomicpowerreview.blogspot.com

Lenin OK-150 nuclear accidents

February 1965 accident

- Due to an operator error in preparation for refueling, water was drained from the shutdown second OK-150 reactor and the core was left without water for some time.
- The reactor coolant inlet is at the bottom of the reactor vessel. This arrangement could have contributed to the inadvertent draining of the primary system.
- The decay heat of the core and the lack of cooling caused deformation and/or melting in part of the core.
- Only 94 of the irradiated fuel elements could be removed.
- The remaining 125 elements were stuck in the core and had to be removed as a unit along with control rods and the "core basket" consisting of the bottom grid plate and the cylindrical thermal shield.
- The removed components were placed in a shielded cask, stored for 2 years, and then in 1967 some or all of the items were dumped at sea near Novaya Zemlya.

1967 accident

- A primary coolant system leak occurred shortly after refueling.
- Finding the leak required breaking through the concrete and metal biological shield around the reactor with sledgehammers, which caused irreparable damage to the nuclear power plant.
- After being abandoned for about a year to allow radiation levels to decline, all three OK-150 reactors were removed, and replaced in 1970 by a two-reactor OK-900 nuclear plant.
- The removed OK-150 reactors may have been dumped at sea near Novaya Zemlia.

Project 10520 Arktika-class

Russian nuclear-powered icebreakers

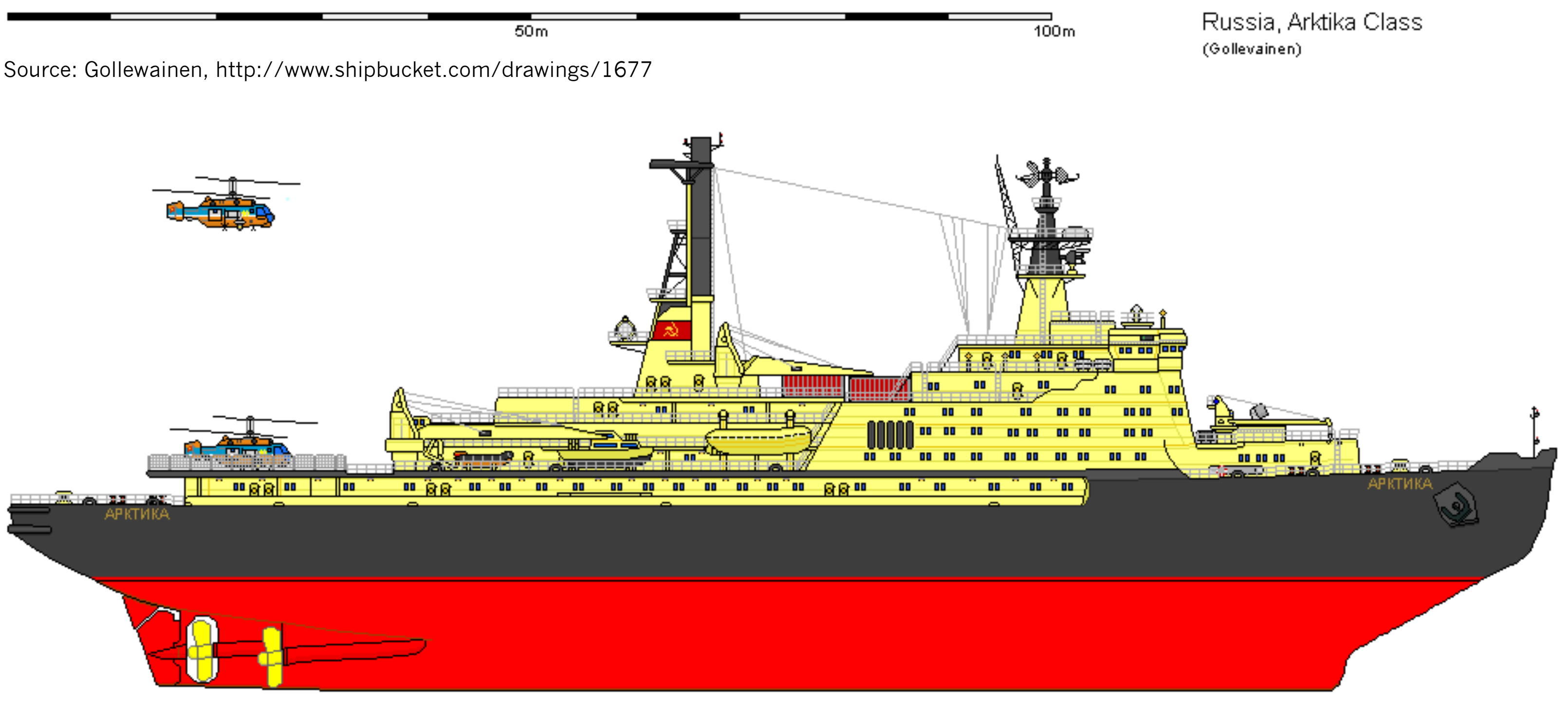
- Six ships in the class entered service between 1975 & 2007.
- Intended for year-round operation in the western Arctic and for summer-to-autumn operation in the eastern Arctic.
  - Designed to operate in ice thickness up to 5 m (16.4 feet).
  - Designed to maintain 3 kts speed while breaking through 2 - 3 m (6.6 – 10 feet) of ice; about twice as fast as *Lenin* under these conditions.
- Propulsion:
  - OK-900A nuclear power plant with 2 x PWRs, each rated @ 171 MWt.
  - Normally one reactor is operating and the other is in standby.
  - 69,700 shp (49 MW) DC electric motor propulsion system drives three shafts with fixed-pitch propellers.
  - Two separate diesel generator auxiliary electric power systems provided supplementary power.

Icebreaker *Rossiya*. Source: ROSATOMFLOT

- Vessel parameters:
  - Length: 148 - 159 m (486 - 522 ft)
  - Beam: 30 m (98 ft)
  - Displacement: 23,000 - 25,000 tons
  - Max. speed 20.6 kts

Project 10520 Arktika-class

Russian nuclear-powered icebreakers



Source: Gollewainen, http://www.shipbucket.com/drawings/1677

- Operational matters:
  - On 17 Aug 1977, *Arktika* was the first surface ship to reach the North Pole.
  - Commercial polar cruises from Murmansk to the North Pole aboard Arktika-class nuclear icebreakers have been offered since 1990, when *Sovetskiy Soyuz* made the first tourist cruise.
  - In 2000, *Arktika* became the first civilian ship to spend more than a year at sea without making port.

Project 10520 Arktika-class

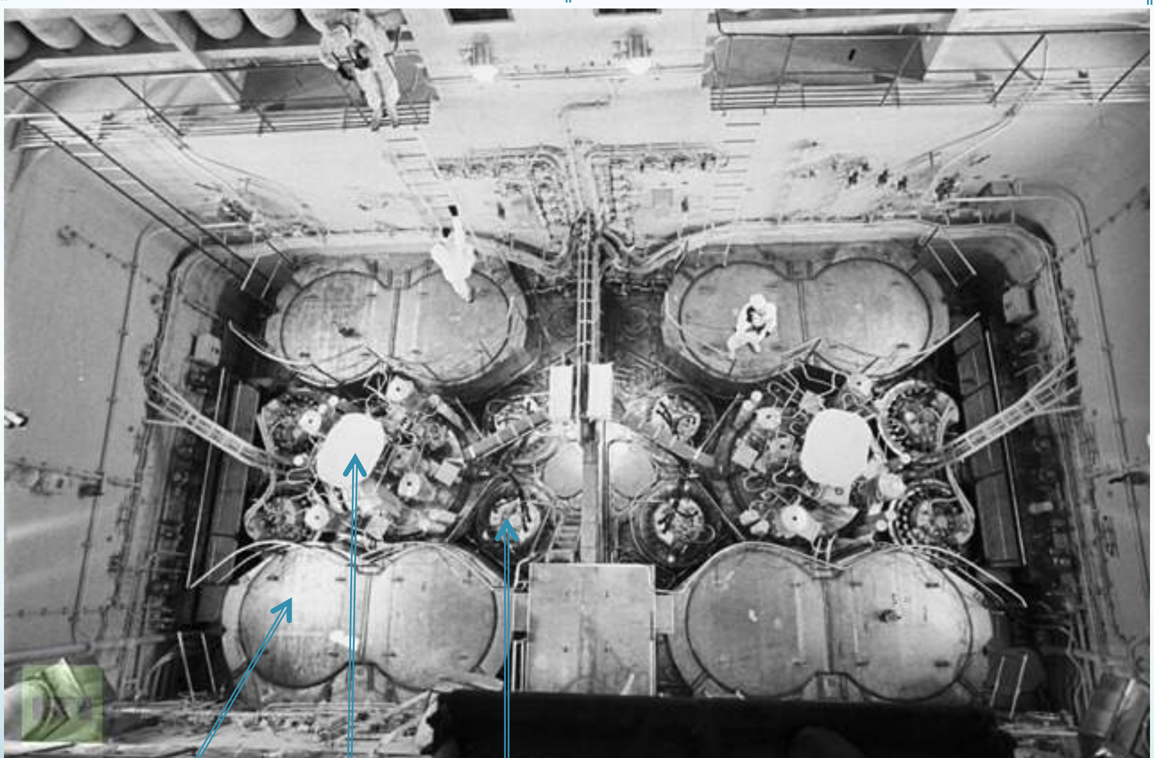
Russian nuclear-powered icebreakers

- Operational matters (cont'd):
  - *Arktika* originally was designed for a 25-year service life and 100,000 hours of reactor operation with periodic refueling. Refueling was required after about 3-1/2 years of reactor operation.
    - In 2000, *Arktika's* service life initially was extended by 50,000 hours. After a conference of experts met aboard Arktika in May 2000, 25,000 hours were added for a total of 175,000 hours of reactor operation.
    - This added about eight years to a 25-year planned service life.
    - The life extensions required replacing some critical equipment to assure the continued safe operation of the OK-900A reactor plant.

OK-900A icebreaker installation

Right: New reactor core loaded

Reactor #1 | Reactor #2



Steam generator (4 per reactor)

Control rod drive mechanisms (above reactor)

Main coolant pump (4 per reactor)

Above: Reactor compartment operating floor removed

Right: Reactor compartment operating floor installed

Source, three photos: ROSATOMFLOT

Project 10520 Arktika-class

Russian nuclear-powered icebreakers

- Operational matters (cont'd):
  - Four Project 10520 Arktika-class icebreakers have been retired:
    - 1993: *Sibir* was removed from service after only 15 years of operation because of engineering issues. Two steam generators were removed from an OK-900A reactor on *Sibir* to replace similar units in a KLT-40M reactor on *Taymyr.*
    - 2008: *Arktika* was withdrawn from service after operating for 33 years and accumulating 177,000 hours of reactor operation while cruising more than 1 million nautical miles (1,852,000 km).
      - After retiring, *Arktika* was used for research work to determine how to extend the engineering resource life of other nuclear icebreakers.
      - *Arktika* is expected to become a museum ship in St. Petersburg.
    - 2008: After operating for about 20 years, *Sovetskiy Soyuz* was laid up at the Atomflot icebreaker port in Murmansk in a condition that would have allowed it to return to sea in 6 – 8 months if needed.
      - Alternative roles for the ship, including serving as a mobile Arctic command post for the Russian military and supporting Arctic commercial oil and gas exploration, were considered but rejected.
      - In 2017, ROSATOMFLOT retired *Sovetskiy Soyuz.*
    - 2013: *Rossiya* was retired after 30 years of service.
    - Decommissioning work is expected to take place at the Nerpa shipyard, north of Murmansk.

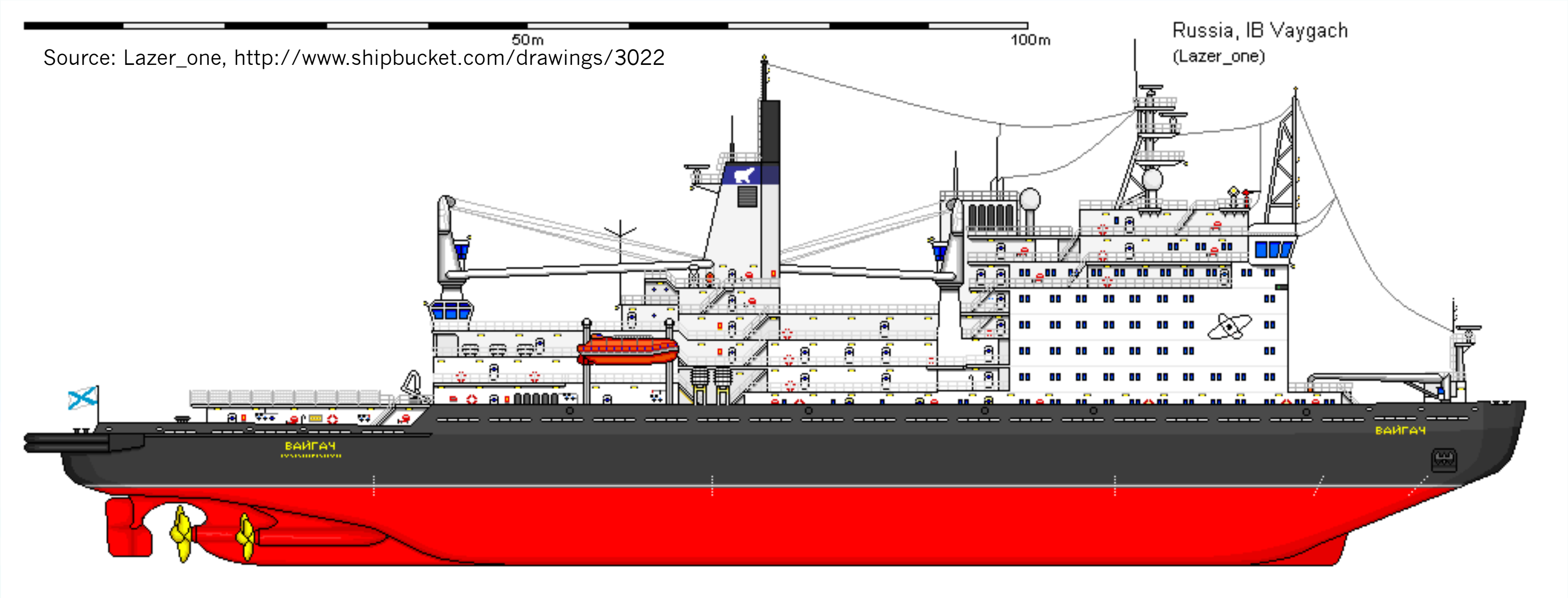
Project 10520 Arktika-class

Russian nuclear-powered icebreakers

- Operational matters (cont'd):
  - Atomflot representatives have stated that currently the nuclear icebreaker fleet is not profitable. It has more icebreakers, but their services at full capacity are not in demand. Issues affecting profitability and demand include:
    - High-operating cost for Arktika-class icebreakers.
    - Western economic sanctions against Russia have significantly reduced Russia's Arctic oil and gas exploration activities.
    - Some historic customers are building their own fleets of conventionally-powered icebreakers and ice-capable transports:
      - Norilsk Nickel, one of the chief users of nuclear icebreaker services to accompany its loads through the Northern shipping route, is now building its own ice-capable ships that can operate without icebreaker support.
      - Icebreakers were also seen as critical to accompanying tankers from the Varandeisky Oil Terminal, but both Lukoil and ConocoPhillips are building their own icebreaker fleets.
  - As of early 2018, only the two "youngest" Project 10520 Arktika-class icebreakers remain in service: *Yamal* (commissioned in 1992) *and 50 Let Pobedy* (commissioned in 2007).

Project 10580 Taymyr-class

Russian nuclear-powered river (shallow water) icebreakers



- The two ships in this class were built at Wärtsilä Shipyard in Helsink, towed to St. Petersburg, Russia for installation of the reactors and related systems at Baltic Shipyard, and entered service between 1989 & 1990.
- Key parameters:
  - Length: 149.7 m (491 ft);
  - Beam: 28.9 m (94.7 ft);
  - Displacement: 20,790 tons;
  - Max speed: 16.5 kts.

Project 10580 Taymyr-class

Russian nuclear-powered river (shallow water) icebreakers

- Propulsion:
  - One KLT-40M PWR rated @ 171 MWt.
  - Normally one reactor is operating and the other is in standby.
  - Electric motor propulsion system drives three shafts with fixed-pitch propellers for a total 43,600 shp (32.5 MW).
  - Three diesel-driven alternators provide backup power. Two can be used to provide approximately 4 MW (5,350 hp) for the propulsion motors while the third takes care of the auxiliary load.

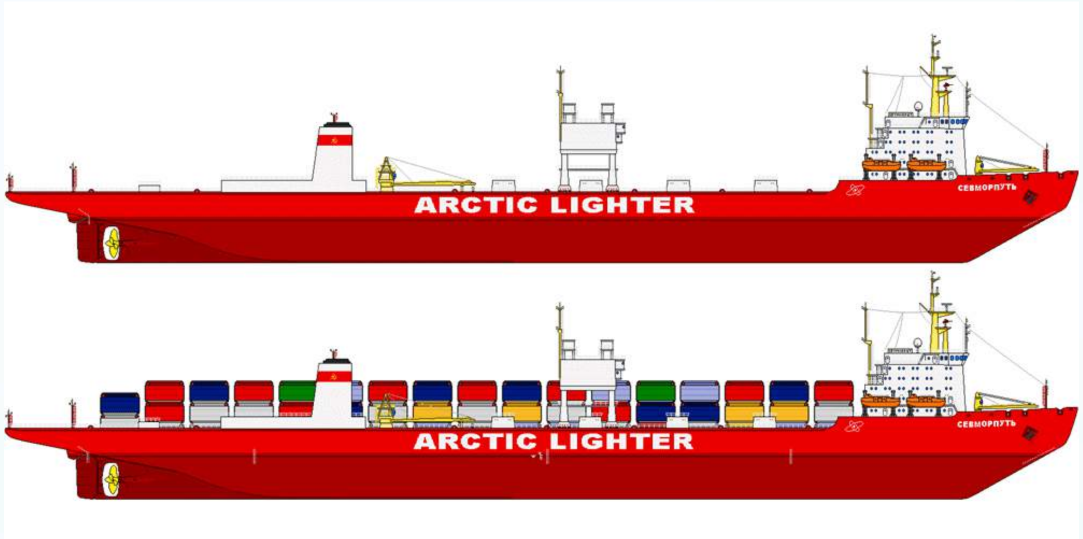
Vaygach. Source: ROSATOMFLOT

- Operational matters:
  - In March 2012, a leak occurred in one steam generator on *Taymyr*, resulting in about 6,000 liter water loss from the primary system. Two steam generators were replaced by steam generators taken from the decommissioned Project 10520 Arktika-class icebreaker *Sibir* (an OK-900A nuclear plant, confirming its similarity with the KLT-40M). *Taymyr* returned to service in March 2013.
  - In 2016, *Vaygach* had its nuclear reactor service life extended from the original 175,000 hours to 200,000 hours, thereby enabling *Vaygach* to continue operating through 2022, when a replacement LK-60Ya-class icebreaker should be available to take its place.
  - A similar life extension for *Taymyr* should be completed by 2018.

Project 10081 *Sevmorput*

Russian nuclear-powered icebreaking LASH (lighter aboard ship) carrier and container ship

- Launched Feb 1986, delivered Dec 1988
- Length: 260.30 m (854.0 ft); beam: 32.20 m (105.6 ft); max. displacement: 61,880 tons; max speed 20.8 kts
- Can carry 74 lighters (barges) or 1328 x 20 ft containers. Lighters enable cargo delivery at coastal sites that lack port facilities.



Source: http://www.cruisemapper.com/ships/Sevmorput-icebreaker-1771

- Propulsion:
  - One KLT-40 PWR nuclear power plant, rated @ 135 MWt
  - Steam turbine delivering 39,450 shp directly drives a single ducted propeller
- Operational matters:
  - Following the Chernobly accident in April 1986, few Russian arctic ports and international ports allowed this ship to dock. The ship was idle in Murmansk for several years, and has been used primarily on the sea route between Murmansk and Dudnika.
  - Refueled in 2001 and 2015.
  - A decision to decommission the ship was cancelled in Dec 2013. Instead, the ship was overhauled, refueled and returned to service in early 2016. The nuclear plant was given a life extension, and ROSATOMFLOT expects that the ship will operate for 15 years, until about 2031.

Project 10081 *Sevmorput*

Russian nuclear-powered icebreaking LASH (lighter aboard ship) carrier and container ship

Source, left: ROSATOMFLOT

Source: JSC "Afrikantov OKBM"

Project 22220 (LK-60Ya)

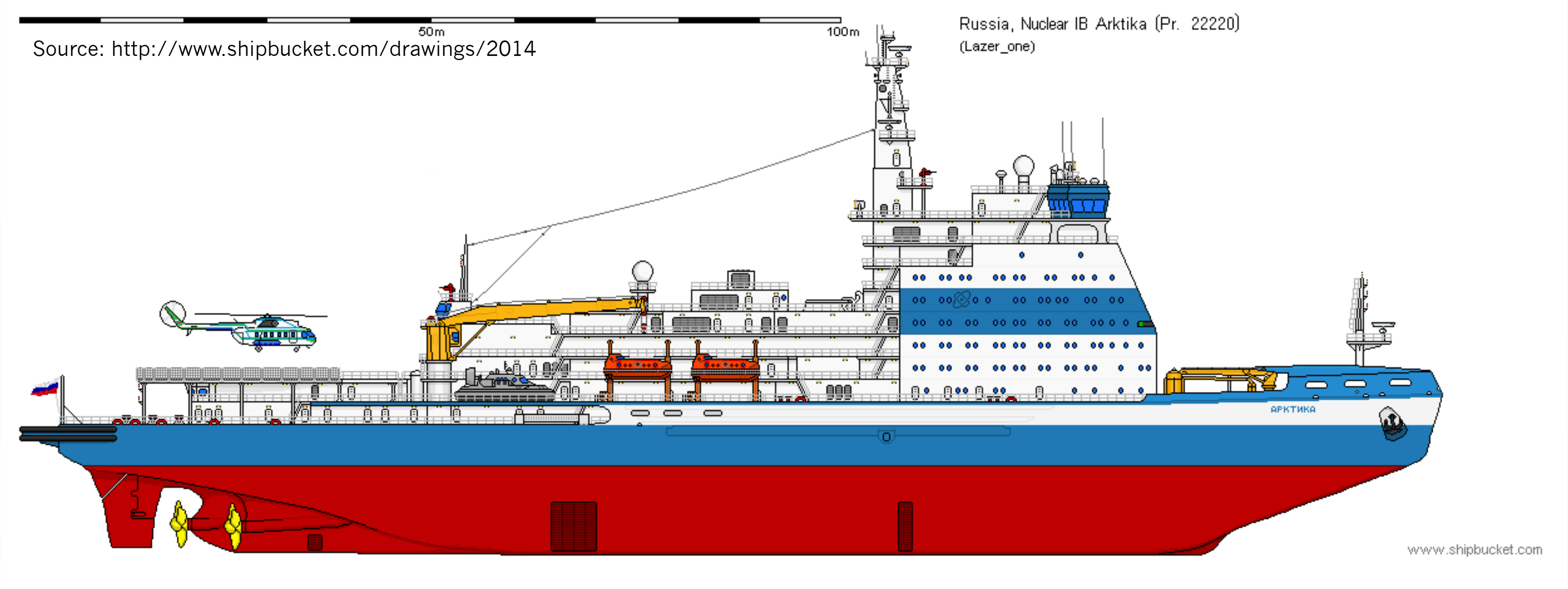
Russian nuclear-powered "universal" icebreakers

- This new generation of icebreakers is designed to operate in ice thickness up to 2.8 meters (9.2 feet).
- Length: 173.1 m (568 ft); Beam 33.8 m (111 ft); Displacement: 33,540 tons; Max speed: > 20 kts
- Larger beam accommodates considerably larger cargo vessels, such as tankers up to 70,000 tons. Previously, two icebreakers working together were necessary to cut a wide enough channel for large ships.
- "Variable draft" ballast system allows LK-60Ya to replace both the deep water Arktika-class and shallow-draft Taymyr-class nuclear-powered ice-breakers.
- Propulsion:
  - Two RITM-200 nuclear reactors, each rated @ 175 MWt.
  - Secondary system can deliver a total of 60 MW (80,460 shp) to an electric motor propulsion system driving three shafts.
  - Reactor operating life is about seven years.
  - Diesel generators provide backup electric power.

Source, two graphics: ROSATOMFLOT

Project 22220 (LK-60Ya)

Russian nuclear-powered "universal" icebreakers



- The 1st-in-class LK-60Ya icebreaker was named *Arktika* (same name as the retired lead ship for the previous deep water nuclear icebreaker class).
- The contract for *Arktika* was placed in Aug 2012 with Baltic Shipyard, St. Petersburg. Contracts for two additional LK-60Ya ships, *Sibir* and *Ural*, were placed in May 2014.
- Construction of the new icebreakers has fallen behind schedule. Two factors reported by the Barents Observer are:
  - Steam generators for the RITM-200 reactor originally were to be manufactured by Turboatom, a Ukrainian company based in Kharkiv. As a consequence of the current war in eastern Ukraine, a replacement Russian manufacturer had to be qualified.
  - General Electrics' deliveries of the electric propulsion systems for the icebreakers was stalled due to the east-west sanctions against Russia. A Russian electric propulsion system was used instead.

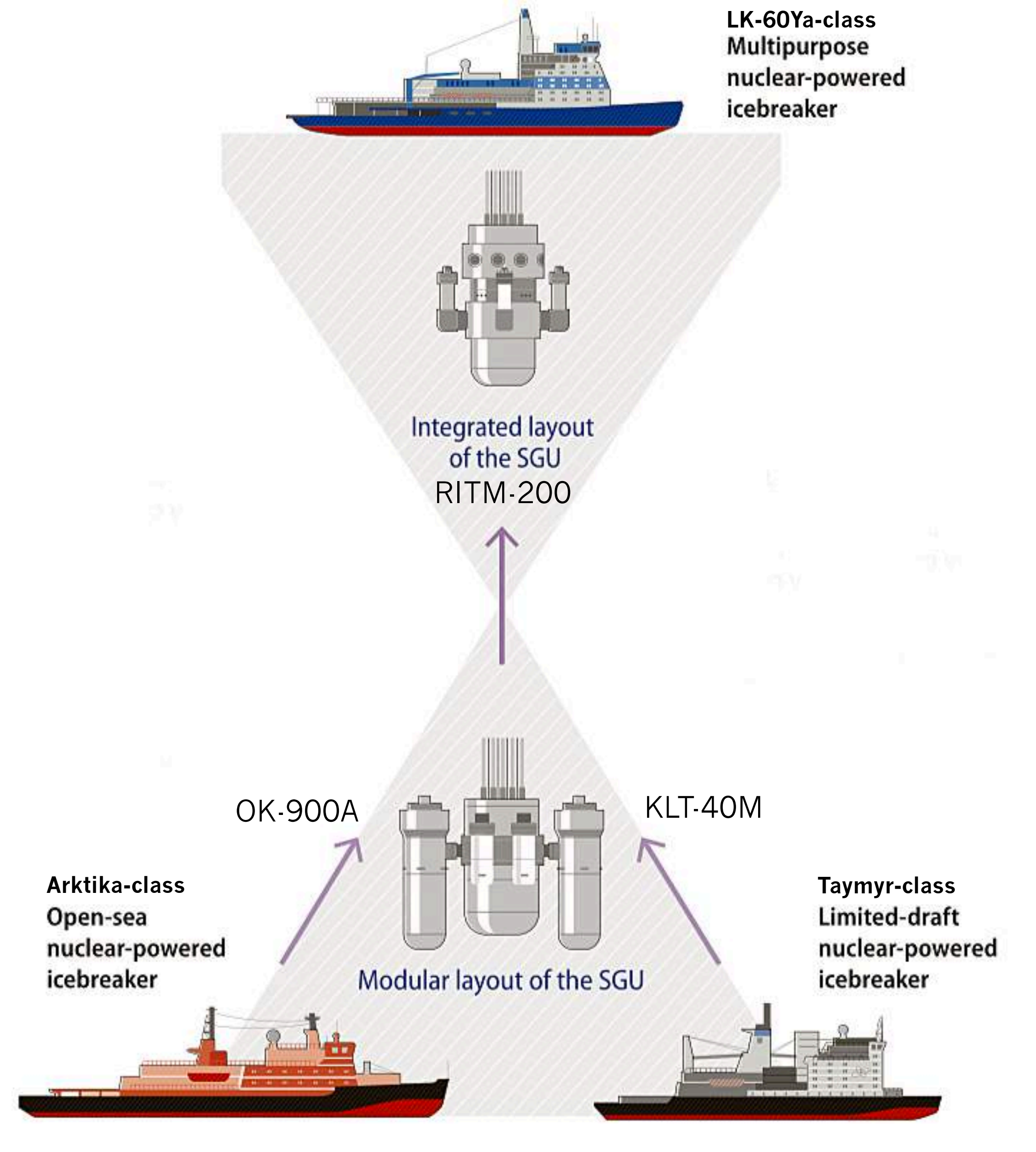
Project 22220 (LK-60Ya)

Russian nuclear-powered "universal" icebreakers

- *Arktika* key dates:
  - Nov 2013: Keel laid
  - Jun 2016: Launched
  - September 2016: Two RITM-200 integral reactor vessels were installed
  - Then the shipyard started final assembly of reactor systems, auxiliary equipment and accessories.
  - mid-2019: *Arktika* is scheduled to be service-ready and will operate from the Atomflot icebreaker port in Murmansk.
- *Sibir* key dates:
  - May 2015: Keel laid
  - Sep 2017: Launched
  - December 2017: Two RITM-200 integral reactor vessels were installed
  - 2020: scheduled for delivery
- *Ural* key dates:
  - Jul 2016: Keel laid
  - 2021: scheduled for delivery
- Each of these vessels will, when completed, cost about $1.8 billion.

Arktika's bow installed Aug 2015. Source: http://bellona.org

Arktika launched Aug 2016. Source: Reuters UK



Source: adapted from http://www.okbm.nnov.ru/images/pdf/ritm-200_extended_en_web.pdf

Evolution of Afrikantov icebreaker nuclear plant design

Project 22220 (LK-60Ya)

RITM-200 reactor installation

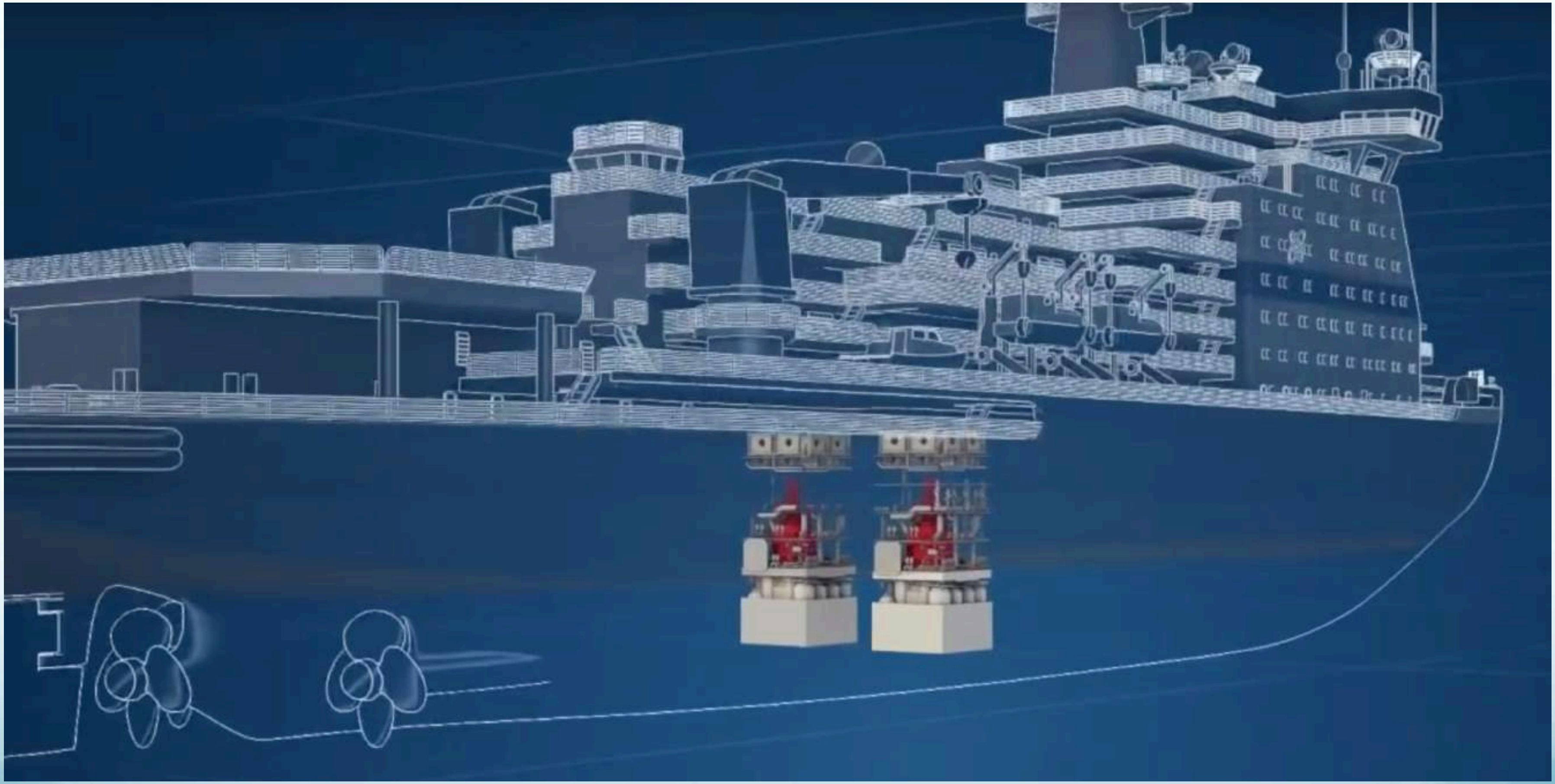
RITM-200 being loaded onto *Arktika* in Sep 2016.
Source: https://www.marinelink.com/news/

RITM-200 being loaded on *Arktika* in Sep 2016.
Source: http://www.navyrecognition.com/

RITM-200 being loaded on *Sibir* in Dec 2017.
Source: http://www.atomic-energy.ru/news/2017/12/25/82032

Project 22220 (LK-60Ya)

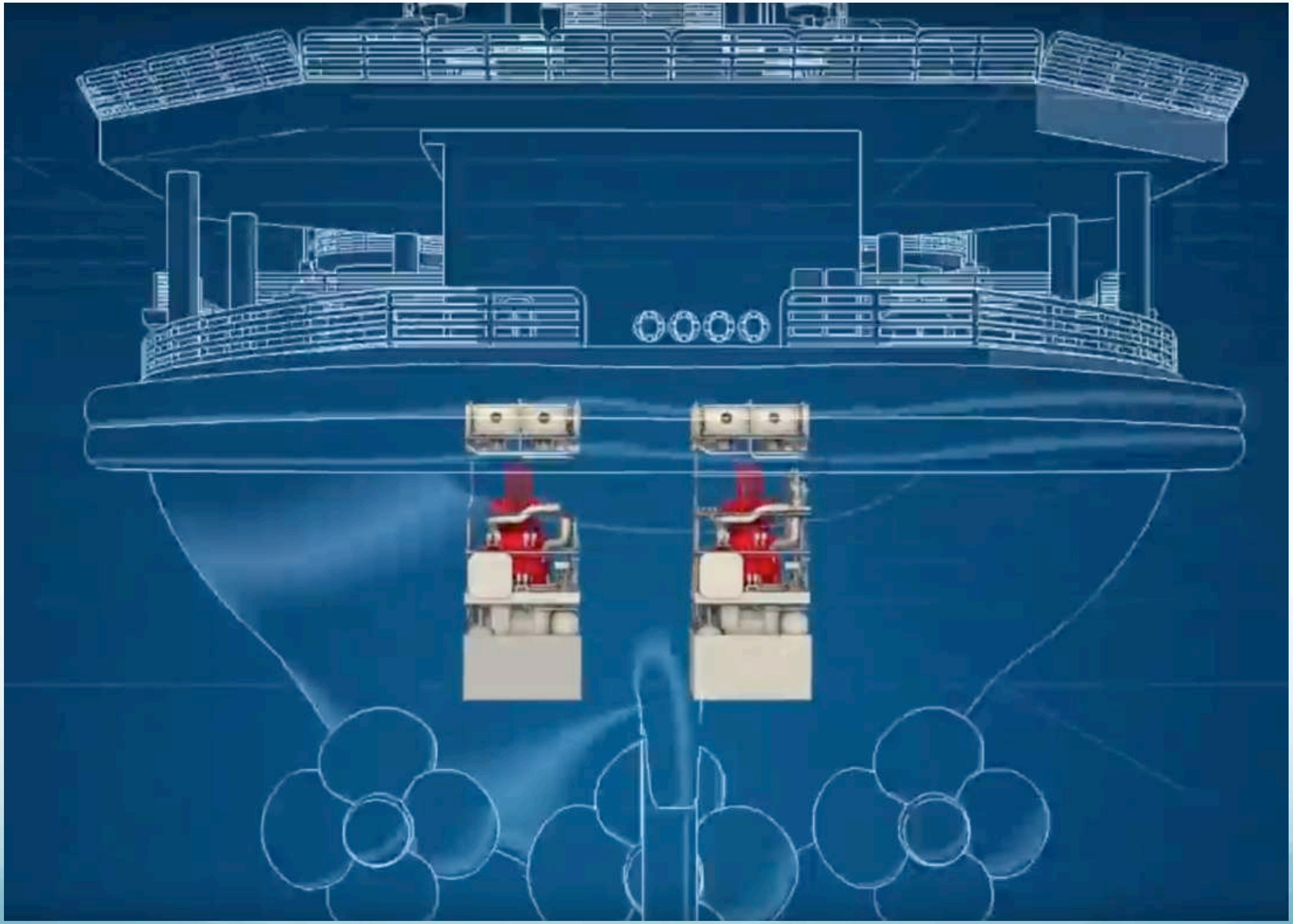
RITM-200 shipboard arrangement



The weight of the two reactor compartment, with two RITM-200 reactor systems and the containment system, is about 2,200 tonnes.
Source: ROSATOM

Project 22220 (LK-60Ya)

RITM-200 shipboard arrangement



Source: ROSATOM

Project 22220 (LK-60Ya)

Lead ship, *Arktika*, being outfitted dockside in 2017

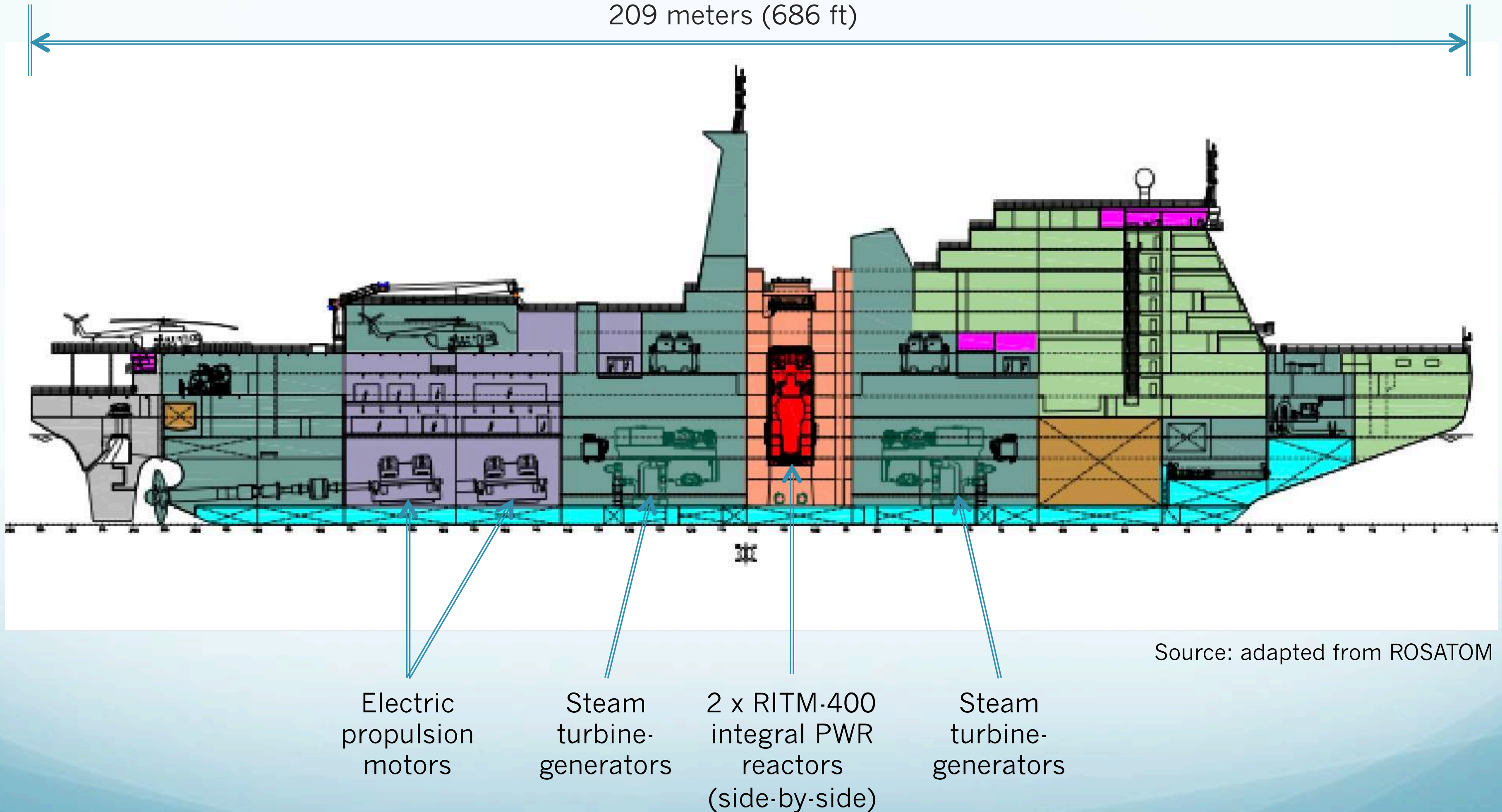
Source: ROSATOM

Project 10510 (LK-110Ya)
Lider-class nuclear-powered icebreakers

- In May 2015, Rosatom announced plans for a new, larger class of nuclear-powered icebreakers that are intended to enable year-round navigation in all areas of the Arctic except shallow water and river estuaries.
  - Capable of operating in ice thicknesses up to 4.1 meters (13.5 feet).
  - Capable of cruising through 2 meter (6.6 foot) thick ice at a speed of 14 knots, which is about four times faster than the Project 10520 (“old” Arktika”-class) nuclear icebreakers operating today.
  - Designed for a 40 year service life.
- In December 2016, Russian Deputy Prime Minister Dmitry Rogozin confirmed that the Krylov design bureau had officially been commissioned for the technical design of the Leader-class.
- Vessel dimensions: length: 209 meters (686 ft); beam: 47.5 meter (156 ft); displacement 70,674 tons.
  - LK-110Ya beam will match the beam of very large “Yamalmax” tankers.
  - LK-101Ya icebreakers will have a 13.5 meter (42.3 feet) wider beam and double the displacement of LK-60Ya icebreakers .
- Propulsion: 2 x RITM-400 integral PWRs, each rated at 315 MWt, yielding 120 MW (160,922 shp) propulsion power with electric motors driving the propellers.
  - This is twice the propulsion power of the LK-60Ya icebreakers.
- ROSATOM indicated the 1st LK-110Ya icebreaker may be operational by 2026.

Project 10510 (LK-110Ya)

Concept views of the Lider-class nuclear-powered icebreakers



Source: adapted from ROSATOM

Project 10570

Multifunction offshore nuclear-powered icebreakers

Source: ROSATOM

- Intended to support off-shore activities on the Arctic shelf & in shallow seas.
  - Will support activities such as oil & gas exploration, platform construction and maintenance.
  - Capable of operating in ice thicknesses up to 2.4 meters (7.9 feet).
  - Conceptual design completed.
  - Designed for a 40 year service life.
- Vessel dimensions: length: 152 meters (499 ft); beam: 31 meter (102 ft); displacement 20,700 tons.
- Propulsion: Unspecified reactor(s), yielding 40 MW propulsion power with electric motors driving the propellers.
- ROSATOM indicated that the 1st multifunction icebreaker may be operational by 2026.

Icebreaker support for the Russian military in the Arctic

- Russia's nuclear icebreakers are considered to be civilian vessels operated by Rosatomflot, not the Russian Navy.
- The basic goal of keeping the Northern Sea Route open year-round has both commercial and military implications.
- Lessons learned from Russia's recent large-scale military exercises in the Arctic demonstrate the need for ice-capable military vessels. (Source: https://www.rt.com/news/353899-russia-military-icebreakers-arctic/)
  - "The recent naval drills in the Arctic, which implied landing of troops on Kotelny Island (New Siberian Islands archipelago, located between the Laptev Sea and the East Siberian Sea, on the 75th parallel) has shown that even the presence of huge icebreakers powered with megawatts of nuclear power cannot guarantee the integrity of the hull of a standard military vessel operating in ice conditions. The vessels themselves need to be 'ice-proof' to be able to maintain Russia's constant military presence in the Arctic region".
  - "Construction of a series of icebreakers to work with military vessels is already underway, with the first new generation diesel-electric icebreaker *Ilya Muromets* (Project 21180) - built at the Admiralty Shipyards in St. Petersburg - floated out in June (2016)……However, the design of a typical icebreaker leaves no place for deployment of modern military hardware, such as radar and missile complexes, so an ice-class warship needs to be designed independently, keeping in mind specific hardware to be installed onboard to ensure its military capabilities".
- Russia's 7,000 – 8,500 ton diesel-electric Project 23550 military icebreaking patrol vessels (corvettes) will be armed combatant vessels capable of breaking ice with a thickness up to 1.7 meters (5.6 feet). The keel for the lead ship, *Ivan Papanin*, was laid down at the Admiralty Shipyard in St. Petersburg on 19 April 2017.

Nuclear-powered naval surface ships

- Guided-missile cruisers
- Command ship
- Aircraft carrier
- Multi-purpose destroyers

Russian nuclear-powered naval surface ships

Project #	Class	# in Class	Length	Beam	Displacement (tons)	Reactor	Shaft hp	Max speed (kts)	Years delivered	Years in service
1144.2 Orlan	Orlan (Kirov) guided missile cruiser (CGN)	4	252 m (867 ft)	28.5 m (94 ft)	26,500	KN-3 with 2 x VM-16 reactors + CONAS	140,000	>30	1980 - 98	1980 – present
1941 Titan	Ural (SSV-33) command, control, comm. ship	1	265 m (869 ft)	30 m (98 ft)	36,500	OK-900A variant	75,000	21.6	1989	1989 - 2001
1143.7	Ulyanovsk aircraft carrier (CVN)	1	321.2 m (1,054 ft)	Waterline 40 m (130 ft) Overall 83.9 m (275 ft)	75,000 (est.)	KN-3 with 4 x VM-16 reactors, probably with CONAS	280,000 (est)	30	Not completed Scrapped in 1992	
2195.6	Leader (Lider) guided missile destroyer (DDGN)	Not known	Not known	Not known	10,000 (est.)	Reactor power of about 285 MWt needed. Specific reactor(s) not known	55,000 (est.)	30	1st ship expected mid-2020s	

Nuclear-powered guided missile cruisers

Project 1144.2 Orlan (Kirov)-class

Nuclear-powered guided missile cruisers (CGN)

- Five Kirov-class cruisers were laid down between 1974 and 1989, four were completed and the fifth was scrapped.
  - One is in service (*Pyotr Veliky*, last Kirov-class ship, commissioned in 1998)
  - One is being modernized for return to service in 2022 (*Admiral Nakhimov*, commissioned in 1988)
  - Two have not yet been funded for modernization (*Admiral Ushakov* & *Admiral Lazarev*, commissioned in 1980 & 1984, respectively)
- Length 252 m (867 ft); displacement 26,500 tons; maximum speed > 30 kts.
  - A 1983 CIA report* stated that Kirov reached 40 knots at 83% power during sea trials.
- Propulsion: KN-3 combined nuclear and steam (CONAS) propulsion plant:
  - 2 x PWRs, each rated @ about 300 MWt. The PWRs are believed to be variants of the Afrikantov OK-900A modular PWR.
  - 2 x oil-fired auxiliary boilers each rated at 115 t/h steam capacity (at unspecified steam conditions)
  - Steam output from two reactors and two oil-fired auxiliary boilers together yield the combined power output needed for high-speed cruise.
  - Two shafts, fixed-pitch propellers, maximum combined total horsepower: 140,000 shp
  - 76 mm (3 in) steel plating around reactor compartment for "light splinter" protection during battle.

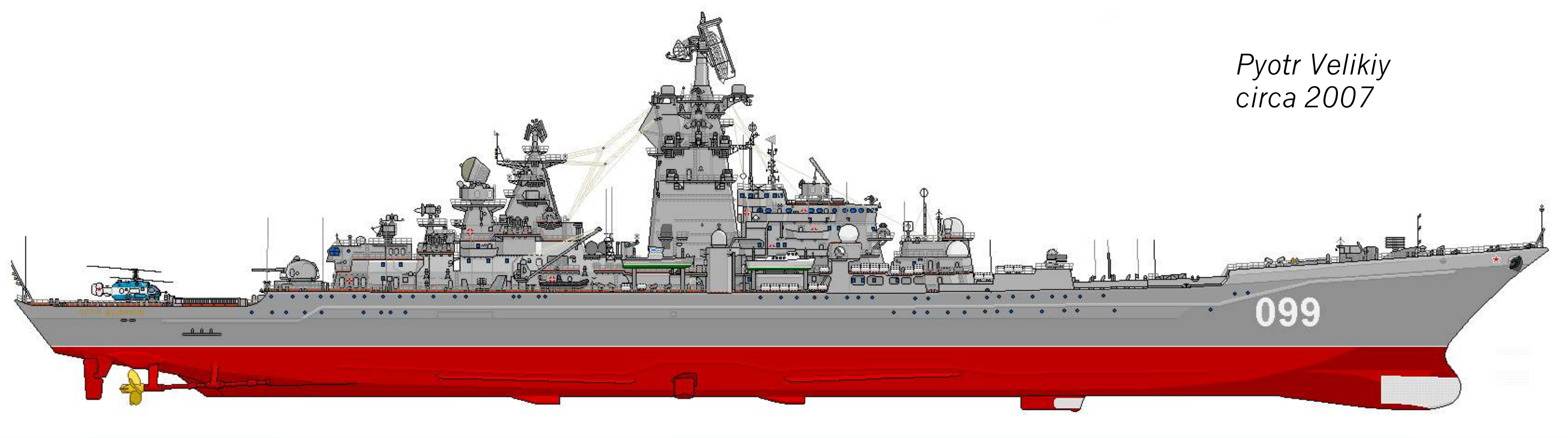
Pyotr Veliky. Source: foxtrotalpha.jalopnik.com

Admiral Ushakov (*ex-Kirov*) dockside, circa 2015. Source: russiamil.wordpress.com

* Intelligence Information Special Report, "Design and Performance of Soviet Naval Nuclear Reactors," Central Intelligence Agency, 11 January 1983, declassified and approved for release 16 June 2017

Project 1144.2 Orlan (Kirov)-class

Nuclear-powered guided missile cruiser (CGN)

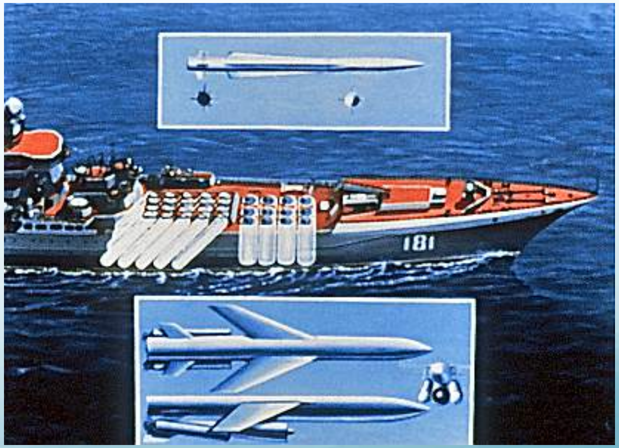


Pyotr Velikiy
circa 2007

Source: adapted from Gollevainen, http://www.shipbucket.com/drawings/2617

- Armament (on *Pyotr Velikiy*):
  - In foredeck vertical launch system (VLS):
    - 20 x P-700 Granit (SS-N-19) long-range anti-ship cruise missiles
    - 12 x octuple S-300FM (SA-N-6) long-range anti-air/anti-missile launchers; total of 96 missiles.
    - 16 x octuple 3K95 (SA-N-9) anti-air missile launchers; total of 128 missiles.
  - Comprehensive short-range anti-air system, including 2 x Osa-MA short-range SAM batteries (44 missiles); point defense guns & missiles.
  - Comprehensive ASW system, including 3 x Ka-25 or Ka-27 helicopters; 10 x torpedo tubes for Type 53 torpedoes & SS-N-15 ASW missile; short-range ASW rocket launchers.

Anti-ship and anti-air missile launch tubes on the foredeck



Source: US DoD

Project 1144.2 Orlan (Kirov)-class

Nuclear-powered guided missile cruiser (CGN)

- Operational matters:
  - Except for aircraft carriers, the Kirov-class CGNs are the largest surface combatants ships in the world.
  - Like the Oscar-class SSGNs, Kirov-class CGNs originally were designed to defeat an American aircraft carrier strike group by firing a salvo of many supersonic cruise missiles, which may overwhelm the carrier strike group's defenses.
  - *Pyotr Velikiy (ex-Yuri Andropov)* is in service.
    - This is the only Russian ship with an anti-ballistic missile defense capability using S-300FM / SA-N-20 Gargoyle missiles.
    - *Pyotr Veliki* is expected to enter an extended modernization overhaul after *Admiral Nakhimov* returns to service.
  - *Admiral Nakhimov (ex-Kalinin)* entered the Sevmash shipyard in Severodvinsk in 2014 for an extended modernization overhaul, which is expected to include conversion of the P-700 cruise missile launch tubes to carry three P-800 Oniks cruise missiles or other similar-sized advanced weapons, for a total of 60 cruise missiles.
    - Other weapons systems also are expected to be updated.
    - *Admiral Nakhimov* is expected to return to service in 2022.
    - A similar cruise missile modernization is being done on Oscar-class SSGNs.
  - *Admiral Lazarev (ex-Frunze)* is laid up, with uncertain plans for modernization.
  - *Admiral Ushakov* (*ex-Kirov*) experienced a reactor accident in the Mediterranean in 1990. Since then, the ship has been laid up in Severodvinsk awaiting core unloading and final disposition.

Project 1144.2 Orlan (Kirov)-class

Nuclear-powered guided missile cruiser (CGN)

Sources,
top right: https://sputniknews.com/military/
left & bottom right: https://defence.pk/pdf/threads/russian-navy.313299/page-45

Pyotr Velikiy

Flagship of the Northern Fleet

Source, both photos: http://horseformer.blogspot.com/2017/04/kirov-part-3-kirovs-in-sovietrussian.html

Pyotr Velikiy

Transiting the English Channel in January 2017 with conventionally-powered aircraft carrier *Admiral Kuznetzov*

UK Type 23 frigate *HMS St. Albans* (foreground) and three RAF Typhoon fighters monitor Russian cruiser *Pyotr Velikiy* and aircraft carrier *Admiral Kuznetzov* returning from the Mediterranean via the English Channel.
Source, photo: https://defence.pk/pdf/threads/russian-navy.313299/page-45; map inset: http://www.dailymail.co.uk/

Admiral Nakhimov

Modernization in progress

Under refit in Sevmash shipyard in Severodvinsk since 2014; scheduled for completion in 2020 - 21 and expected return to service in 2022.

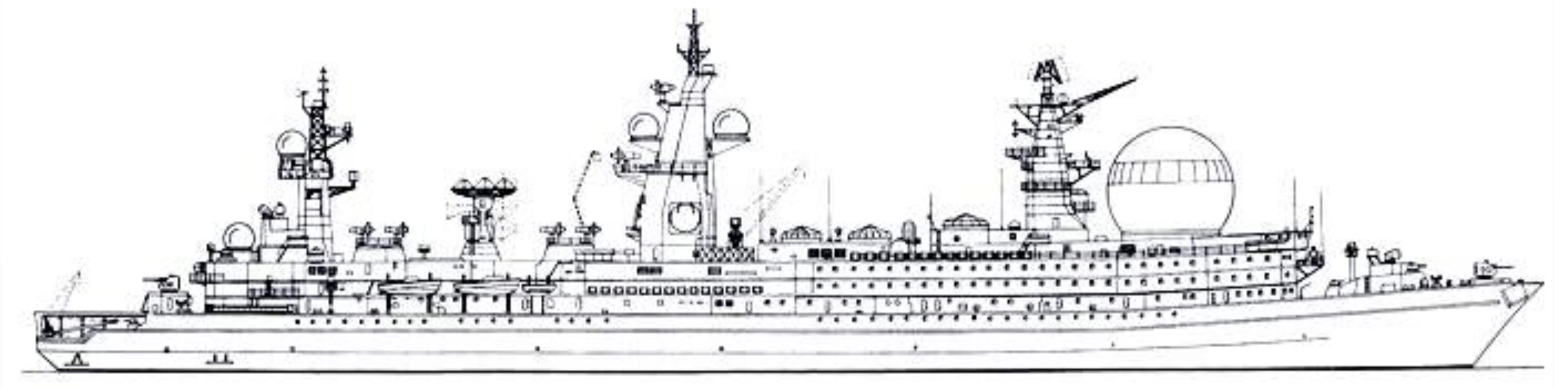
Above & below, Source: https://www.reddit.com/r/WarshipPorn/

Source: http://www.navyrecognition.com

Nuclear-powered command ship

Project 1941 (Titan)

Nuclear-powered command, control & communications ship



Source: http://thekristoffersuniverseinwar.wikia.com/

- SSV-33 *Ural* launched May 1983, commissioned Dec 1989. Known as “Kapusta” by NATO.
  - Intended roles included flagship, space / missile tracking, surveillance and communications relay.
- Hull based on Project 1144.2 Orlan/Kirov CGN.
  - Length 265 m (869 ft); Beam: 30 m (98 ft); displacement 36,500 tons.
- Propulsion:
  - A Russian report prepared in connection with dismantling the *Ural* disclosed that the *Ural’s* reactor plant is similar to the reactor installations on nuclear icebreakers, but considerably different from the reactor installations on the Project 1144.2 Orlan (Kirov)-class CGNs.
  - The Russian report stated that *Ural’s* reactor refueling would be conducted in Murmansk at "Atomflot” using the same equipment as the nuclear ice breakers. Therefore, special equipment for refueling "Ural" was not produced.
  - *Ural’s* reactor plant most likely is an Afrikantov OK-900A variant with 2 x PWRs, each rated @ 171 MWt, driving steam turbines that deliver a total of about 75,000 shp to two shafts.

Project 1941 (Titan)

Nuclear-powered command, control & communications ship

- Operational matters:
  - Deployed from Baltic Sea to Pacific Fleet in 1989, but was not used operationally thereafter because of various problems with the ship's nuclear power plant and other ship systems, and inadequate local port infrastructure.
  - Only 25 - 30% of the reactor core life was used before decommissioning.
  - The vessel was decommissioned in 2001, initial scrapping started in 2008, and the reactors were defueled in 2009 in Bolshoy Kamen in the Primorsky region. Dismantling is expected to be complete in 2017.
  - When removed from the ship, the reactor compartment will be sealed and put in "afloat storage" pending completion of the on-shore storage facility at Cape Ustrichny, near Vladivostok.

Source: en.wikipedia.org

Source: http://forum.keypublishing.com/

Project 1941 (Titan)

Nuclear-powered command, control & communications ship

Source, both photos: http://horseformer.blogspot.com/2017/04/kirov-part-3-kirovs-in-sovietrussian.html

Project 1941 (Titan)

Nuclear-powered command, control & communications ship

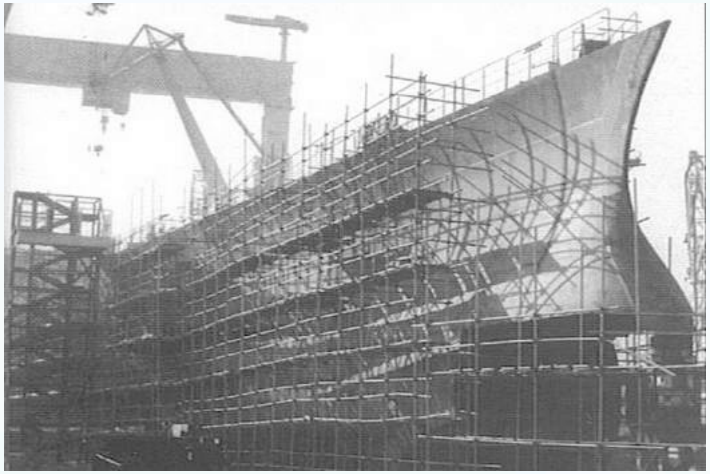
Awaiting final disposition. Source: http://horseformer.blogspot.com/2017/04/kirov-part-3-kirovs-in-sovietrussian.html

Nuclear-powered aircraft carrier

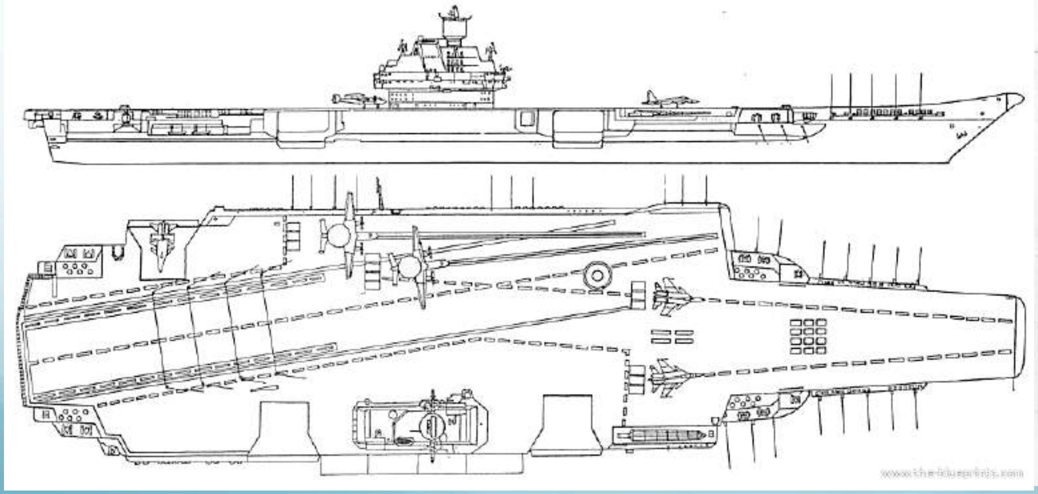
Project 1143.7 Ulyanovsk-class

Russian nuclear-powered large aircraft carrier

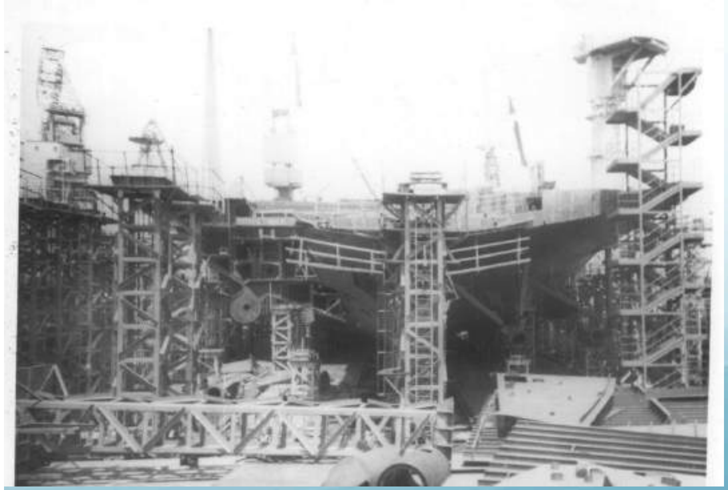
- Lead ship hull was laid down in 25 November 1988 at the Black Sea Shipyard in Ukraine, but cancelled at 20% complete in January 1991 and scrapped in 1992. Planned second hull was never laid down.
- Length 321.2 m (1,054 ft); full load displacement 75,000 tons; max. speed 30 kts.
  - KN-3: 4 x PWR reactors each rated @ 300 MWt
  - 4 x steam turbines
  - 4 x shafts, 280,000 hp (206 MW)
  - Likely to have had the same CONAS propulsion plant as on Orlan (Kirov)-class CGN.
- Basic characteristics were similar to US Nimitz-class aircraft carriers, but with “ski-jump” bow.



Source: www.taringa.net



Source: www.the-blueprints.com



Source: survincity.com

Timeline for a future Russian aircraft carrier

- **2005:** *Interfax* reported that the Russian Navy was planning a class of two to four new aircraft carriers.
- **2008:** Russian President Dmitriy Medvedev reaffirmed Russian plans to build new nuclear powered aircraft carriers.
- **30 Jun 2011:** The head of United Shipbuilding Corporation, a Russian state holding company, said his company expected to begin design work for a new aircraft carrier in 2016, with a goal of beginning construction in 2018, and having the carrier achieve an initial operational capability by 2023.
- **3 Nov 2011:** Russian newspaper *Izvestiya* reported the naval building plan now included the construction of a new shipyard capable of building large hull ships, after which Russia will build four nuclear-powered aircraft carriers by 2023.
- **May 2015:** The Project 23000E (Shtorm) aircraft carrier concept was unveiled by State Unitary Enterprise "Krylov Shipbuilding Research Institute,"
- **2018:** Currently, Russia does not have a shipyard capable of building an aircraft carrier. However, that will change with the expansion of the Zvezda Shipbuilding Complex at Bolshoi Kamen, in the Russian Far East. Upon completion in 2019, the Zvezda Shipbuilding Complex will be the biggest shipbuilding complex in Russia, fitted to build all types of naval and merchant ships, up to 350,000 ton tankers. Thereafter, the availability of funding in the Russian defense budget likely will be the limiting factor for initiating a new project to build an aircraft carrier.

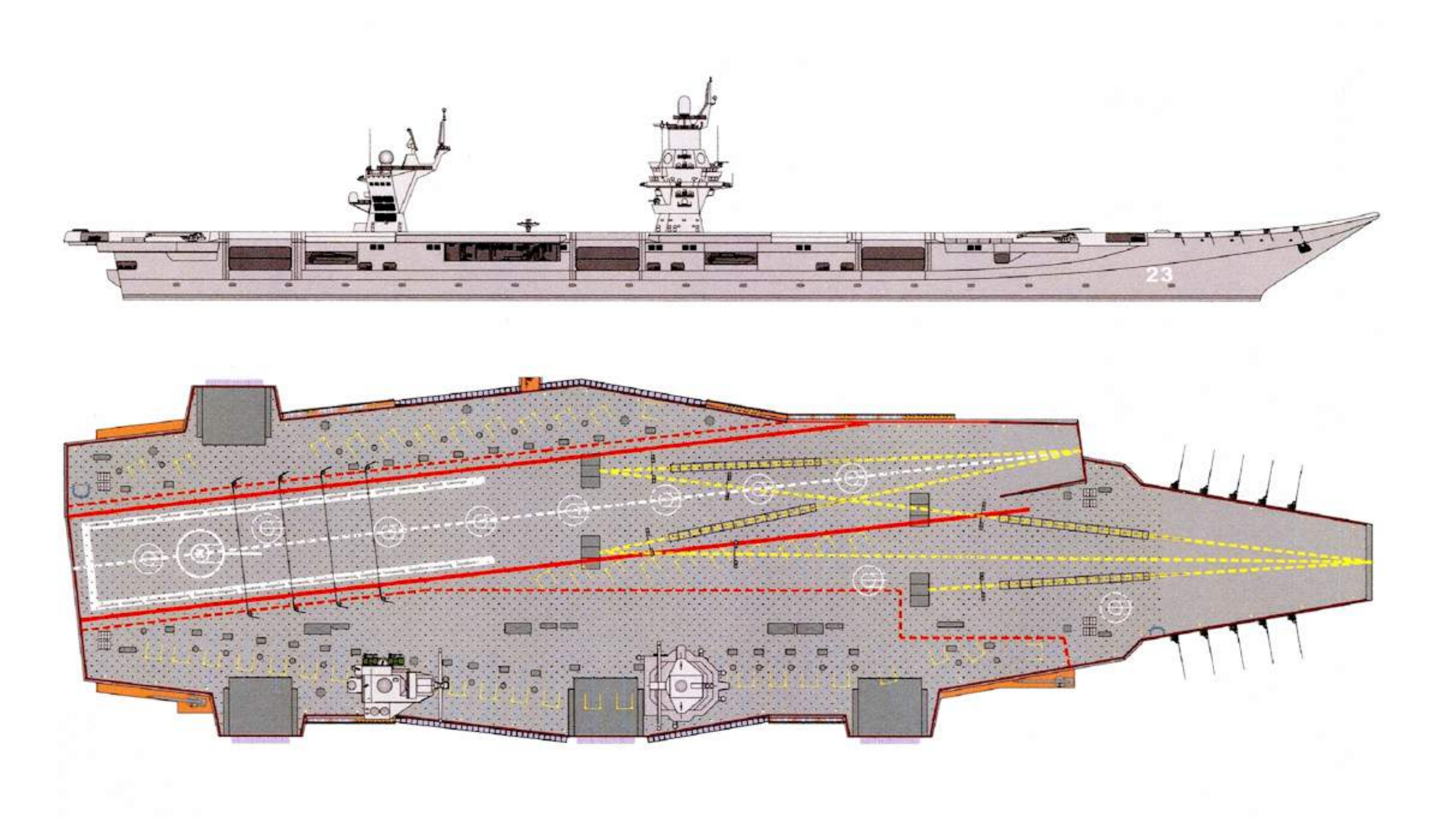
Project 23000E (Shtorm)

Aircraft carrier, possibly nuclear powered

- A new Russian aircraft carrier has been designed by the State Unitary Enterprise "Krylov Shipbuilding Research Institute," which is the largest such institute in Russia. A model of this aircraft carrier was displayed in May 2015.
  - Designed under Project 23000E, code named Shtorm (Storm).
  - Approximately the size of US Nimitz-class nuclear-powered aircraft carriers: length about 330 m (1,082 ft.), maximum flight deck width 40 m (131 ft.), draft 11 m (36 ft.), displacement about 95 - 100,000 tons
  - Carrier air wing is expected to be comprised of up to 90 aircraft, including the current generation carrier-qualified MiG-29K and a naval version of a next-generation fighter aircraft.
  - Vessel service life is expected to be about 50 years
  - The propulsion plant may be conventional or nuclear.
    - Propulsion power requirements for 30 kt maximum speed should be comparable to Nimitz-class carriers: 260,000 shp (194 MW) driving four screws; total reactor power about 1,100 MWt.
    - A nuclear-powered Project 23000 Shtorm aircraft carrier may use reactors similar to the Project 22220 "universal" icebreaker, which has 2 x RITM-200 reactors delivering a total of 80,460 shp (60 MW) of propulsion power. Six RITM-200 reactors would be needed to deliver propulsion power comparable to a Nimitz-class aircraft carrier.
- In 2015, funding for an aircraft carrier was expected to be included in future defense budgets, with construction starting in about 2025 and completion in 2030.
  - The Russian lead ship would likely be deployed with the Northern Fleet.
  - Russia reportedly offered to build a Project 23000E aircraft carrier for India.
- The declining Russian defense budget projected from 2017 – 2020 suggest that plans for an aircraft carrier will be delayed.

Project 23000E (Shtorm)

Aircraft carrier concept, possibly nuclear powered



Concept drawing. Source: GlobalSecurity.org

Project 23000E (Shtorm)

Aircraft carrier concept, possibly nuclear powered

Concept drawing. Source: Krylov Shipbuilding Research Institute

Project 23000E (Shtorm)

Aircraft carrier concept, possibly nuclear powered

May 2015 model. Source: GlobalSecurity.org

Project 23000E (Shtorm)

Aircraft carrier concept, possibly nuclear powered

May 2015 model. Source: nevskii-bastion.ru

May 2015 model. Source: bastion-karpenko.ru

Nuclear-powered multi-purpose destroyer

Project 2195.6 (Lider)

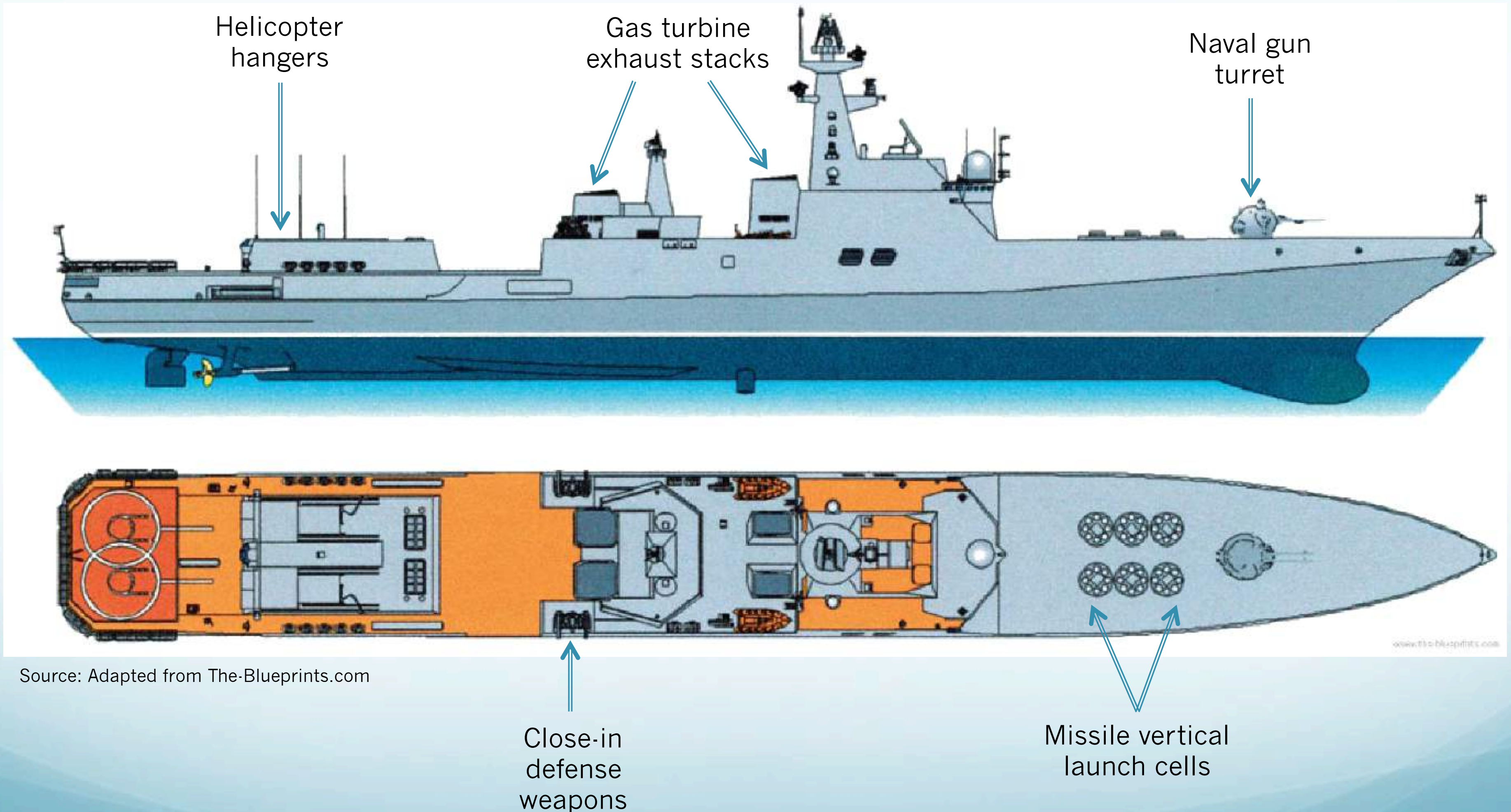
Destroyer concept, possibly nuclear powered

Early concept drawing

- The Russian Navy intends to order 12 advanced 10,000 ton Lider-class destroyers.
- Intended as a cruise missile (Kaliber) and anti-air / anti-missile (S-500) platform.
- Half will be designed for the Northern Fleet, and the other half for the Pacific Fleet.
- Construction of the lead ship in the class is expected to begin in 2019, with completion in 2025.
- The Severnoye Design Bureau, St. Petersburg, is responsible for engineering design.
- Two versions are expected: one with a gas turbine power plant and one with an nuclear power plant.
- Either propulsion system is expected to generate about 55,000 shaft hp, for a speed about 30 kts. The nuclear-powered version will likely require a reactor rated at about 240 MWt.

Project 2195.6 (Lider)

Destroyer concept, conventionally-powered version shown



Source: Adapted from The-Blueprints.com

Non-propulsion marine nuclear applications

- Small reactors for non-propulsion marine nuclear applications
- Floating nuclear power plants (FNPP)
- Transportable reactor units (TRU)
- Arctic seabed applications for marine nuclear power
- Radioisotope Thermoelectric Generators (RTGs)

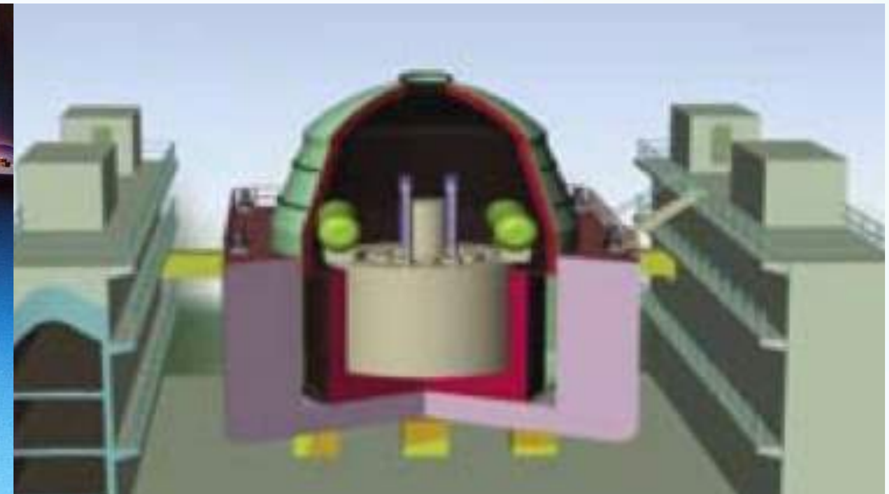
Non-propulsion nuclear marine applications

- Based on their experience in developing marine nuclear reactors, OKBM Afrikantov, Nikiet and OKB Gidropress offer a variety of small size reactors in relatively small packages that are designed for deployment in remote areas, particularly in the Arctic, for combined electricity and heat supply to isolated end-users and systems.
- Applications:
  - Floating nuclear power plant (FNPP)
    - Electric power with or without process heat supplied to coastal territories or ocean surface structures (i.e., oil & gas drilling and production facilities).
    - Minimum end-user infrastructure required to receive power.
  - Modular, transportable nuclear steam supply system (NSSS)
    - NSSS module is delivered by ship or barge to a coastal facility where permanent balance-of-plant (BOP) facilities have been constructed.
    - The NSSS module periodically is replaced by a new module and then transported to a remote factory for refueling and maintenance.
  - Power plant for an above-water industrial facility
    - Small reactor and power conversion system built into a major above-water industrial facility (i.e., oil & gas drilling / production facilities).
  - Underwater power generating complex:
    - Seafloor-sited autonomous power generating modules.
    - Power supply to underwater objects at great depths and under ice-bound conditions. Also capable of supplying power to ocean surface structures.
    - Multiple modules can be connected to an underwater transmission and distribution grid to support many end-user facilities and activities.

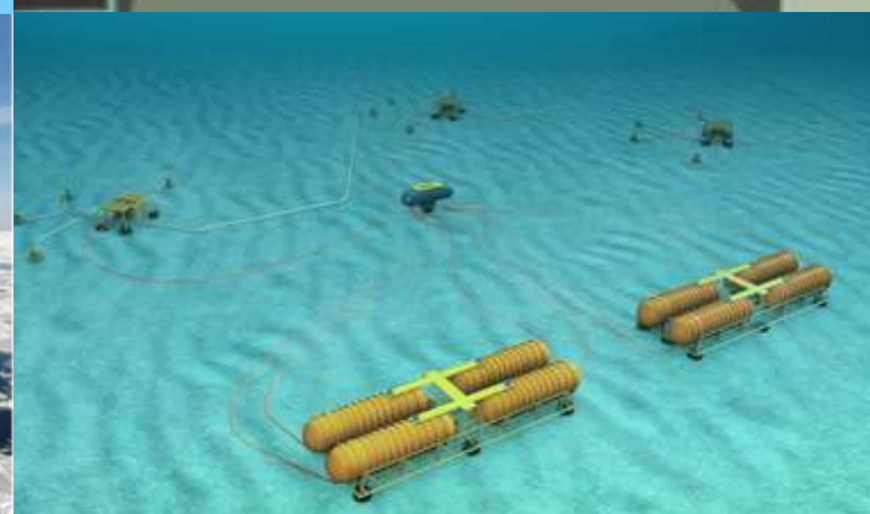
Non-propulsion nuclear marine applications

Floating nuclear power plant. Source: OKBM Afrikantov

Modular, transportable nuclear steam supply system (NSSS). Source: OKB Gidropress



Power plant on above-water industrial facility. Source: OKBM Afrikantov



Underwater power generating complex. Source: OKBM Afrikantov

Small reactors for non-propulsion marine nuclear applications

Small reactors for non-propulsion marine applications

Reactor system	Reactor type	Design bureau	Reactor power (MWt)	Power delivered (MWe) *	Initial ops	Marine application
KLT-40S	Modular PWR	Afrikantov	150	35	2015 expected	• 2 x KLT-40S are installed on the floating nuclear power plant *Akademik Lomonozov*
RITM-200M	Integral PWR	Afrikantov	200	50	TBD	• Floating nuclear power plant • Over-water industrial platform
VBER-300	Modular PWR	Afrikantov	917	325	TBD	• Floating nuclear power plant
ABV-6E	Integral PWR	Afrikantov	16-45	4 - 10	TBD	• Floating nuclear power plant • Transportable Reactor Unit (TRU) for coastal site • Seabed sited power module
Aisberg (Iceberg)	Integral PWR	Afrikantov	38 – 150 (est)	6 – 25	TBD	• Seabed sited power module • Floating nuclear power plant • Over-water industrial platform • TRU for a coastal powerplant site
Autonomous HTGR	Modular direct cycle HTGR	Afrikantov	TBD	6 – 25	TBD	• Seabed sited power module • Over-water industrial platform • TRU for a coastal powerplant site
SHELF (ATGU)	Integral PWR	NIKIET	28	6	TBD	• Seabed sited power module • TRU for a coastal powerplant site

* This listing only includes electrical power delivered. Most of these small reactors are capable of delivering process heat to end-users: PWRs can deliver low-temperature process heat. HTGRs and LMRs can deliver higher-temperature process heat.

Small reactors for non-propulsion marine applications

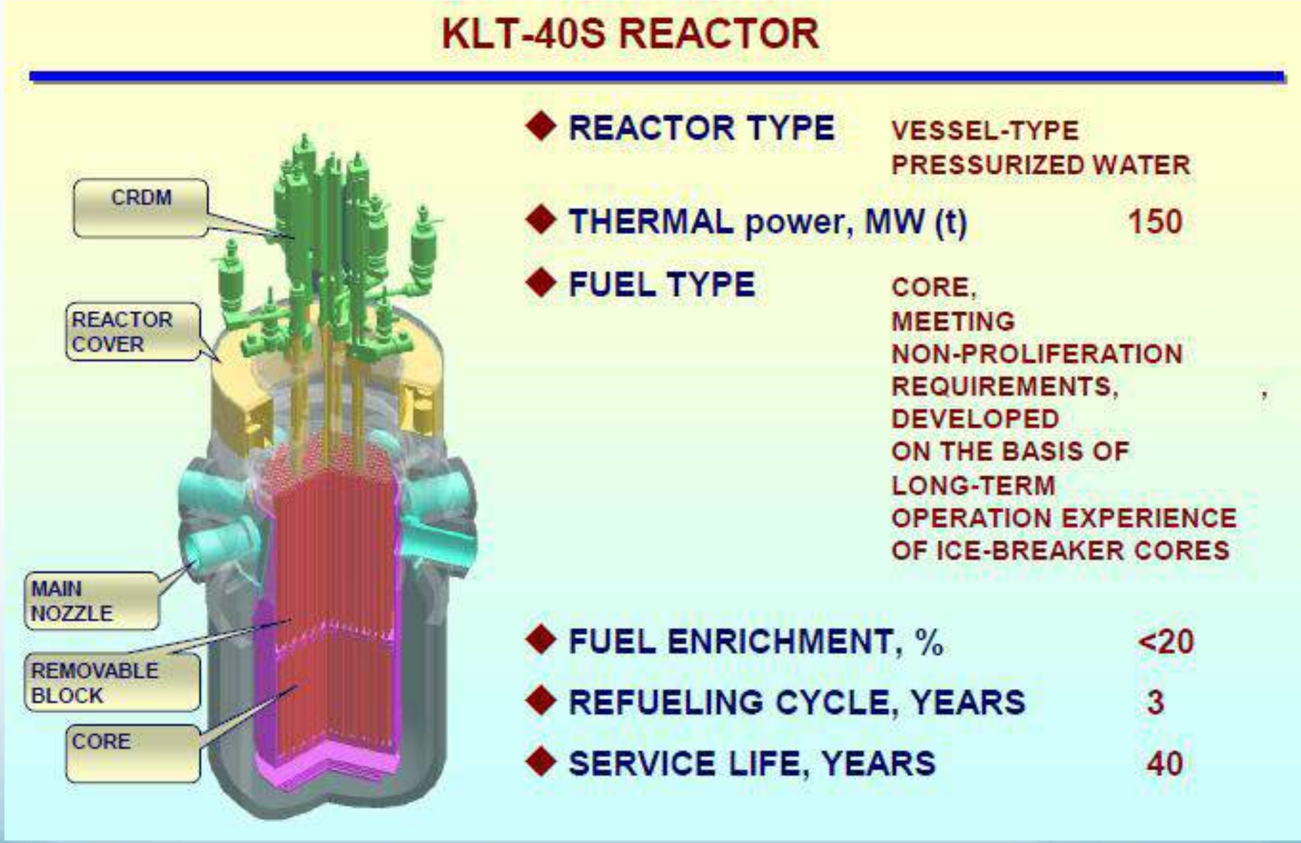
Reactor system	Reactor type	Design bureau	Reactor power (MWt)	Power delivered (MWe) *	Initial ops	Marine application
SVBR-75/100	Integral LMR	Gidropress	280	80	TBD	• TRU for a coastal powerplant site
SVBR-10	Integral LMR	Gidropress	43.3	12	TBD	• Floating nuclear power plant • STAR configuration is a TRU for a coastal powerplant site
ELENA	PWR with direct conversion	Kurchatov Institute	3.3	0.068	TBD	• Seabed sited power module

* This listing only includes electrical power delivered. Most of these small reactors are capable of delivering process heat to end-users: PWRs can deliver low-temperature process heat. HTGRs and LMRs can deliver higher-temperature process heat.

KLT-40S

Modular PWR

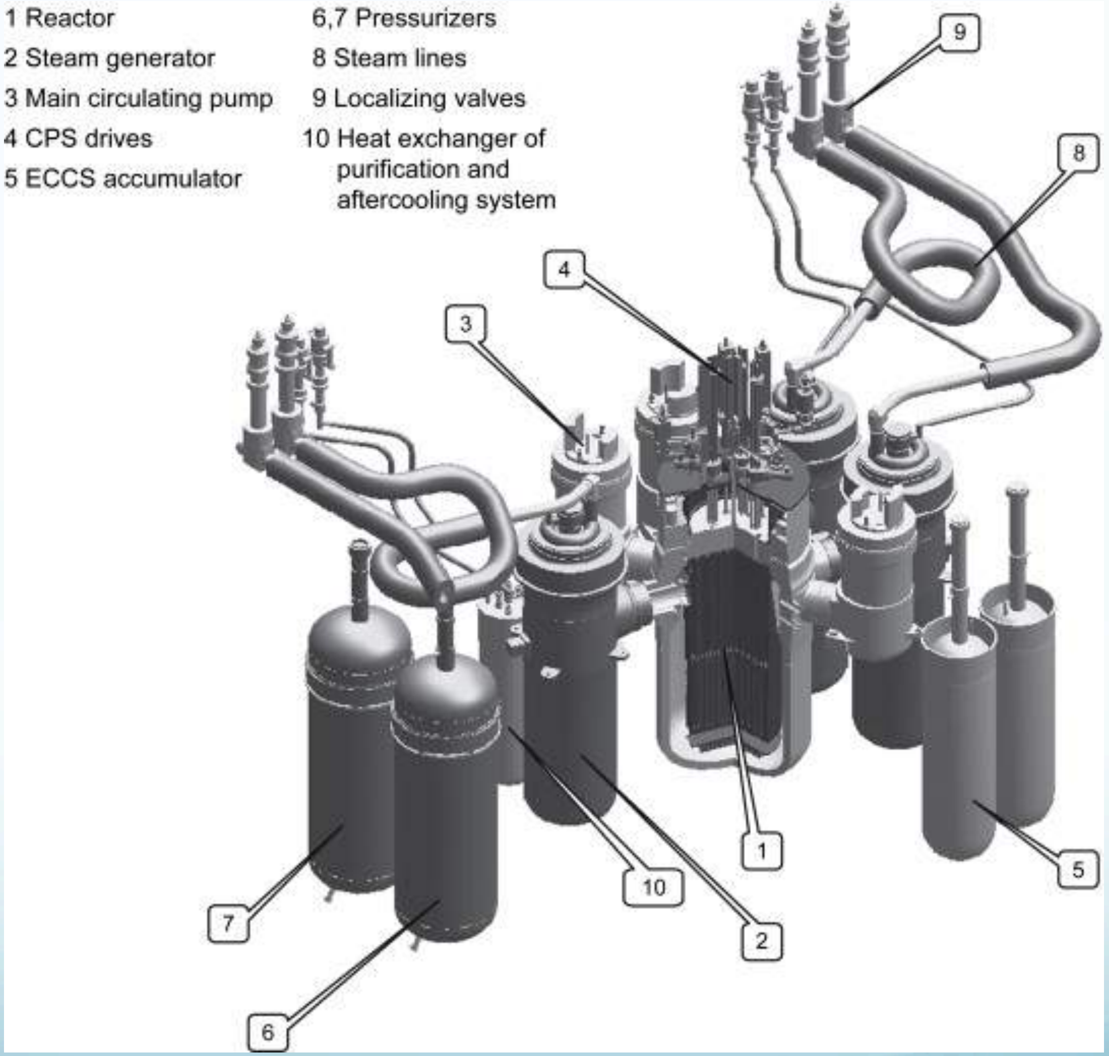
- Based on the Afrikantov KLT-40 and KLT-40M, which are used for marine propulsion on icebreakers.
- First application is on the floating nuclear power plant *Akademik Lomonosov*, which has 2 x KLT-40S nuclear plants that can deliver a total of 70 MWe and 25 Gcal /hour (29 MW) of low-temperature process heat to shore-side end-users. Initial operations is expected by 2021.



Source: OKBM Afrikantov

KLT-40S

The complete nuclear steam supply system (NSSS)



Source: OKBM Afrikantov / Vladimir Kuznetzov, "Options for small and medium sized reactors (SMRs) to overcome loss of economies of scale and incorporate increased proliferation resistance and energy security," Progress in Nuclear Energy, Vol. 50, 2008

KLT-40S

The industrial team behind this modular PWR

- Fuel is LEU UO_2 is a silumin matrix.
- The Russian firms involved the KLT-40S nuclear plant for the floating nuclear power plant *Akademik Lomonosov* are identified in the table below.
- These firms have the same roles and responsibilities in the development of the smaller ABV-6E/-6M nuclear power plant.

Company	Role in the development of the small NPP
JSC "Afrikantov OKBM"	Developer of the reactor plant, general contractor for development of the entire facility (consolidation and coordination of design participants' work)
JSC "Atomenergo"	Developer of the small NPP as a floating and modular transportable unit
Krylov State Research Center	Research manager for activities on the entire small NPP, developer of the strategy for delivering the energy source to the operating place
Concern AVRORA Scientific and Production Association Joint Stock Company	Developer of the automated control system for the small NPP
JSC "Kaluga Turbine Plant"	Developer of the steam-turbine plant
NRC "Kurchatov Institute"	Research manager for development of the reactor plant

Source: Fadeev, Y., et al., "Small NPPs of Floating and Modular-Transportable Design for Power Supply to the Arctic Zone Regions," Afrikantov OKBM, Nizhny Novgorod; http://www.nikiet.ru/eng/images/stories/NIKIET/Publications/Conf/mntk_nikiet_2014/IV-4_en.pdf

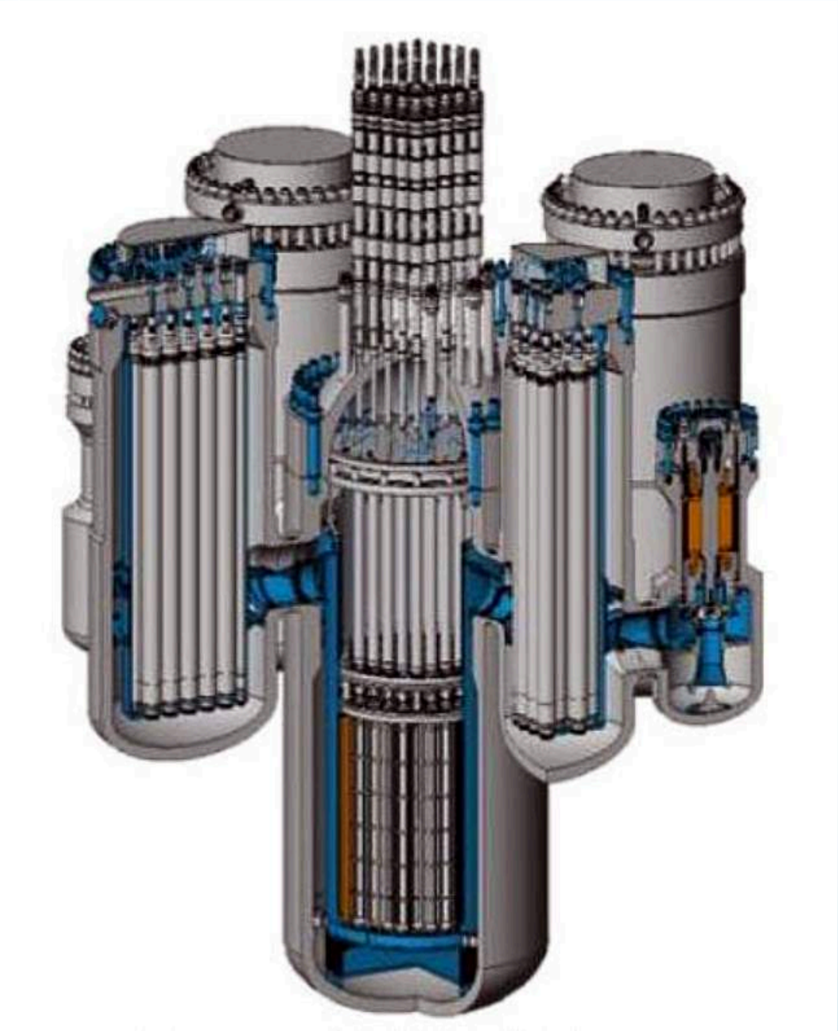
RITM-200M

Integral PWR

- The RITM-200M is similar to the RITM-200, but is optimized for non-propulsion applications, primarily for use on a non-self-propelled floating nuclear power plant (FNPP).
- The RITM-200M is rated at 200 MWt, and is designed to deliver 50 MWe. It also can deliver low-temperature process heat for desalination plants, various industrial applications and district heating.
- Its LEU fuel (< 20% enriched) is similar to that used in the KLT-40S.
- Refueling interval in FNPP service is expected to be 10 – 12 years.
- Rubin Central Design Bureau for Marine Engineering has proposed an FNPP with 2 x RITM-200M reactors delivering 95 MWe net and low-temperature process heat to shore-side end users.

VBER-300

Modular PWR



Source: OKBM Afrikantov via International Atomic Energy Agency (IAEA), "Advances in Small Modular Reactor Technology Developments," 2016

- VBER-300 is a medium-size modular PWR rated at 917 MWt, and capable of delivering 325 MWe.
- It is intended for use in land-based nuclear power plants, nuclear cogeneration plants, and floating nuclear power plants (FNPP).
- The reactor fuel is LEU (4.95% enriched) UO_2 in hexagonal fuel assemblies with burnable poison, similar in many respects to VVER-1000 fuel.
- The reactor and the four once-through steam generators are connected by short, co-axial pipes (similar to OK-900A and KLT-40). One main coolant pump makes a similar connection to each steam generator. The primary loop operates on forced circulation.
- An FNPP will require periodic overhauls at approximately 20 year intervals. The FNPP has a planned operating life of 60 years.

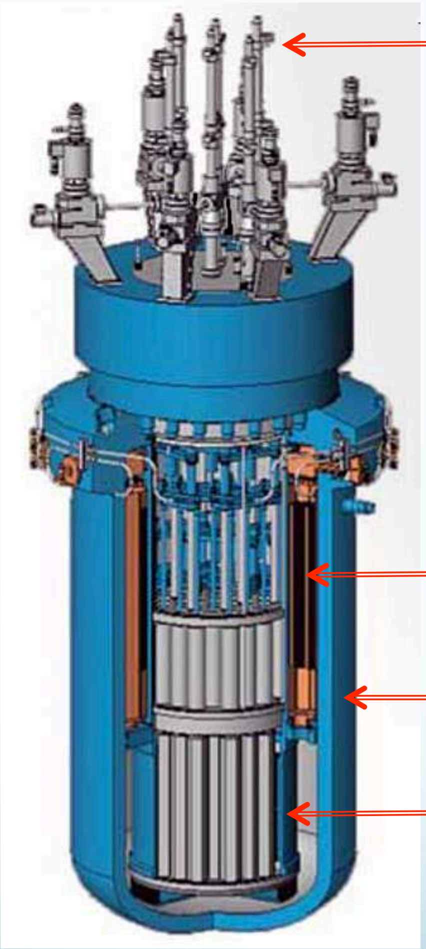
ABV-6E/-6M

Small, natural circulation integral PWR

- The Afrikantov ABV-6E/-6M is a small, integral PWR that can be used in a variety of packages to provide electric power and process heat for regions in the Arctic zone.
- This 16 - 45 MWt integral PWR (reactor and steam generators in the same vessel) operates 100% on natural circulation and is designed to deliver 4 - 10 MWe of electric power to end users. Also can deliver low-temperature process heat
- The reactor core is comprised of 121 fuel assemblies that are similar in design to the fuel assemblies used in the Afrikantov KLT-40S reactor plant.
  - Cermet fuel with uranium-235 enrichment below 20% to enable international exports.
  - This fuel composition was developed and tested as part of the KLT-40S reactor plant development for the *Akademik Lomonosov* floating nuclear power plant.
- Designed with long service life and long intervals between refueling:
  - Service life of permanent equipment: 40 years or 320,000 hours
  - Service life of replaceable equipment: 20 years or 160,000 hours
  - Refueling interval: 10 – 12 years
- See the description of the KLT-40S for a summary of the industrial team that developed the smaller ABV-6E/-6M nuclear power plant.

ABV-6E/-6M

Small, natural circulation integral PWR



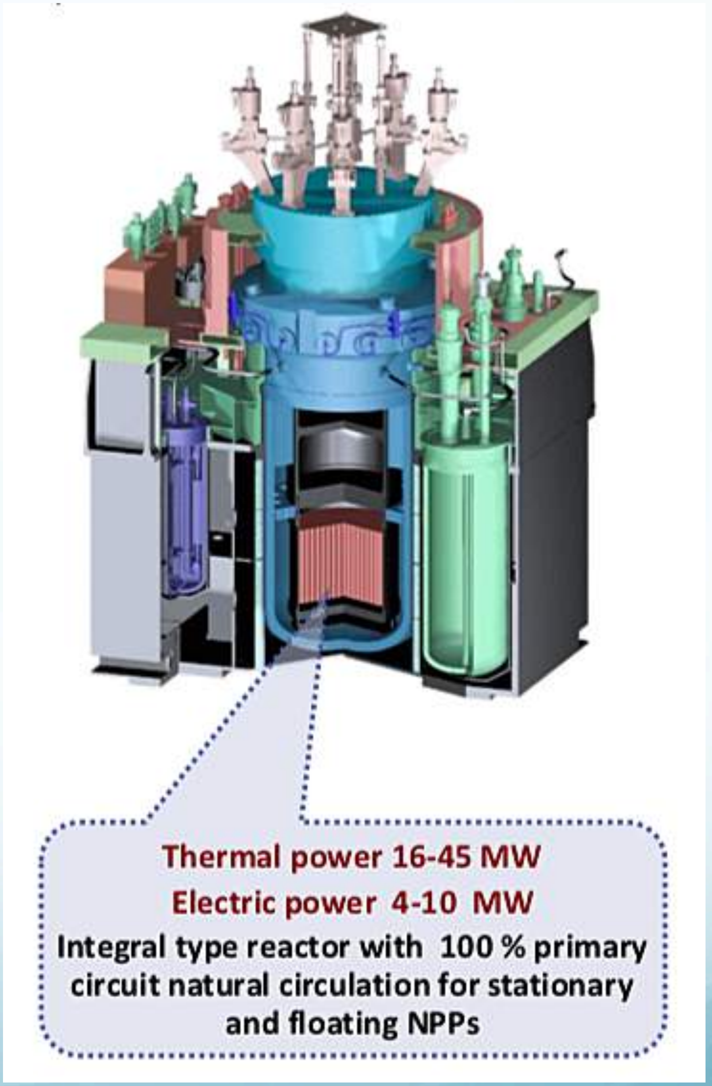
Control rod drive mechanisms

Steam generator modules

Integral reactor vessel

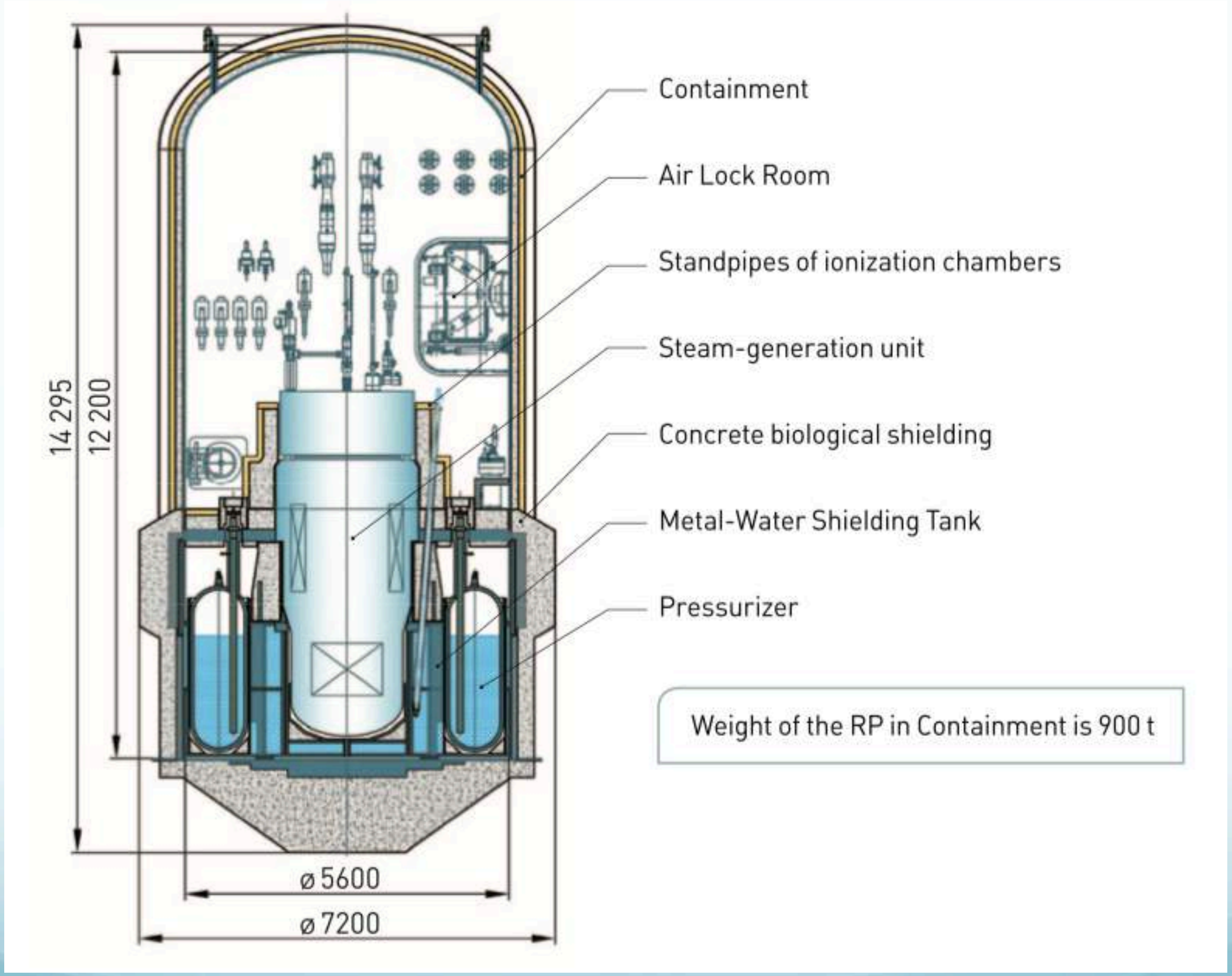
Reactor core

Source, two graphics: OKBM Afrikantov



ABV-6E/-6M

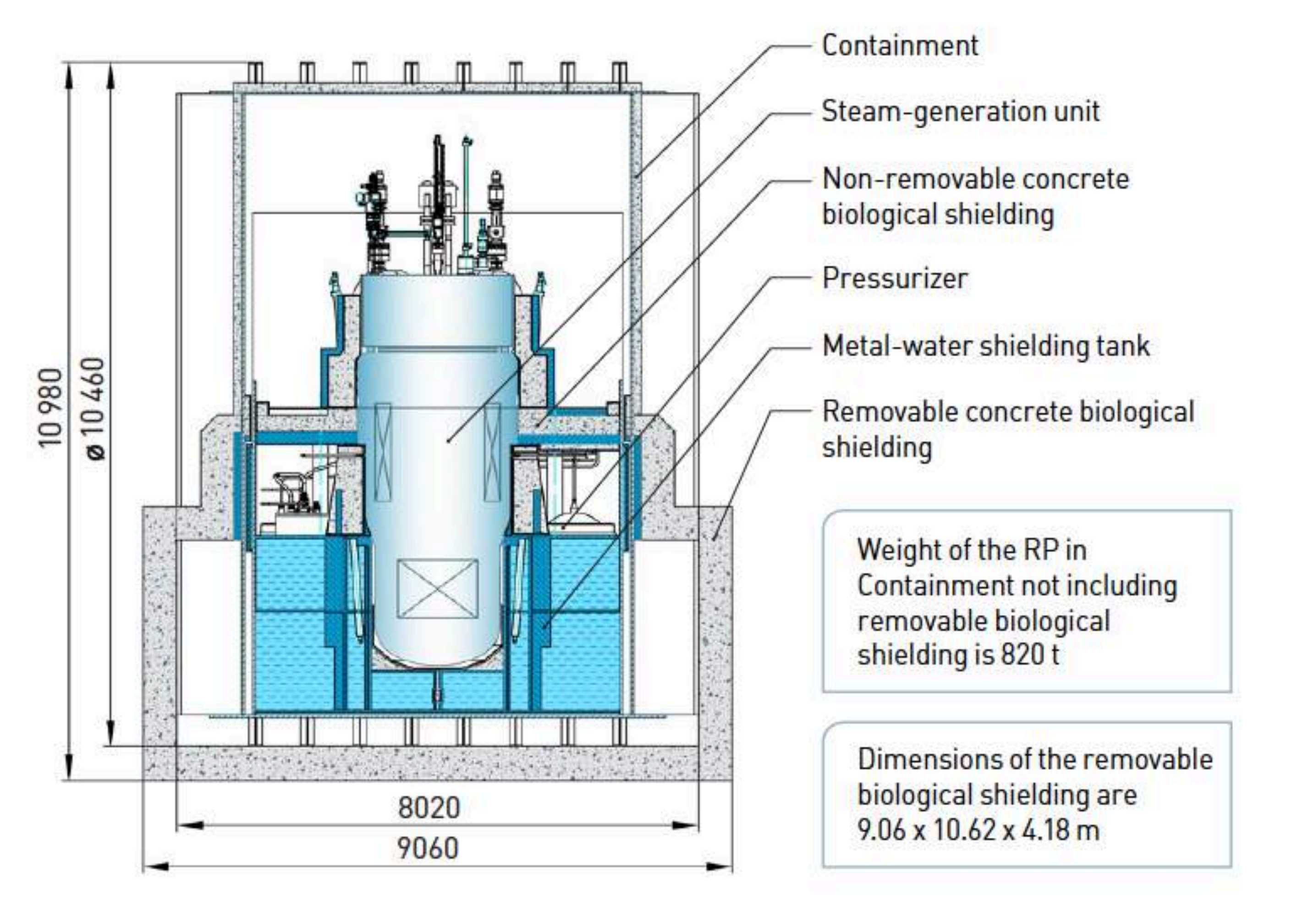
Packaged in a containment for a floating nuclear power plant



Source: OKBM Afrikantov

ABV-6E/-6M

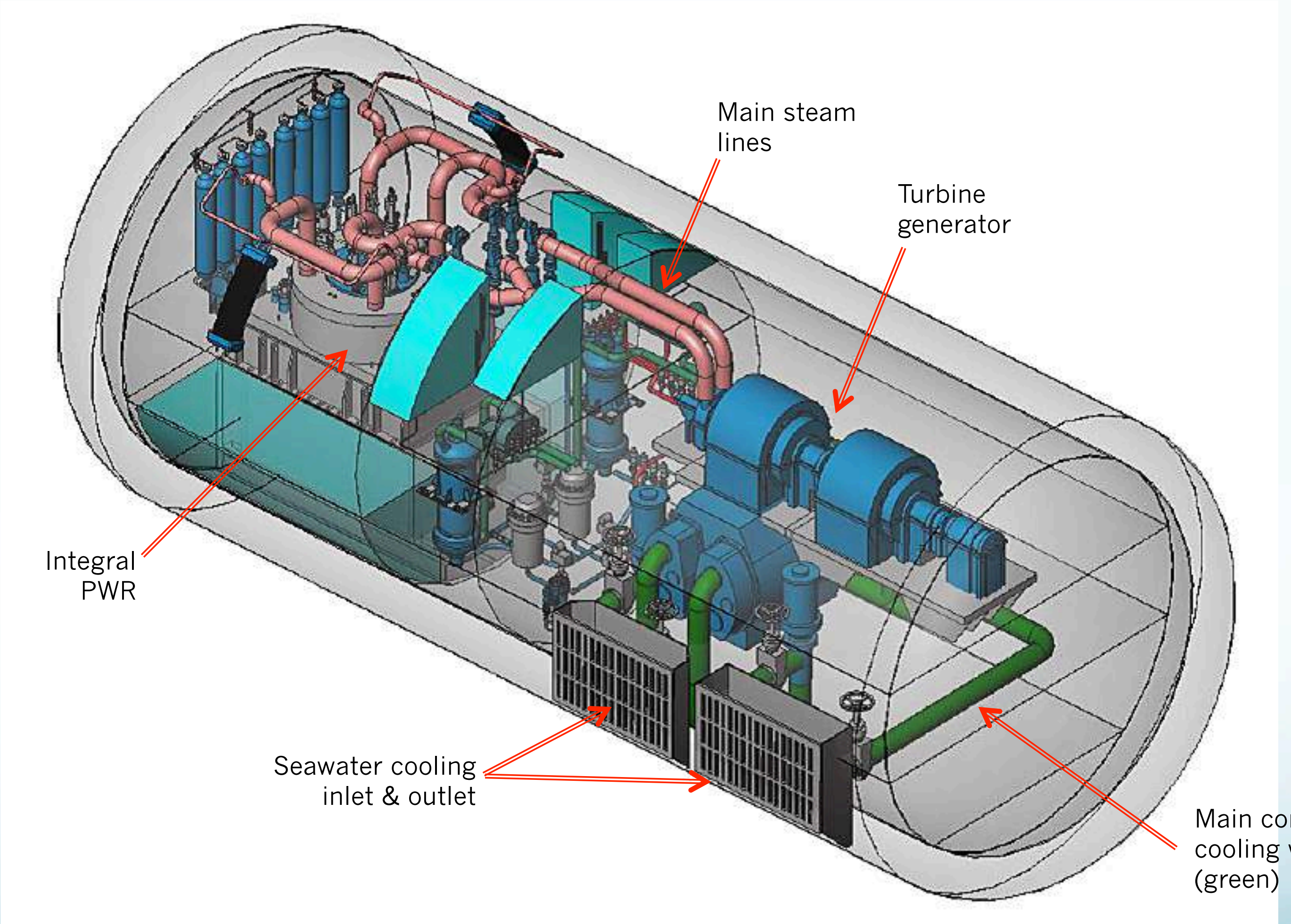
Packaged as a modular transportable reactor unit (TRU)



Source: OKBM Afrikantov

ABV-6E

Packaged for seabed siting

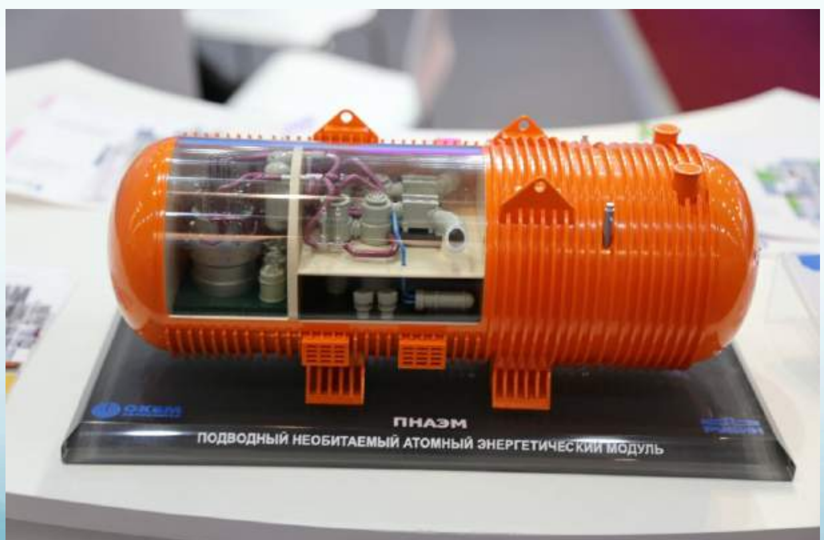


Source: adapted from OKBM Afrikantov via International Atomic Energy Agency (IAEA) "Advances in Small Modular Reactor Technology Development," 2014

Afrikantov Aisberg

Small integral PWR for a subsea power complex

- Aisberg ("Iceberg") is a small, integral PWR designed primarily for use in an unmanned subsea nuclear module to provide electric power for activities in the Arctic sea shelf.
- Module parameters:
  - Useful unit electric power output: 8 to 25 MWe
  - Depth of submersion: up to 400 meters (1,312 feet)
  - Service life: 30 years
  - Factory maintenance interval: 15 years

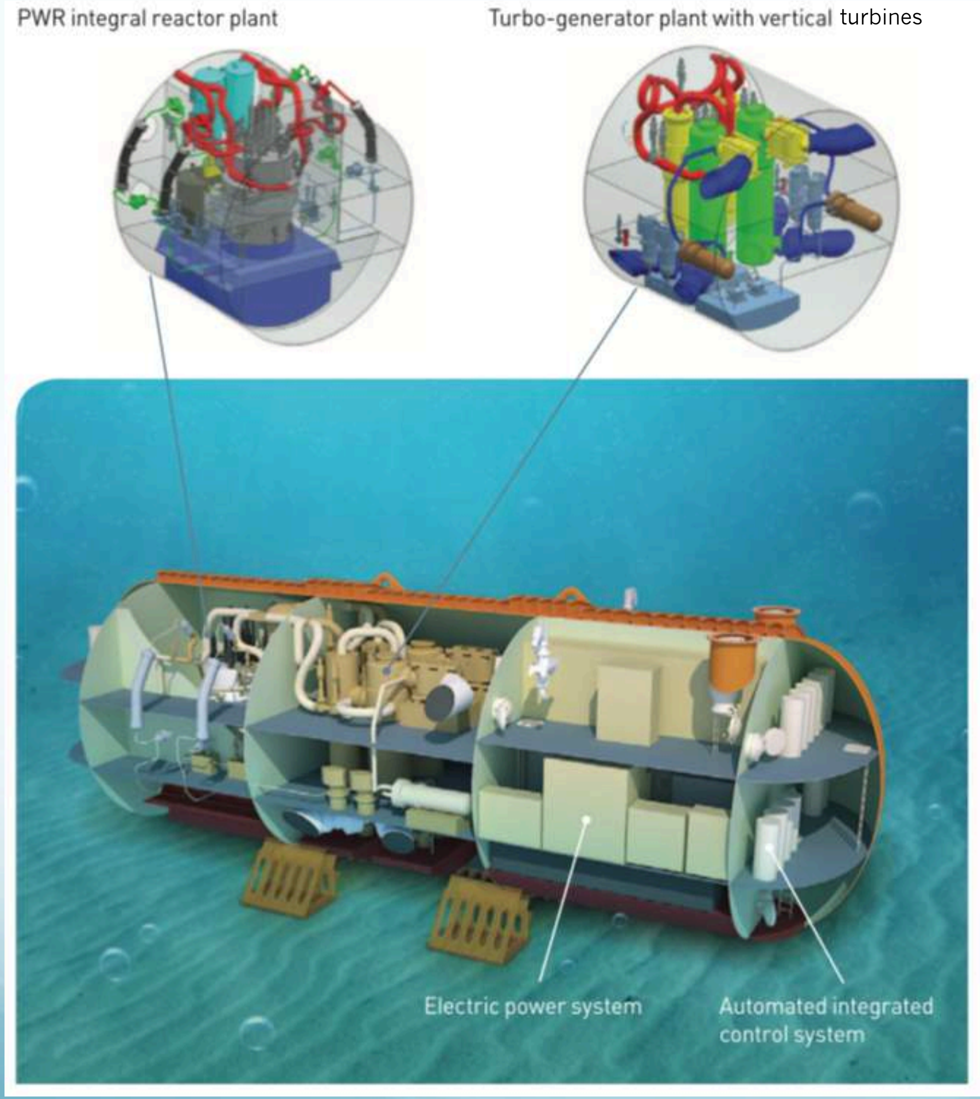


PNAEM - Underwater Uninhabited Nuclear Power Plant. Source: OKBM Afrikantov

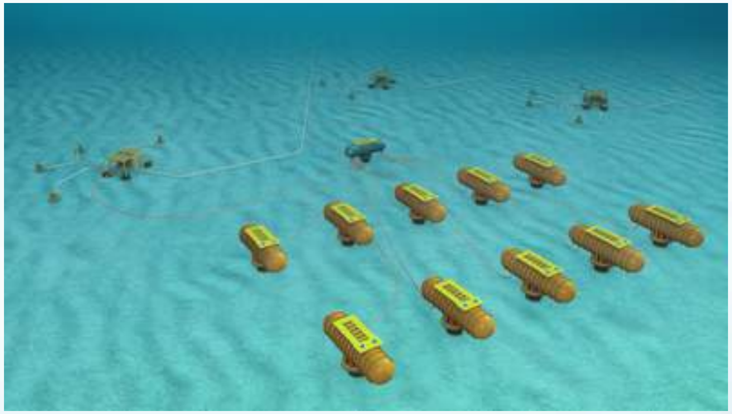
Source: OKBM Afrikantov

Afrikantov Aisberg

Small integral PWR for a subsea power complex



Aisberg PWR module configuration. Source: OKBM Afrikantov



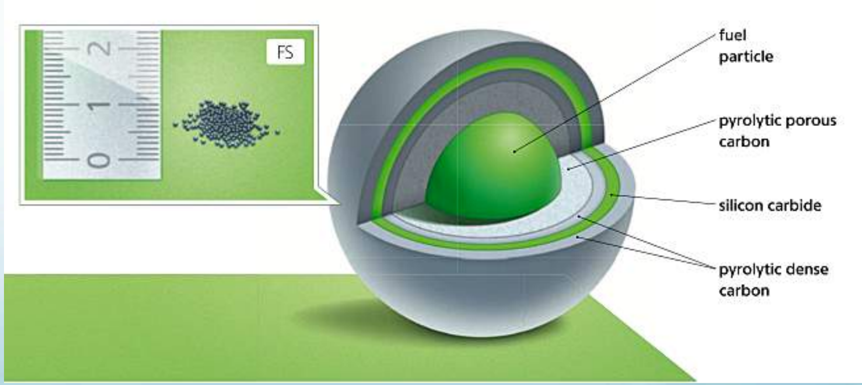
The electrical output from multiple reactor modules can be connected into a subsea power complex serving multiple end-users.

Afrikantov direct cycle HTGR

Concept for marine applications

HTGR reactor vessel. The separate vessel for the direct-cycle gas turbine and heat exchangers is not shown.

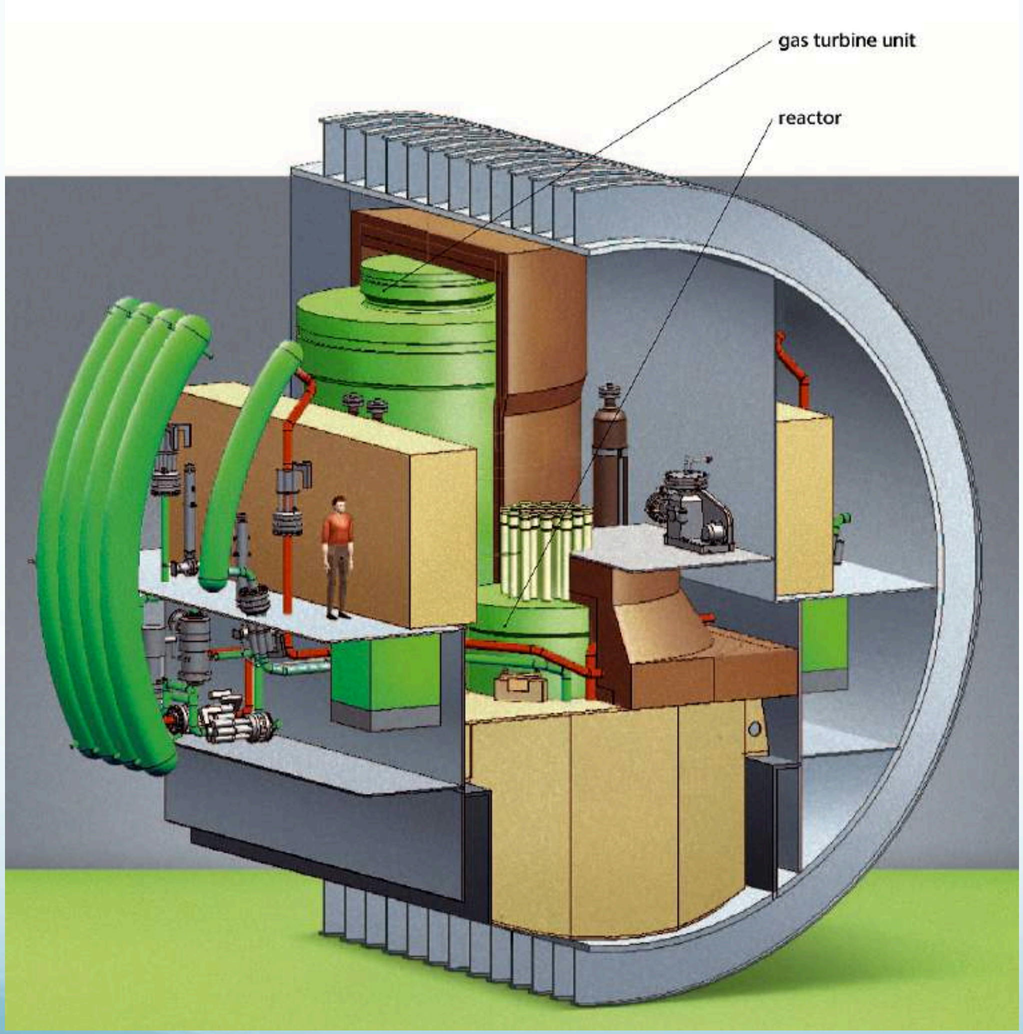
- OKBM Afrikantov has designed a small, direct-cycle High-Temperature Gas-cooled Reactor (HTGR) packaged in a pressure hull that can serve as an autonomous power source in underwater (i.e., sea floor), over-water (i.e., on an industrial platform), and remote land applications in the Arctic and elsewhere.
- The following module parameters are similar to the Afrikantov integral PWR Aisberg:
  - Useful unit electric power output: 8 to 25 MWe
  - Depth of submersion: up to 400 meters (1,312 feet)
  - Service life: 30 years
  - Factory maintenance interval: 15 years



HTGR coated particle fuel. Source, both graphics: OKBM Afrikantov, http://www.okbm.nnov.ru/images/pdf/vtgr_en_web.pdf

Afrikantov direct cycle HTGR

Packaged for seabed siting



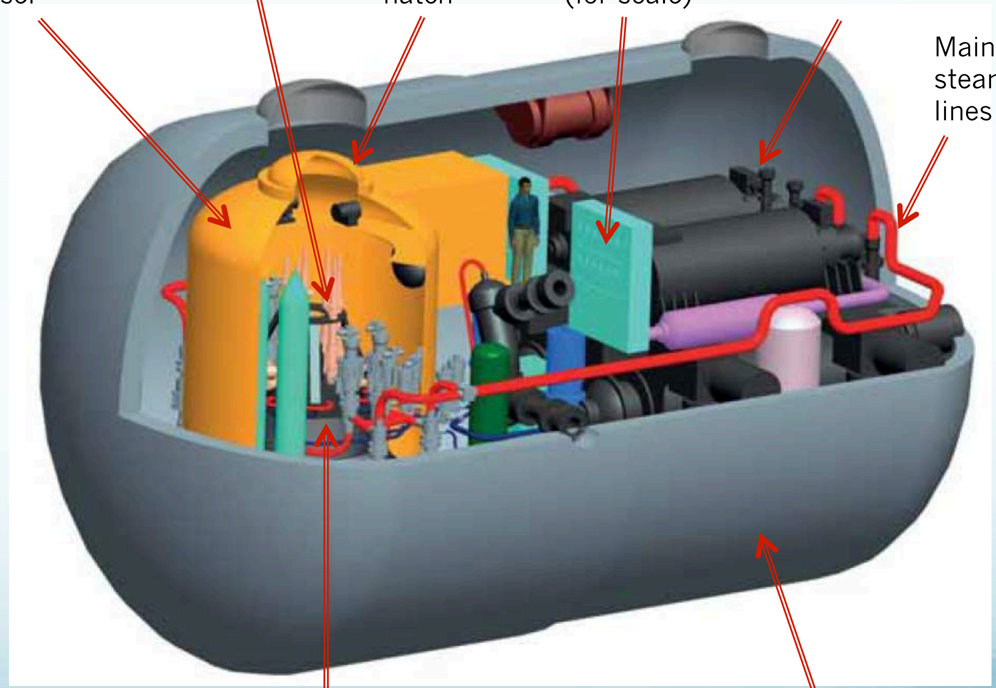
Example layout of a sub-glacialHTGR power supply module for an Arctic drill rig.
Source: OKBM Afrikantov, http://www.okbm.nnov.ru/images/pdf/vtgr_en_web.pdf

- The HTGR provides a more efficient thermal cycle than the PWR Aisberg and, as a co-generator, can provide high/ medium temperature process heat and low-temperature process heat for multiple end-users.

Nikiet SHELF

Automated Atomic Turbine Generator Set (ATGU, Atomnaya turbogeneratornaya ustanov)

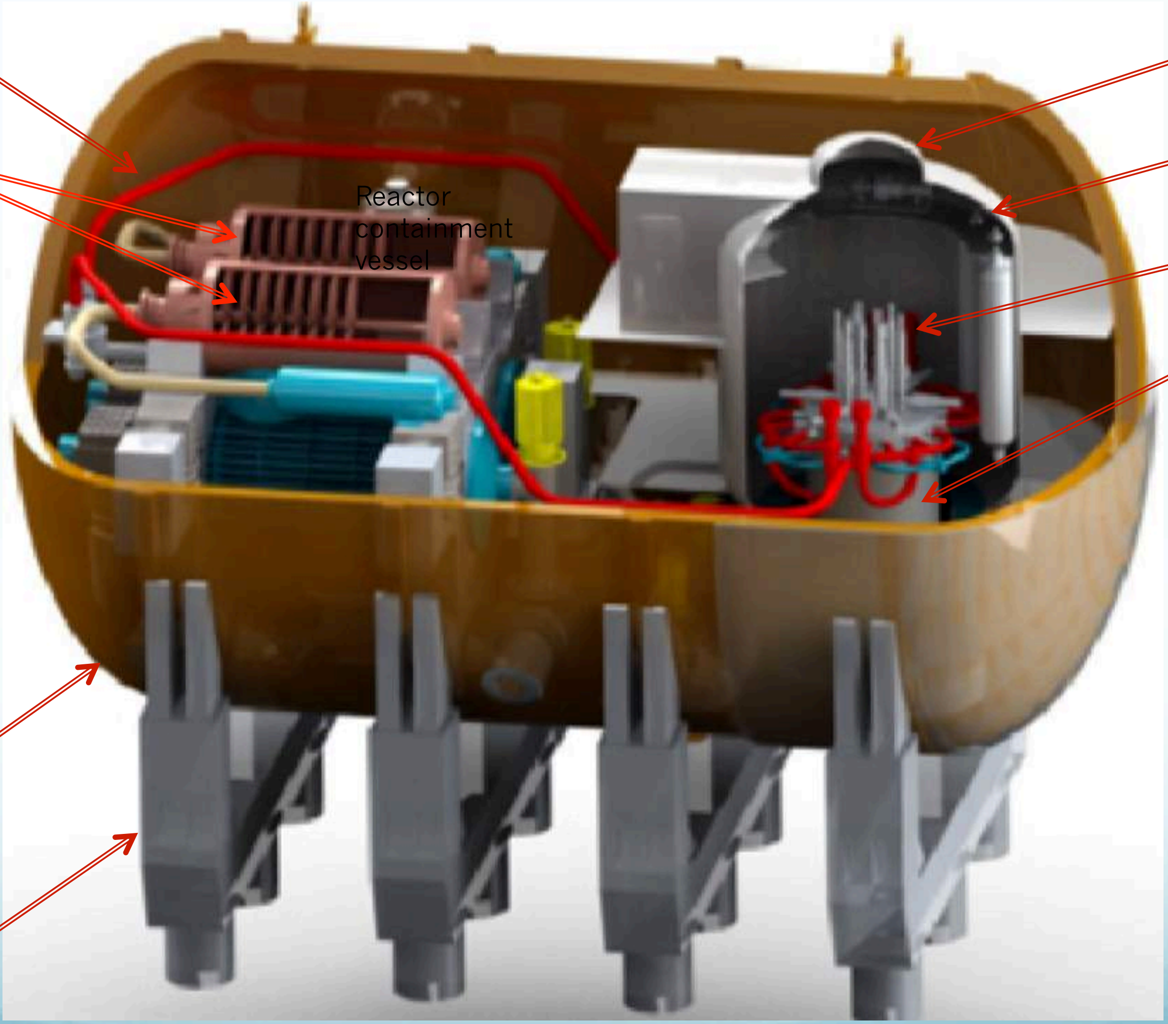
- Dollezhal Research and Design Institute of Power Engineering (Nikiet) designed the SHELF reactor for autonomous operation at remote sites, to generate power for offshore facilities (i.e., oil and gas drilling & production facilities), including in the Arctic, as well as for regions with inadequate energy and transport infrastructure.
- The integral PWR includes the reactor, steam generators, canned pumps and pressurizer within the primary system vessel.
- The LEU-fueled reactor is rated at 28 MWt, delivering an electrical output of 6 MWe plus low-temperature process heat to end-users.
- SHELF is designed for load following from 15 – 100%.
- Once deployed, the autonomous SHELF reactor can be controlled from a remote location (i.e., an offshore or land facility).



Source: Nikiet via International Atomic Energy Agency (IAEA), "Status of Small and Medium Sized Reactor Designs," September 2012

Nikiet SHELF

Automated Atomic Turbine Generator Set
(ATGU, Atomnaya turbogeneratornaya ustanov)



Source: adapted from NIKIET via International Atomic Energy Agency (IAEA) ARIS (2016)

Nikiet SHELF

Automated Atomic Turbine Generator Set
(ATGU, Atomnaya turbogeneratornaya ustanov)

- The compact pressure hull of a SHELF module is designed for underwater siting, with an optional capability for siting on land.
  - The pressure hull measures 8 m (26.2 feet) in diameter, 14 m (46 feet) in length and weighs 335 tons.
  - The hull is designed for operation in water depths up to 300 m (984 feet), although the targeted depth of a seabed site is 50 - 100 m (164 - 328 feet).
- The SHELF reactor incorporates numerous passive safety features. The ocean is the ultimate heat sink.
- Nikiet reports that the SHELF reactor incorporates experience from the design of marine (naval) propulsion reactors, including:
  - Zirconium (Zr)-coated dispersed UO_2 particles in a Zr matrix coated by silumin (Si-Al). Such fuel has excellent heat conductivity characteristics and is capable of very high burn-ups. In spite of its long refueling interval, the low average power density in the SHELF reactor will limit its maximum fuel burnup to significantly less than what can be achieved with similar fuel in large, land-based reactors.
  - Self-spaced cylindrical fuel elements with external twisted ribs that employ no spacer grids. The core is a triangular lattice.
- The reactor is designed for factory refueling at 56 month (4.6 years) intervals.
  - For refueling, the SHELF module will be disconnected from its underwater power network and moorings that secure the module to the ocean floor. Then it will be raised to the surface and brought to a refueling base by a dedicated ship.
  - After refueling, the SHELF module can be re-deployed until the module's end-of-life is reached after an operating life of about 30 years.

Nikiet SHELF

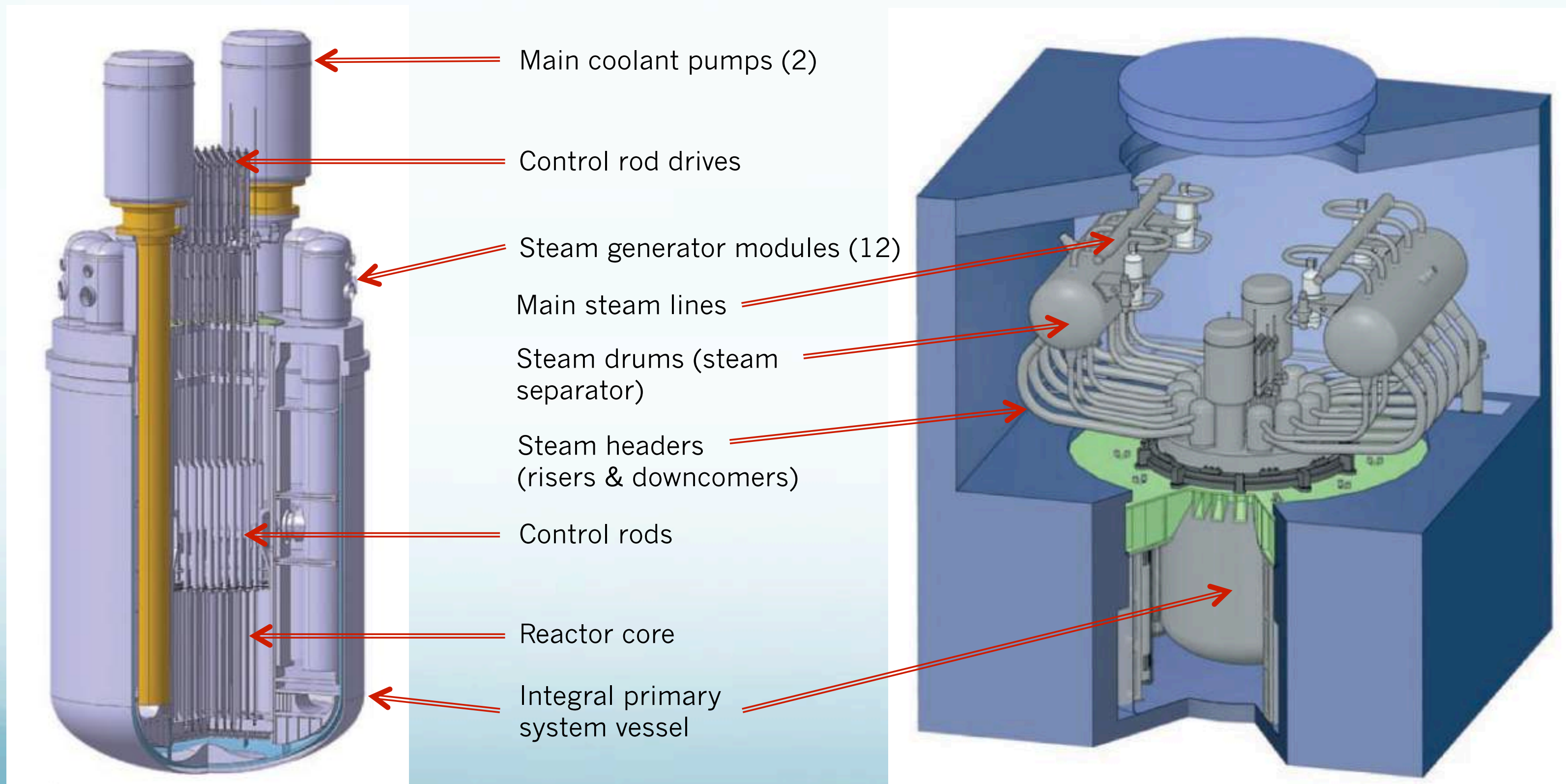
Automated Atomic Turbine Generator Set (ATGU, Atomnaya turbogeneratornaya ustanov)

- The Nikiet SHELF reactor module is similar in concept the PNAEM - Underwater Uninhabited Nuclear Power Plant proposed by OKBM Afrikantov and the FlexBlue® underwater nuclear module being developed in France by DCNS (Direction des Constructions Navales).
- In November 2017, Nikiet Deputy Director General for Innovative Projects, Alexander Pimenov, proposed using the SHELF reactor to supply power for development of the Pavlovskoye lead and zinc deposit on the Novaya Zemlya Archipelago.
  - "We propose using this reactor at the Pavlovskoye deposit and the Chaun-Bilibino energy hub on the Chukotka Peninsula," Pimenov said. He added that one such reactor installed at the Pavlovskoye deposit could replace a two-unit power plant. The diesel stations at the deposit will produce the bulk of electricity, while the reactor will smooth peak loads and hence keep the electricity system at the deposit in the optimal mode of operation."
  - "The first such reactor will cost some 6.7 billion rubles ($108.8 M in 2018 dollars), but commercial production will cut the cost to 5.2 billion ($83.2 M)," Pimenov said. A standard 6.4 MWe SHELF reactor comprises a nuclear unit plus systems responsible for its operation, emergency cooling, emergency protection and safe maintenance.

Gidropress SVBR-75/100

Integral LMR

- OKB Gidropress makes the following claim about their 280 MWt SVBR-75/100 lead-bismuth cooled fast reactor design:
  - "SVBR-75/100 reactor has been developed within the framework of conversion program for a unique Russian reactor technology applied in nuclear submarines. The well-proven engineering basis for SVBR-75/100 reactor design is created by the 50-year experience in designing and operation of lead-bismuth reactors for nuclear submarines (the BM-40A) and Russian experience in elaboration and operation of fast sodium reactors."



SVBR-75. Source, both graphics: Gidropress

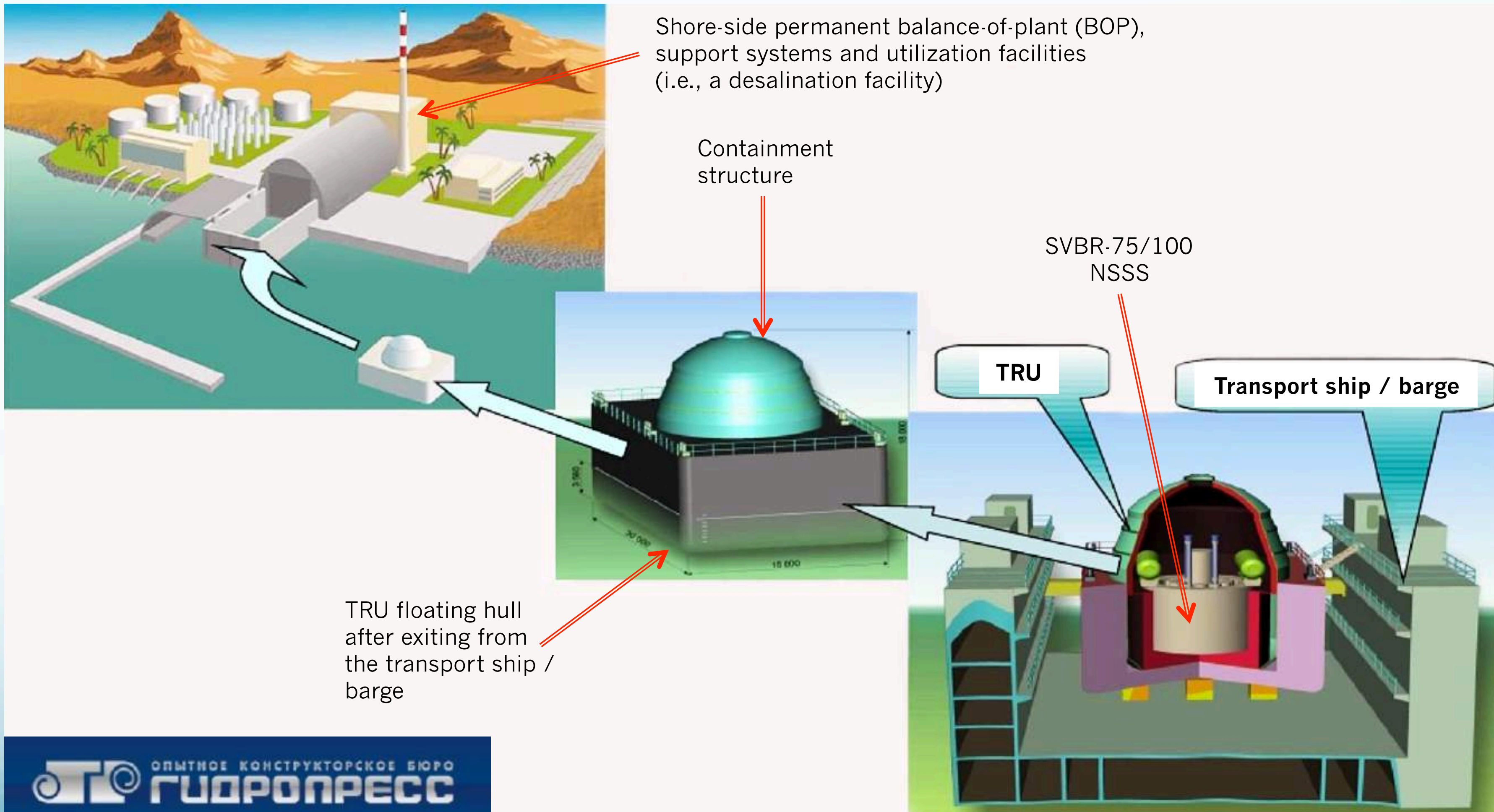
Gidropress SVBR-75/100

Integral LMR

- Summary of SVBR-75/100 general characteristics:
  - Fast reactor with a chemically inert, heavy, liquid-metal coolant – a eutectic lead-bismuth alloy – with a very high boiling temperature and a low melting temperature.
  - Integral layout of the reactor & primary system as a single unit (monoblock):
    - No valves or pipelines for liquid-metal coolant.
    - Additional unit shielding is provided by placing the unit (monoblock) inside a water tank, which also serves as a passive reactor core heat removal system.
  - Several different types of fuel can be used without changes in reactor design or safety: UO_2 fuel, mixed-oxide (MOX) fuel with warhead or reprocessed reactor plutonium, MOX fuel with minor actinides (TRUOX), or nitride fuel.
  - Two-circuit heat removal with natural circulation on the steam generator secondary side.
  - Normal operation and safety functions combined in reactor systems as much as possible.
  - Modular reactor and primary system components simplify replacement and repair.
- Applications:
  - The SVBR-75/100 nuclear steam supply system (NSSS) can be packaged in the Gidropress “secure transportable autonomous reactor” (STAR) configuration, which is designed as a Transportable Reactor Unit (TRU) for use in a coastal nuclear electric power or cogeneration plant.
  - Conventional land-based nuclear power plants.

Gidropress SVBR-75/100

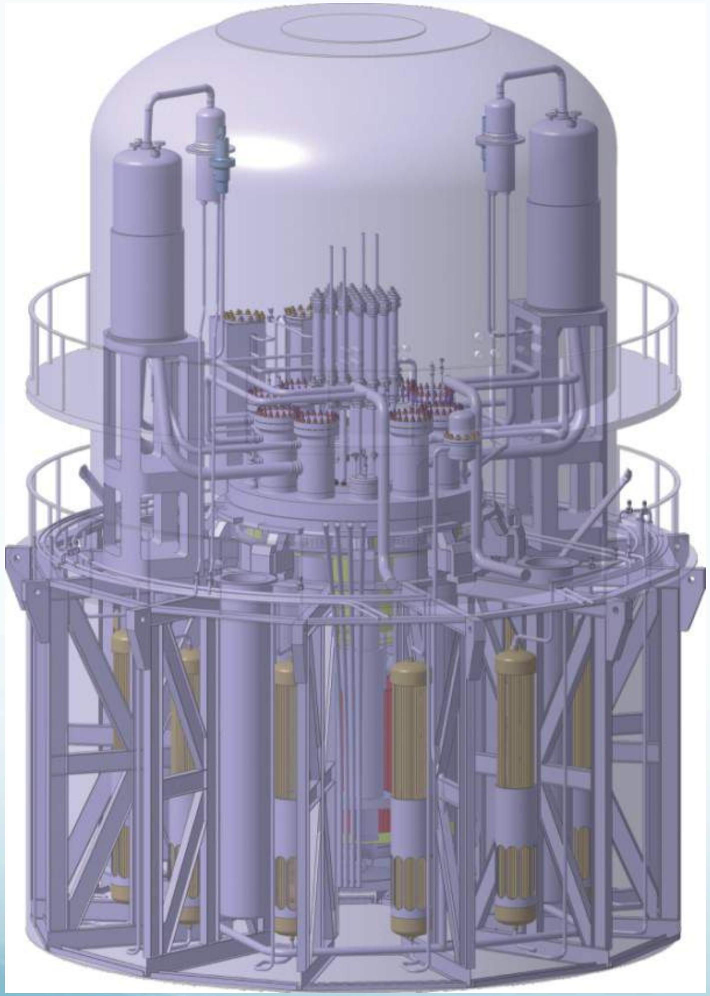
Packaged as a transportable reactor unit (TRU)



SVBR-75/100 in “Secure, Transportable, Autonomous Reactor” (STAR) configuration.
Source: adapted from Gidropress, https://www.slideshare.net/myatom/klimov-gidropress-svbr

Gidropress SVBR-10

Small integral LMR



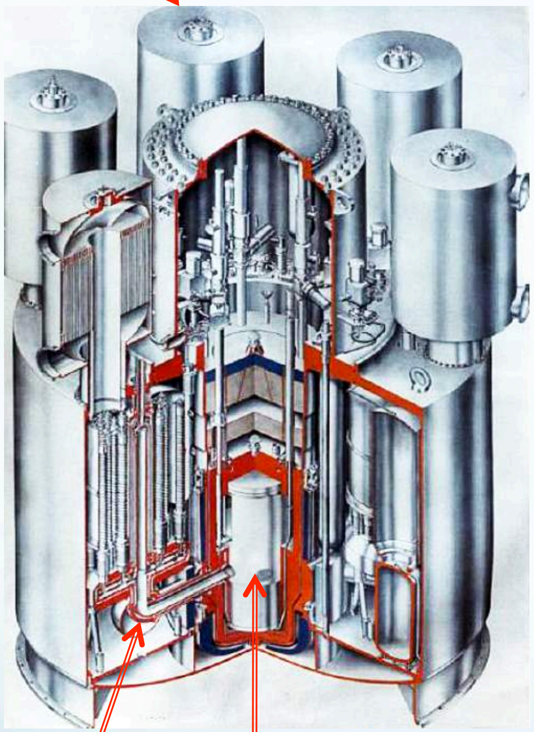
SVBR-10.
Source: http://www.gidropress.podolsk.ru/en/projects/svbr10.php

- The SVBR-10 liquid metal (lead-bismuth) reactor plant is designed for energy and heat supply to population and industrial consumers in remote areas characterized by undeveloped transportation and industrial infrastructure.
- SVBR-10 has an integral reactor layout with the core, primary equipment, reactor coolant pumps and steam generator units located inside the reactor vessel ("monoblock"), without valves or coolant pipelines.
- Reactor is rated at 43.3 MWt.
  - UO_2 fuel enriched to 18.7%. U-235 loading is 755 kg (1,664 pounds).
  - Core lifetime: 135,000 hours
  - Refueling period: about 20 years
- Gross electrical generating capacity: 12 MWe.
- Design life of irreplaceable equipment: 60 yrs.
- Applications:
  - Offshore floating nuclear power plant.
  - The SVBR-10 in the Secure Transportable Autonomous Reactor (STAR) configuration is a Transportable Reactor Unit (TRU) intended for a coastal nuclear electric power or cogeneration plant.
  - Conventional land-based nuclear power plant.

Kurchatov ELENA

Modular PWR with direct energy conversion

Thermoelectric generator (TEG) modules



Primary coolant loop to TEG modules

Reactor vessel

Source: I. V. Kurchatov Institute via International Atomic Energy Agency (IAEA), "Advances in Small Modular Reactor Technology Developments," 2016

- The ELENA nuclear thermoelectric plant (NTEP) is a direct conversion modular pressurized water reactor (PWR) rated at 3.3 MWt.
  - LEU fuel, 15.2% enriched UO_2
  - Reactor vessel measures 1.5 m (5 feet) OD, 3.7 m (12.1 feet) tall.
  - Core inlet / exit temp: 311 / 328 °C (592 / 622 °F) @ 2,345 psig
- Cooling circuits:
  - Primary: Reactor to 6 x TEG module "hot" sides
  - Secondary: TEG "cold" sides to intermediate heat exchangers (IHX)
  - Tertiary: IHX to end-user heat transport systems
- The TEGs have low electrical conversion efficiency. ELENA is capable to supplying 68 kWe (0.068 MWe) of electricity. The balance of TEG "waste heat" is the source of low-temperature process heat for end users.
- Core life is 25 years. The ELENA module would be removed and refueling would be done at a remote servicing facility.
- Designed for autonomous operation, requiring few operating or maintenance actions over the lifetime of the unit.
- Originally conceived as a land-based plant. In principle it could be deployed in underground or underwater versions.

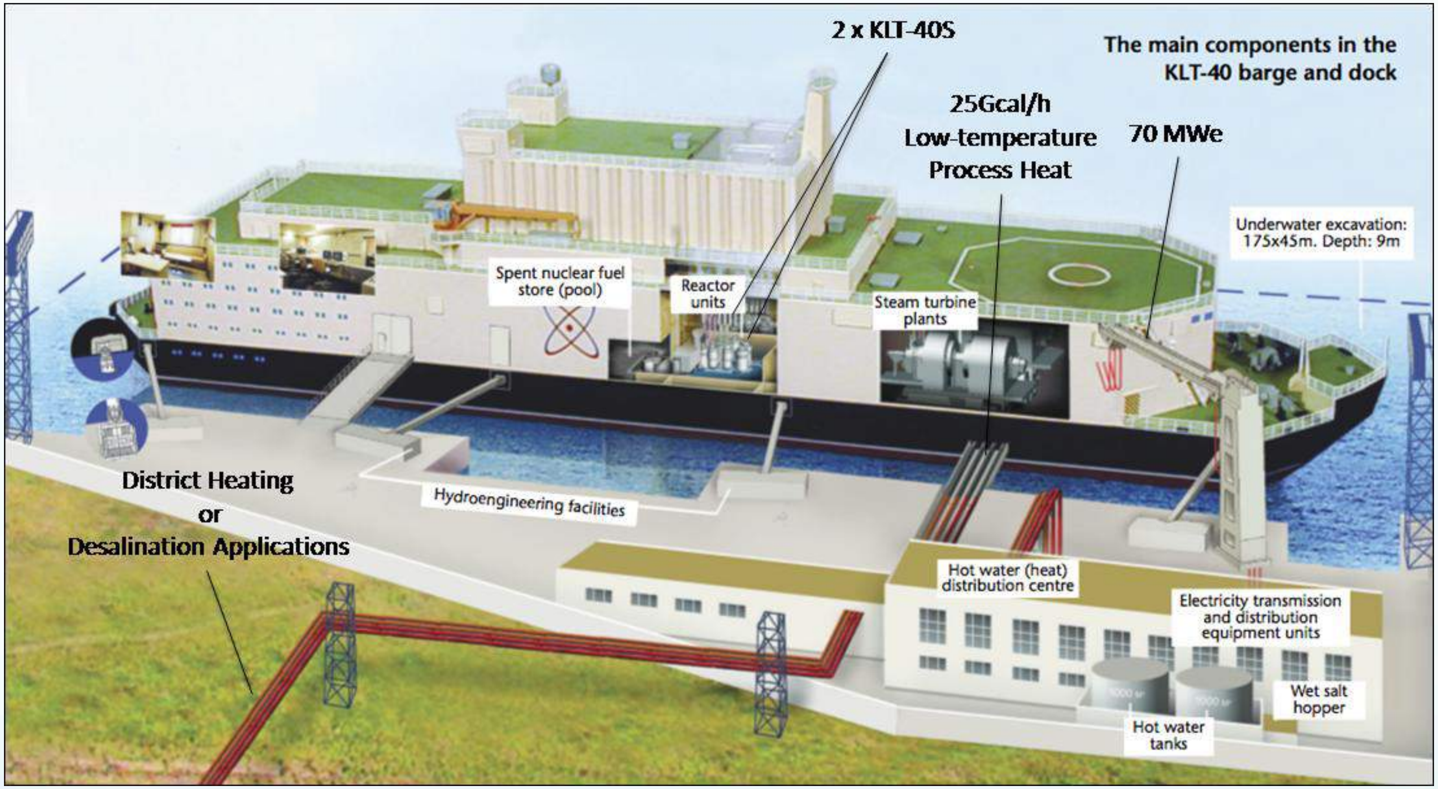
Floating nuclear power plants (FNPP)

Floating nuclear power plant (FNPP)

Source, three graphics: World Nuclear Association

Project 20870 - *Akademik Lomonosov*

First Russian floating nuclear power plant (FNPP)



FNPP *Akademik Lomonosov* and its associated shore-side facilities. Source: OKBM Afrikantov

- *Akademik Lomonosov* was constructed at the Baltic Shipyard in St. Petersburg. The keel was laid in May 2009. Length: 140 m (459.3 ft); width: 30 m (98.4 ft); displacement: 21,000 tons.
- 2 x KLT-40S reactors, each rated at 150 MWt, will deliver up to 77 MWe net and low-temperature process heat to users on shore. The FNPP can deliver up to 25 Gcal/h (about 29 MW) of process heat with reduced electric generation.

220 ton KLT-40S installation

Akademik Lomonosov, Baltic Shipyard, St. Petersburg

Sep – Oct 2013: Two KLT-40S reactors installed. Source: survincity.com

Akademik Lomonosov

Final construction and outfitting, Baltic Shipyard, St. Petersburg

Construction and outfitting work at Baltic Shipyard was completed in April 2018.

Source, left: http://www.world-nuclear-news.org/

Source: https://www.nucnet.org/

Source: https://thebarentsobserver.com/

Akademik Lomonosov

28 April – 19 May 2018: Tow from St. Petersburg to Murmansk

Source: Anton Vaganov / TASS

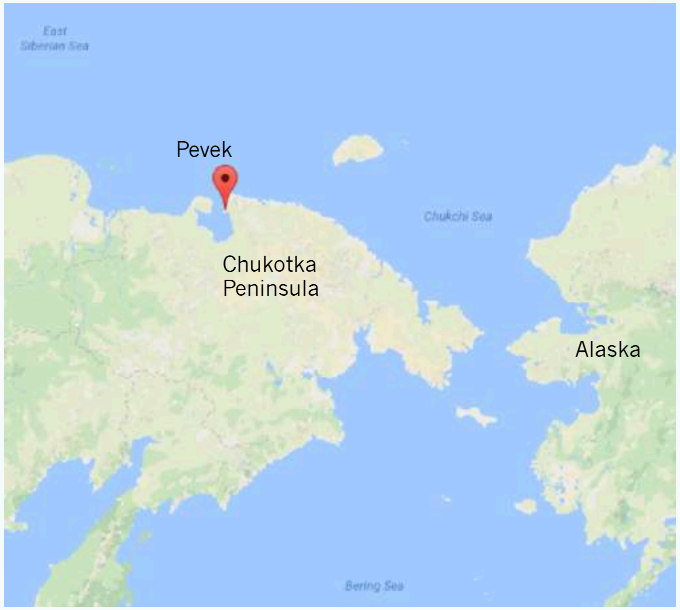
Source: https://www.trendsmap.com/

Source: http://en.prothomalo.com/science-technology/news/

Source: AP / http://betternews.info/

Akademik Lomonosov will be deployed to Pevek

- October 2017: Start of shore-side construction in Pevek, on the Chukotka Peninsula.
- December 2017: Russian State Expert Examination Board (Glavgosexpertiza) announced that *Akademik Lomonosov* met construction standards and they approved the project to install the FNPP in Pevek.
- April 2018: Construction and outfitting work was completed at Baltic Shipyard, St. Petersburg, followed by a tow to Murmansk.
- November 2018: Expected fuel loading in Murmansk followed by reactor testing.



Source: Google maps

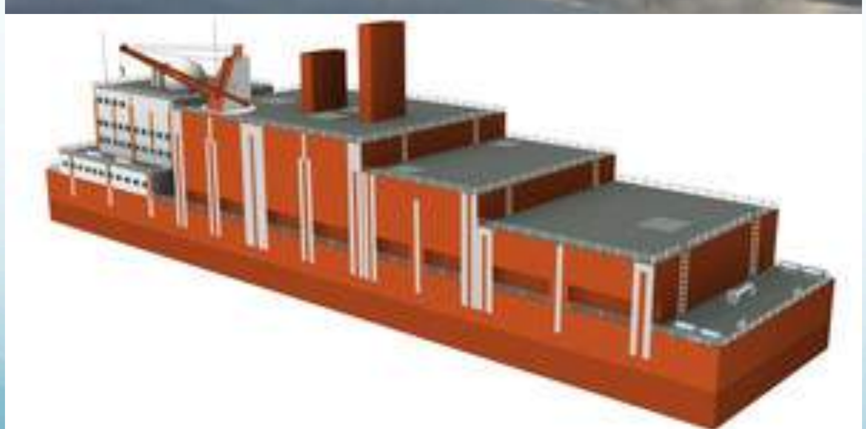
- November 2019: Expected commissioning in Murmansk.
- 2020: The FNPP has no propulsion system. *Akademik Lomonosov* will be towed 9,000 km (5,592 miles) along the Northern Sea Route from Murmansk to Pevek.
- 2020 – 2021: The FNPP needs to start operation before the last unit at the aging Bilibino nuclear power plant is shut down in 2021.
- Refueling will be required at 3 – 5 year intervals. Operating life of the FNPP is expected to be 40 years, possibly extendable to 50 years.

Akademik Lomonosov as it may appear in Pevek

Source: OKBM Afrikantov & Atomenergomash presentation at the OECD/NEA Workshop on Innovations in Water-cooled Reactor Technologies, Issy-les-Moulineaux, France, 11 – 12 February 2015

Rubin FNPP design concept

Floating nuclear power plant



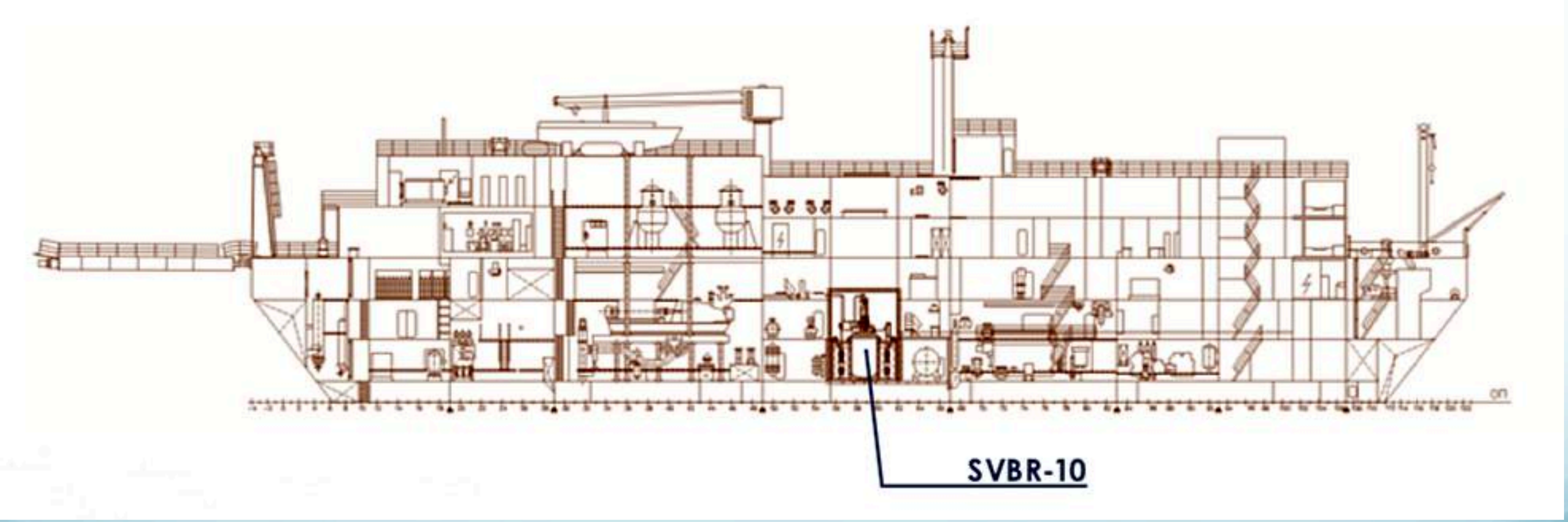
Source: Rubin Central Design Bureau for Marine Engineering

- 2 x RITM-200M reactors will provide about 95 MWe net to the onshore power grid.
- The floating power unit is a non-propelled, moored, double-bottom and double-hull vessel with an extensive superstructure.
- Length: 104 m (341.2 feet); width: 25 m (82 feet); displacement: 10,146 tons (smaller and about ½ the displacement of *Akademik Lomonosov*)
- The unit, fully packaged and with the reactor cores fueled, is towed or shipped by barge to the operation site.
- Design lifetime for the floating power unit is 40 years with annual maintenance of main equipment. Medium overhaul and docking is to be done at 10 year intervals. During the overhaul, core refueling is also done.

Gidropress FNPP design concept

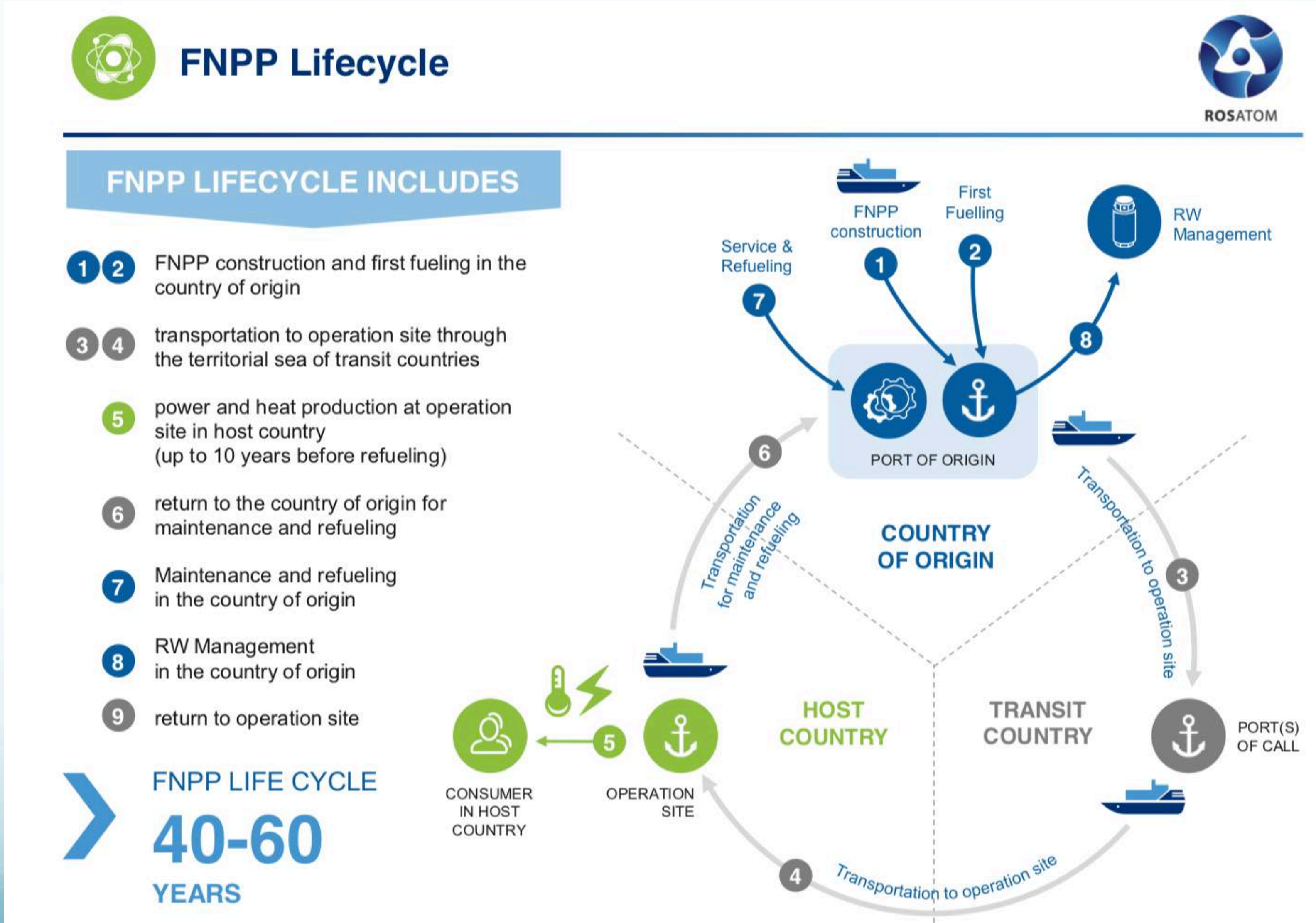
Floating nuclear power plant

- JSC Atomenergo and Gidropress developed a conceptual design of a floating NPP with two SVBR-10 liquid metal-cooled reactors delivering a total of 24 MWe and process heat to end-users.
- The design exercise concluded that a floating nuclear plant with LMR power sources could provide better economic efficiency than a floating nuclear plant with PWR reactors.



Source: Gidropress, http://www.gidropress.podolsk.ru/files/booklets/en/rusvbr_en.pdf

FNPP life cycle



Source: Rosatom

Transportable reactor units (TRU)

Transportable Reactor Unit (TRU)

Barge-delivered integral LMR for coastal sites

- A TRU is a nuclear steam supply system (NSSS) that has been packaged into a compact module that can be transported by a vessel between two points with access to navigable waterways. For example:
  - Transport between a TRU manufacturer and a coastal cogenerating plant,
  - From the coastal cogenerating plant back to the manufacturer or a third-party site for periodic refueling and servicing, and
  - Final transportation to a cleanup and decommissioning site.
- Like a floating nuclear plant (FNPP), the TRU is intended for electric power generation, cogeneration and/or desalination of seawater in isolated regions of the world with little or no local electric power generation or transmission infrastructure that could bring in power from another location.
- Unlike a FNPP, which includes the NSSS and a balance-of-plant (BOP) for electric power generation and/or process heat delivery, the TRU is only the NSSS module, related support systems and a containment structure. The entire BOP for the cogeneration facility and power distribution systems to end-users need to be built on shore and designed receive and interface with a TRU module. These permanent facilities include:
  - A dock with handling equipment for receiving the TRU an moving it into position inside the facility
  - A protected dock where a removed TRU can remain for a period of time for reactor cooling after being removed from service (and replaced by a new TRU)
  - Turbine-generator systems, cooling water systems, control room
  - Electrical systems and switchgear to connect the generating plant to the local grid and end users
  - Infrastructure buildings and other structures for physical protection of the site.

Source: http://www.gidropress.podolsk.ru/files/booklets/en/svbr75_100_en.pdf

Transportable Reactor Unit (TRU)

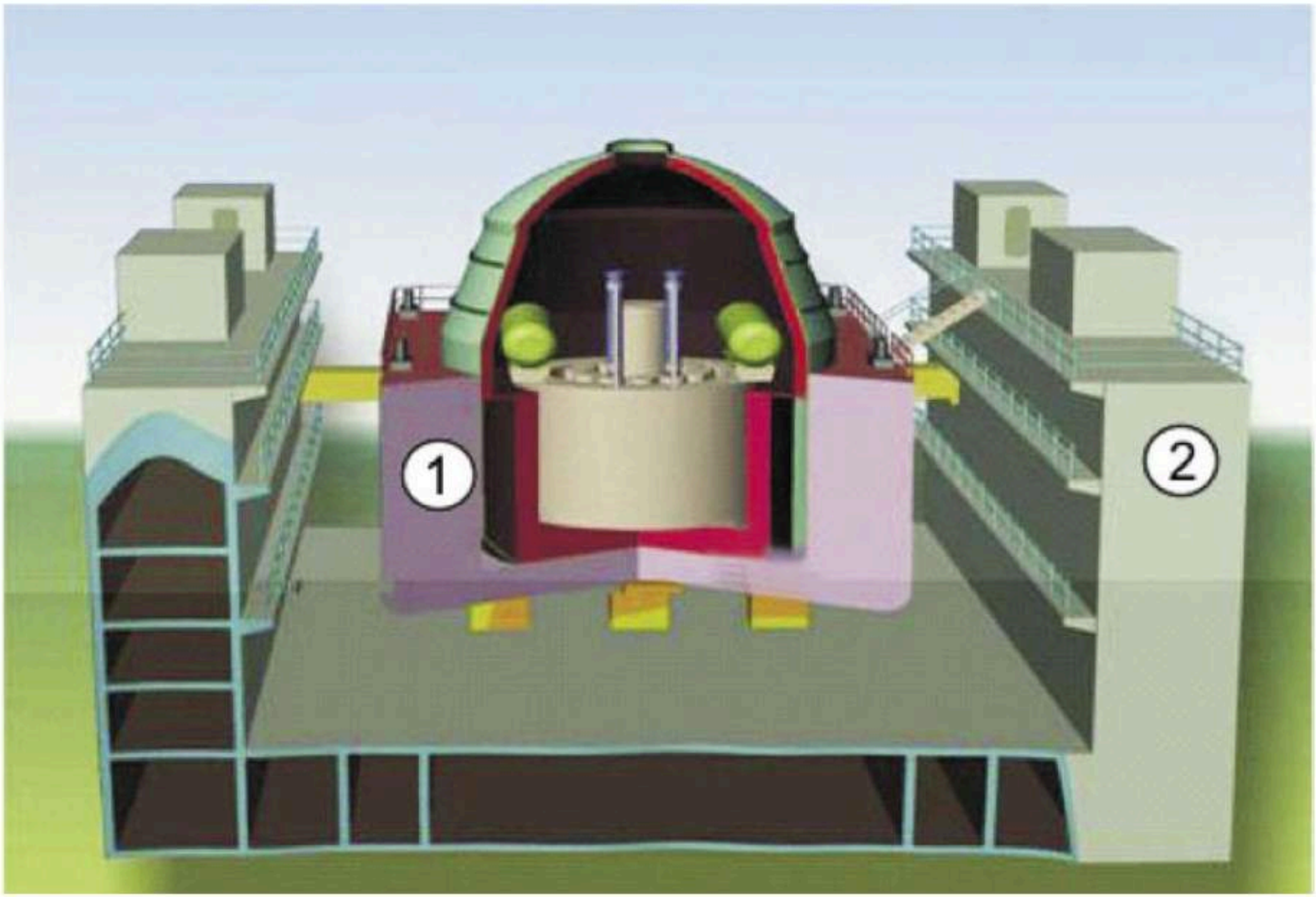
Barge-delivered SVBR-75/100 integral LMR for coastal sites

- The SVBR-75/100 TRU is a "plug-in" module that functions like a large "nuclear battery," with a service life of about 8 years. SVBR-75/100 TRU power ratings are:
  - Reactor thermal power: 280 MWt
  - Gross electrical power generation: 80 MWe
  - Power consumption by TRU house loads and maximum desalination plant load: 70.5 MWe
  - Net electric power output to the grid at maximum desalination load: 9.5 MWe
- The transportation barge (in this case, a floating drydock) for moving the TRU between sites was designed by submarine design bureau Malakhit (Malachite) Central Design Bureau, St. Petersburg.
- GIDROPRESS estimates the following construction and operating costs for an SVBR-75/100 TRU-powered cogenerating water desalination plant delivering 200,000 cubic meters of water per day.
  - Capital costs ~ $260 million total, including: coastal structures @ $60 million; distillation desalination equipment @ $120 million; reverse osmosis desalination equipment @ $80 million;
  - Annual operating costs ~ $30 million/year, including: lease for the TRU @ ~ $12 million/year; facility operating cost and maintenance @ ~ $18 million/year.

Source: http://www.gidropress.podolsk.ru/files/booklets/en/svbr75_100_en.pdf

Transportable Reactor Unit (TRU)

Barge-delivered SVBR-75/100 integral LMR for coastal sites



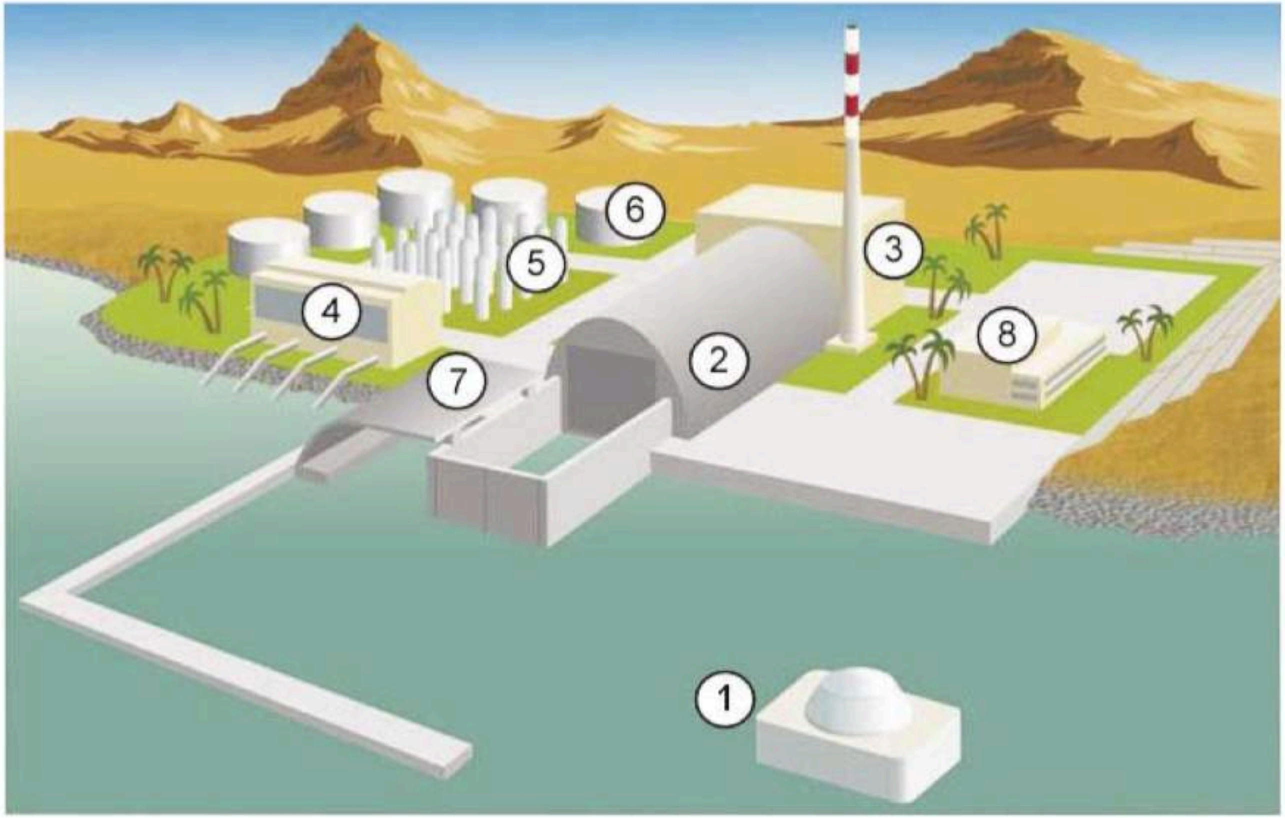
Layout of TRU on board a carrier

1 – transportable reactor unit
2 – floating dock (barge)

Source: http://www.gidropress.podolsk.ru/files/booklets/en/svbr75_100_en.pdf

Transportable Reactor Unit (TRU)

Barge-delivered SVBR-75/100 integral LMR for coastal sites

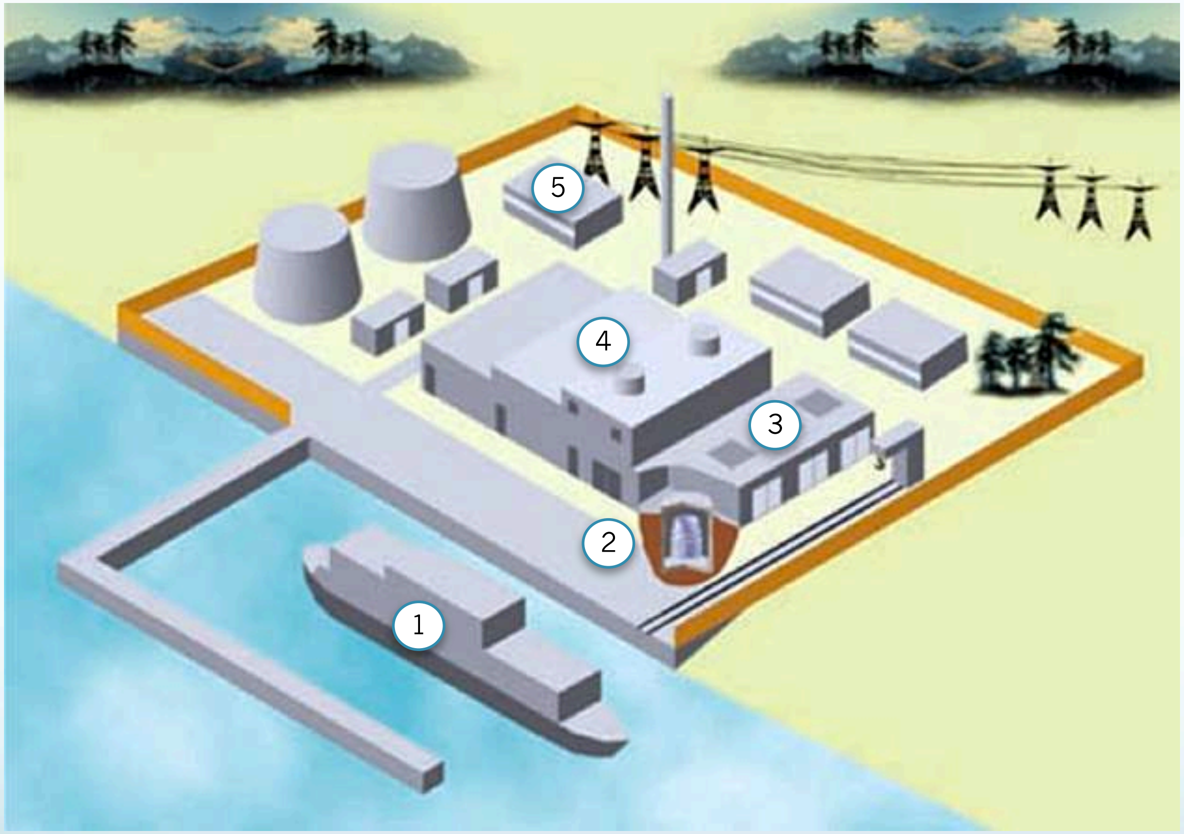


1 – transportable reactor unit (approaching dry dock)
2– protective dry dock
3 – building for steam-turbine plant
4 – building for desalinating plant pumps
5 – water-desalinating plant modules
6 – desalinated water storage tanks
7 – platform for reactor coolant solidification prior to transportation (this is a covered dock)
8 – office building

Source: http://www.gidropress.podolsk.ru/files/booklets/en/svbr75_100_en.pdf

Transportable Reactor Unit (TRU)

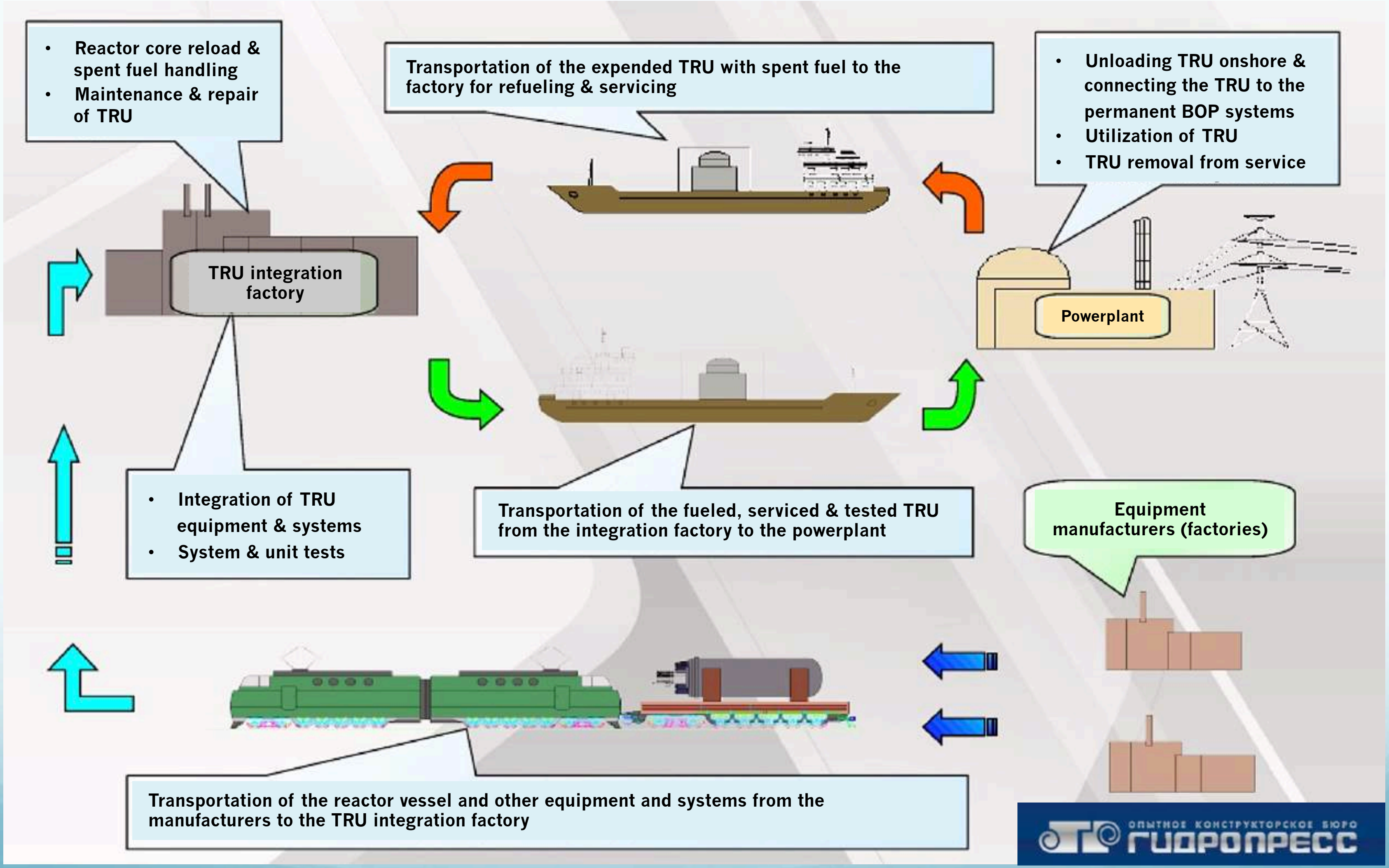
Multiple SVBR-10 STAR NSSS modules for coastal sites



1. 5 Switchyard connecting the NPP to the local grid
2. 4 Permanent power conversion (BOP) and support systems
3. 3 Enclosure for additional SVBR-10 NSSS modules
4. 2 1 of 4 replaceable SVBR-10 STAR NSSS modules shown installed below-grade
5. 1 SVBR-10 STAR NSSS modules delivered and removed by ship

STAR = Secure Transportable Autonomous Reactor
Source: adapted from Gidropress, http://www.gidropress.podolsk.ru/files/booklets/en/rusvbr_en.pdf

Transportable reactor unit (TRU) life cycle



Source: adapted from Gidropress, https://www.slideshare.net/myatom/klimov-gidropress-svbr

Arctic seabed applications for marine nuclear power

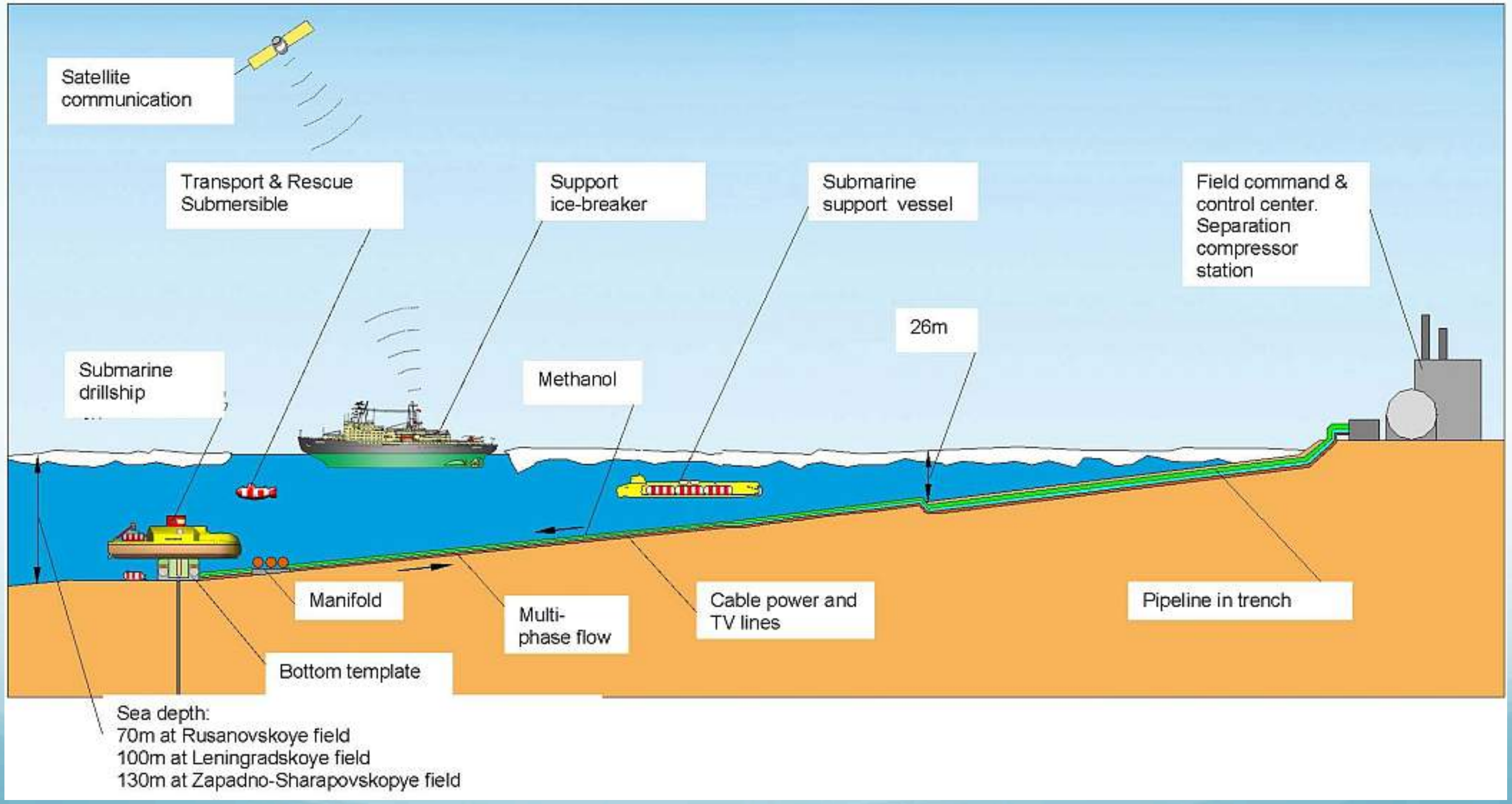
Arctic subsea drilling system (SDS) concept

- Submarine design bureau Lazurite Central Design Bureau, Nizhny Novgorod (designers of the Project 670 Charlie-class SSGN and Project 945 Sierra-class SSN), developed a concept for a Subsea Drilling System (SDS) that is intended for year-round drilling, irrespective of climatic and ice conditions when developing oil and gas fields in the deep offshore areas of the Russian Arctic seas.
- The SDS is comprised of a Submarine Drillship and a Bottom Template for operation at 60 to 400 m (197 to 1,312 feet) sea depth.
  - The Bottom Template defines the location of the well to be drilled, serves as a dock for the Drillship during drilling operations, and an interface between the new well and an undersea pipeline system for collecting and delivery the product.
  - The Submarine Drillship is powered from an external electrical source that us connected to the Drillship via an underwater cable. The power source could be a shore-side nuclear- or fossil-powered generator or a seabed-sited nuclear-powered generator.
- The oil and gas fields would be developed by drilling single wells and/or clusters of wells and installing the necessary manifolds and piping systems to connect the wells to subsea manifolds that will deliver the product to a shore-side facility.

Source: https://www.cdb-lazurit.ru/en_burovie_kompleksi.html

Arctic subsea drilling system (SDS) concept

This concept drawing developed by Lazurite Central Design Bureau shows an Arctic oil/gas field being developed using a Submarine Drillship and Bottom Template supported by a variety of vessels and a shore-side facility.



Source: https://www.cdb-lazurit.ru/en_burovie_kompleksi.html

Arctic subsea drilling system (SDS) concept

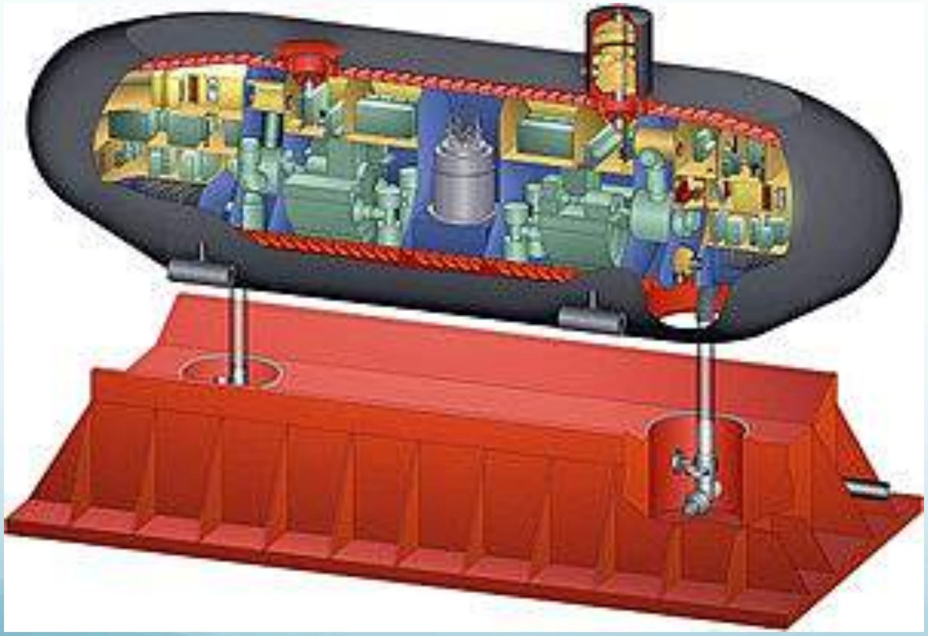
- The conceptual Lazurite Drillship is a large vessel, with a length of 98.6 meters (323 feet), a beam of 31.2 meters (102 feet) and a displacement of about 23,600 tonnes (26,014 tons).
- The Drillship houses a dry-type drilling rig with a stock of drilling consumables for construction of a 3,500 meter (11,482 feet) deep vertical well into the seabed. Consumables would be replenished periodically by a submarine cargo-container delivery system.
- Drilling operations are conducted under standard atmospheric pressure in the Drillship compartments. Underwater robotic devices perform outboard technological operations, while transport and rescue submersibles deliver personnel and supplies and conduct rescue operations if needed.

Drillship sitting on a Bottom Template.
Source: https://www.cdb-lazurit.ru/en_burovie_kompleksi.html

- The Drillship is powered and maintains communication with a coastal command and control centers via an underwater cable. Onboard storage batteries serve as a standby power source. It also may be possible to power the Drillship and underwater infrastructure from a seafloor nuclear power complex.

Subsea nuclear gas compressor station concept

- Rubin Central Design Bureau developed the design concept for a nuclear-powered subsea gas compressor station for use on subsea gas pipelines running from offshore production areas to shore-side facilities.
- The replaceable compressor station is connected via removable mating elements to the pipeline via a permanent mounting base on the seafloor.
- The station is designed for continuous safe automatic operation, maintaining the compression rate of the transferred gas for the required throughput.

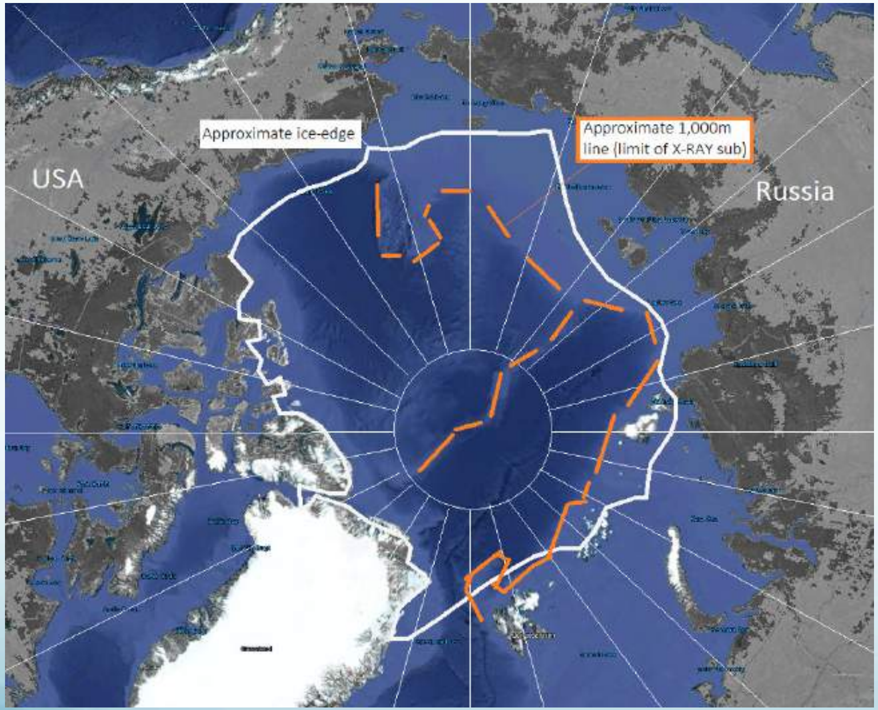


- An underwater vehicle enables regular visits by maintenance personnel to check the equipment and replace consumables.
- When the station reaches its end of service life, it is disconnected from the pipeline and replaced with a similar station.

Source: http://ckb-rubin.ru/en/projects/other_projects/subsea_nuclear_gas_compressor_station/

Arctic sonar arrays

- Naval analyst H. I. Sutton has postulated that Russia has plans to deploy a sonar network in the Arctic Ocean on deep ocean shelves and ridges, at a depth of about 1,000 meters (3,280 feet).
  - That depth is within the operating capabilities of the several small deep-diving, special operations nuclear submarines operated by the Main Directorate for Deep-Sea Research (GUGI).
  - Russian reactor suppliers are developing several small nuclear power plants designed for seabed siting. Such reactors could serve as long-term power sources for a distributed sonar array.



Source: http://www.hisutton.com/

- Such a sonar system would be roughly analogous to the Sound Surveillance System (SOSUS) deployed by the US in the 1950s in the Atlantic and Pacific Oceans to track Soviet submarines at long distances.
- Such a detection capability would support Russia's recent efforts to militarize their Arctic region with new military facilities along their north coast and orders for new, armed icebreaking (non-nuclear-powered) military vessels.
- If Russia's extended continental shelf claims in the Arctic are upheld, they will have the resources to enforce their expanded Exclusive Economic Zone (EEZ).

Radioisotope thermoelectric generators (RTG)

Russian marine / terrestrial RTGs

- An RTG is an electric generator with no moving parts. It uses an array of thermocouples to convert heat released from radioactive decay into electricity.
- Sr-90 (Strontium 90)-fueled RTGs were the common type deployed by Russia.
  - Beta (β) emission, with minor gamma (γ) emission; requires considerable biological shielding; 28.8 year half-life; power density 0.46 watts per gram.
  - Soviet Union / Russia manufactured 1007 RTGs of various types between 1976 and the early 1990s.
  - Initial Sr-90 loading ranged from 35,000 to 465,000 Curies.
- Russia employed RTGs in many marine and terrestrial applications where they functioned as "super batteries", serving in remote locations as reliable electric power sources with operating lives of 5 to 10 years or more, with no maintenance required.
  - Typically used to power light and radio beacons, primarily along coastal navigation routes.
  - All Russian RTGs have come to the end of their service lives.

External view and cross-section of Russian Beta-M RTG

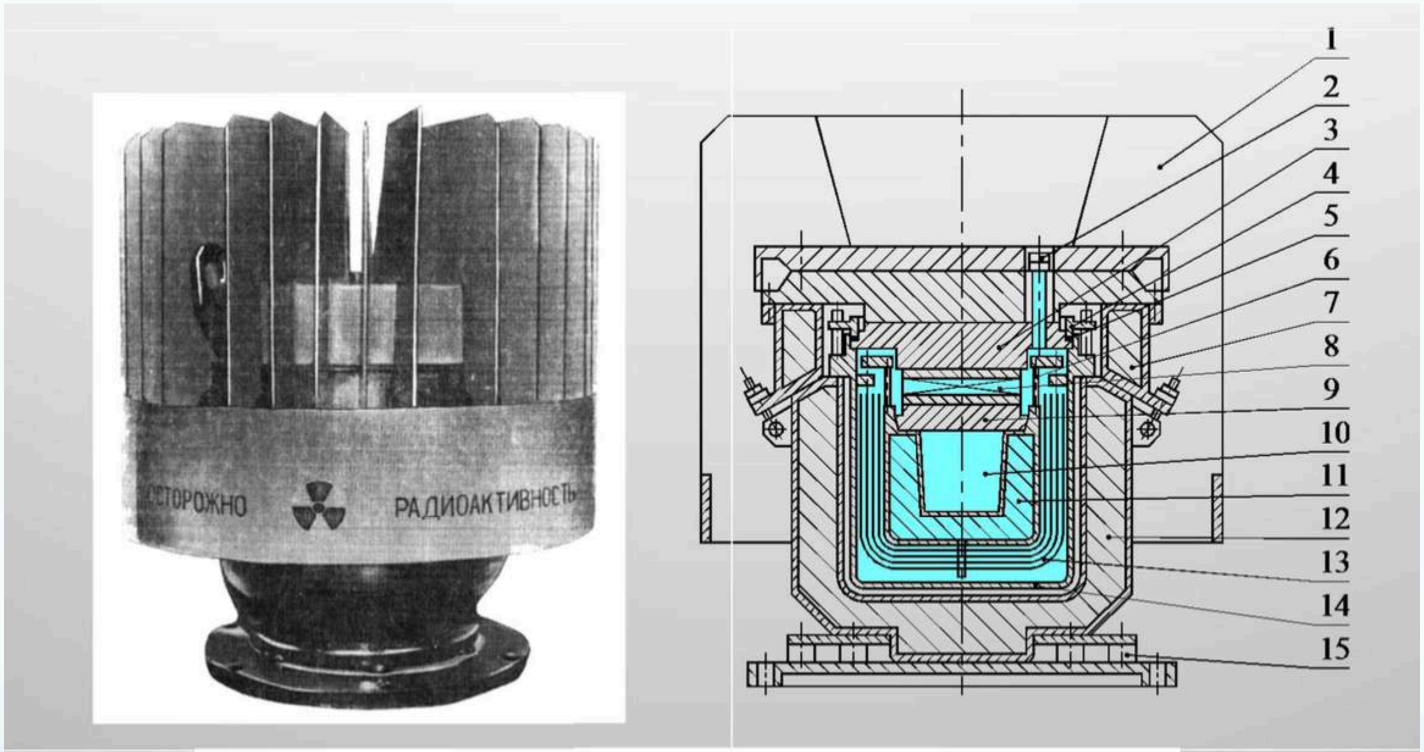


Fig.1. External view and cross-section of a Beta-M RTG:

1—radiator; 2—electrical lead; 3—lid; 4—flange; 5—lining; 6—radiation source support; 7—radiation shielding; 8—thermoelectric unit; 9—lid; 10—heat source; 11—protective unit; 12—radiation shielding; 13—screens; 14—housing; 15—base

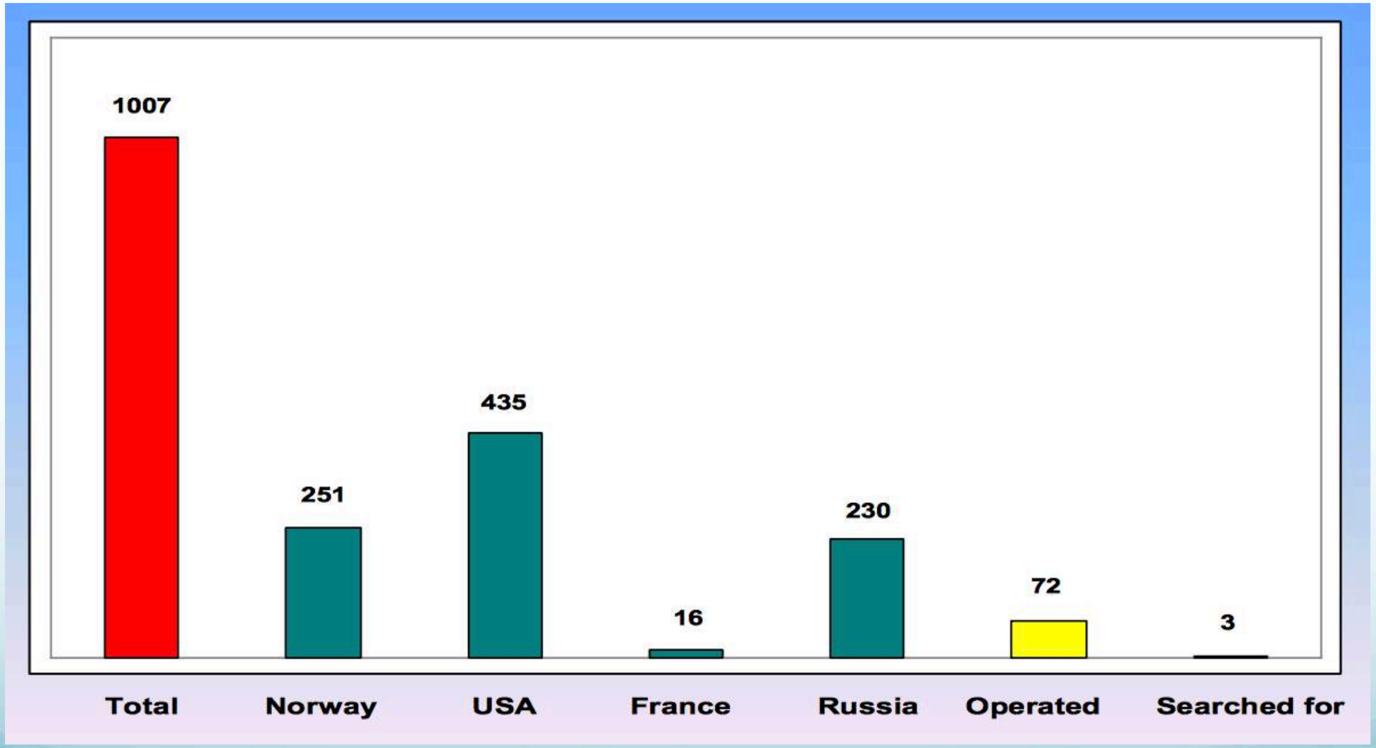
Source: “US-Russian Cooperative Efforts to Decommission Russian RTGs”, Lawrence Livermore National Laboratory

Russian RTG locations

Source: A. Grigoriev & A. Katashev, "*RTG Disposal Program in Russia – Status of RTG Decommissioning Activities*", Kurchatov Institute and NIITFA, 2012

Russian RTG status

- In 2001, Russia and Norway implemented a program for RTG recovery and decommissioning. In 2003, the US and other nations joined the process. Status of RTG recovery in 2012 is summarized in the chart below.
- In 2012, 932 RTGs had been recovered by Russia, US, Norway and France; 72 RTGs were operating (56 along the Northern Sea Route, 4 in Antarctica, and 12 supporting Russian missile forces); and 3 were lost in the Arctic.



Source: A. Grigoriev & A. Katashev, "*Russian RTG Disposal Program Completion Prospects*", Kurchatov Institute and NIITFA, 2012

Russian RTG status

- Plans for further RTG recovery and decommissioning include:
  - The remaining RTGs along the Northern Sea Route were planned for decommissioning in 2013. No RTGs will remain along the Northern Sea Route.
  - The 4 RTGs in Antarctica were planned for decommissioning in 2013 – 2014.
  - The 12 military RTGs in Kamchatka also are planned for decommissioning.
  - RTGs in storage at DalRAO (Russian Far East) and RosRAO (Moscow) will be disassembled.
  - No RTGs will remain in operational service in Russia.

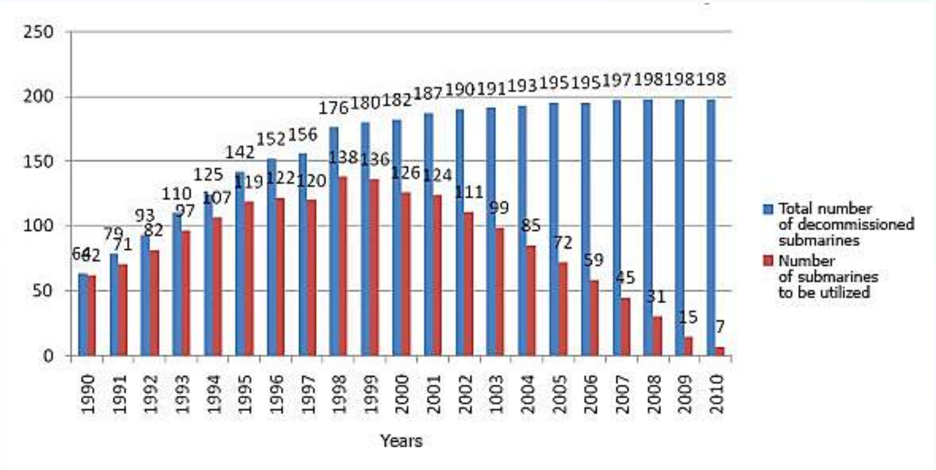
Source: "US-Russian Cooperative Efforts to Decommission Russian RTGs", Lawrence Livermore National Laboratory

Marine nuclear decommissioning and environmental cleanup

Russian decommissioned nuclear submarine status

- In June 2015, Sergei Kiryenko, head of Rosatom, reported that a total of 201 nuclear submarines have been retired, 195 have been dismantled, and 6 are in process.
    - Kiryenko noted that, “when (Rosatom) was put in charge of this function in 1999, 120 submarines were waiting for dismantlement”
- Dismantling takes place at the Nerpa Shipyard, in the Kola Peninsula, Zvezdochka Shipyard in Severodvinsk, Sevmash Shipyard, in Severodvinsk (Alfa-class subs), and Zvezda Shipyard (Bolshoi Kamen) near Vladivostok.
- Spent nuclear fuel is transported by ship and railway to Mayak reprocessing facility near Chelyabinsk, in Siberia, for storage and reprocessing.
- The reactor section of each submarine is cut off and sealed.
- For Northern Fleet, reactor sections are transported for storage at the Regional Centre for Radioactive Waste Conditioning and Long Term Storage at Sayda Bay, near Murmansk.
- For Pacific Fleet, hull sections are placed in “afloat storage” near Chazhma Ship Repair Facility, Vladivostok, awaiting completion of the on-shore storage facility at Cape Ustrichny, near Vladivostok.

Source: Bellona Foundation



Sealed reactor compartments at Sayda Bay Source: NIKIET

Decommissioning Victor III subs

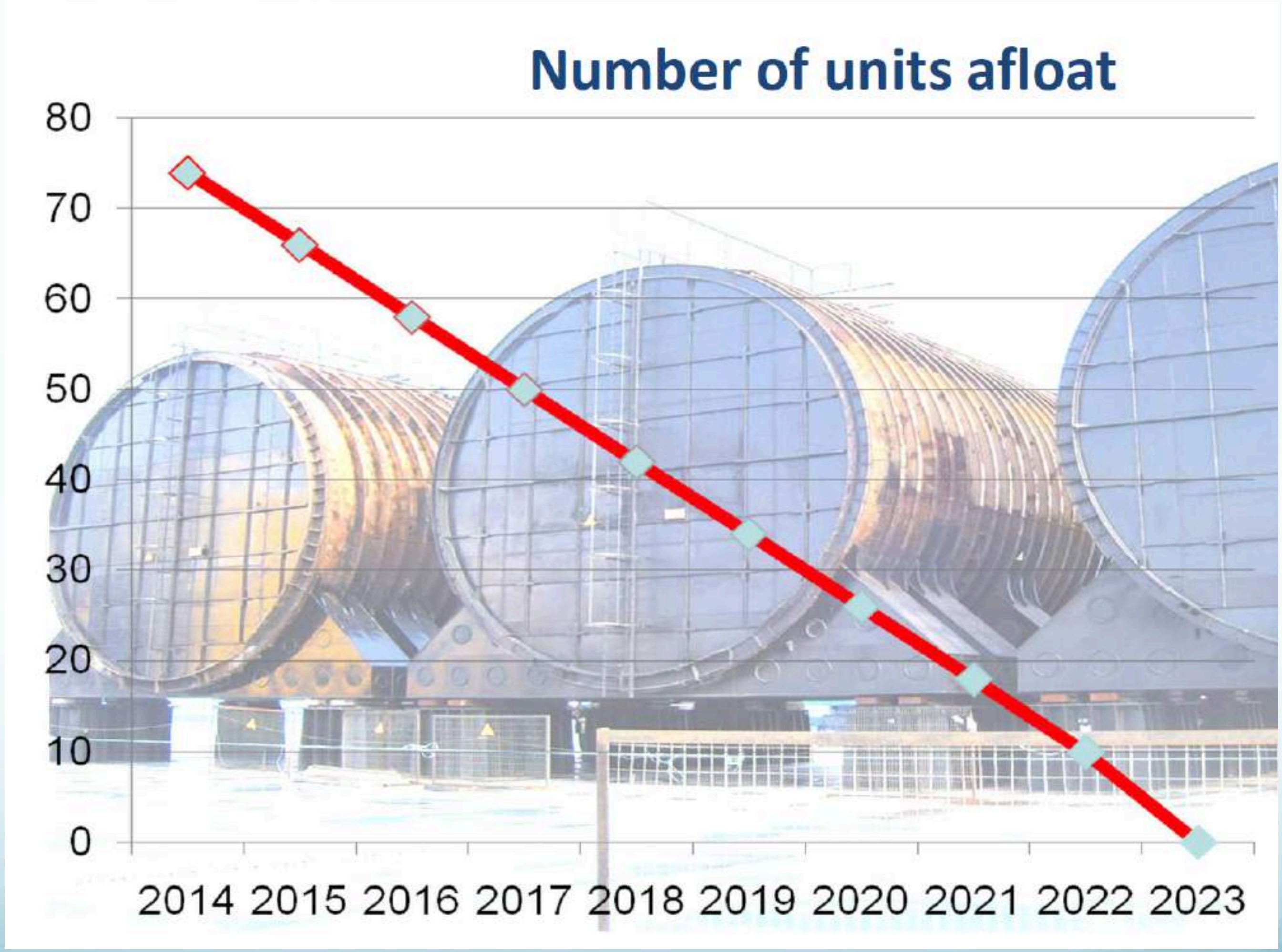
Transshelf semi-submersible open dock vessel delivered two decommissioned Victor III class nuclear submarines to the Zvezda shipyard for scrapping.
Source: Yuri Maltsev / Reuters

Afloat storage of Pacific Fleet submarine reactor compartments

For the Pacific Fleet reactor compartments are removed and sealed along with adjacent compartments that provide the necessary buoyancy for “afloat storage”. These multi-compartment packages are stored afloat in Razboynik Bay, awaiting completion of the Pacific Fleet on-shore storage facility at Cape Ustrichny.

Source: http://bellona.org/

Schedule for Pacific Fleet floating reactor compartment processing



Source: DalRAO: Plans for the Dismantling of Reactor Units of Nuclear Submarines, Nuclear Maintenance Vessels and Nuclear Powered Surface Ships

Isolation building for Pacific Fleet subs not suitable for afloat storage

In 2011-2012 the isolation facility for damaged nuclear submarines was built, and 2 three-compartment units of damaged submarines were placed there.

Source: DalRAO: Plans for the Dismantling of Reactor Units of Nuclear Submarines, Nuclear Maintenance Vessels and Nuclear Powered Surface Ships

Long-term storage facility for nuclear vessel reactor compartments

Cape Ustrichny

- This Pacific Fleet facility will be similar to the Northern Fleet's on-shore storage facility at Sayda Bay, near Murmansk.
- Russian-Japanese cooperation in nuclear vessel disposal is supporting completion of the on-shore facility.
  - May 2012: Japanese equipment for placing nuclear submarine reactor compartments on the long-term shore-based storage pad was handed over to FEC DalRAO.
    - The equipment includes a towboat, two gantry cranes of 10- and 32-ton capacity, and a floating dry dock.
  - Japan also funded a reactor compartment (RC) preparation and coating shop.
- The facility also will provide on-shore storage for the two reactor that will be removed by 2017 from the large naval surface ship SSV-33 *Ural*.

Russian nuclear service ship decommissioning & cleanup status

- In June 2015, Sergei Kiryenko, head Rosatom, said that the 16 remaining decommissioned nuclear service ships that served the Navy and the nuclear icebreaker fleet will be brought into drydock and dismantled by 2020.
  - Nuclear service ships, also called floating technical bases, perform refueling operations for nuclear vessels at sea, and carry away their spent nuclear fuel, contaminated items, and radioactive waste.
  - Some of these service vessels contain large inventories of spent nuclear fuel and/or radioactive waste and represent significant risk.
- Northern Fleet nuclear service ships are being processed at the Nerpa Shipyard, on the Kola Peninsula.
  - The first two ships are: *Volodarsky* (completed in 2014) and *Lepse* (started in mid-2015).
- Pacific Fleet nuclear service ships are being processed by Far Eastern Center "DalRAO" in Shipyard "Zvezda," near Vladivostok.
  - Nuclear service ship TNT-4 started the dismantling process in mid-2015.

Source: http://bellona.org/

Lepse. Source: http://balkanist.net/

Sunken nuclear submarines

Above:
Sunken nuclear submarines in the Atlantic

Right:
Sunken nuclear submarines in the Arctic.

Note that K-141, Oscar II-class *Kursk*, was raised and salvaged.

Map source: Wikipedia

Sunken Russian nuclear submarines

- Kara Sea:
  - Submarine K-27 was intentionally scuttled in the Kara Sea in 1982 at a depth of 33 m (108 ft).
    - Hull integrity judged to be good, but shallow site and inadequately sealed HEU liquid-metal cooled reactor cores make this the highest risk sunken sub site.
- Barents Sea:
  - Two sunken submarines; currently no indication of significant radioactive contamination of the ocean environment.
    - November-class K-159, at a depth of 248 m (814 ft)
      - Hull integrity was poor prior to sinking
    - Mike-class K-278, at a depth of 1,680 meters (5,510 ft)
      - Hull is cracked in several locations.
      - Sub carried two nuclear-armed torpedoes.
      - Site is in a high-marine traffic area.
- Atlantic Ocean:
  - Two sunken Russian submarines in deep water; currently no indication of significant radioactive contamination of the ocean environment:
    - November-class K-8, Bay of Biscay, at a depth of 4,680 m (15,350 ft)
      - Sub carried four nuclear-armed torpedoes
    - Yankee-class K-219, mid-Atlantic, at a depth of 6,000 m (18,000 ft)
      - K-219's full complement of 16 nuclear-armed R-27 (SS-N-6) ballistic missiles was lost along with the vessel. Some missiles were not accounted for in the wreckage.

K-27 Kara Sea disposal site

Source: http://bellona.org/

- The liquid metal coolant in each of the two reactors solidified around the fuel assemblies and control rods, forming a single, solid object that could not be removed from the reactor vessel.
- Before sinking the K-27, the reactors were sealed with a bitumen compound to isolate their 90 kg (198 lb) of highly enriched uranium fuel from seawater.

- 6 Sep 1982: K-27 was scuttled in the Kara Sea.
- Studies by the Kurchatov Institute have shown the bitumen seal is not performing as expected, posing a danger of seawater ingress to the reactor cores.
- Norway's Bellona Foundation has raised the concern of an uncontrolled criticality from water ingress to the reactor.
- 2012: Justin Gwynn, an expert with the Norwegian Radiation Protection Authority (NRPA) said the K-27 is resting upright on the bottom and the hull is in good condition. These factors improve the chance of a successful salvage of the vessel.
- June 2017: Krylov State Institute, St. Petersburg, announced it was working on plans for a floating dock capable of lifting the K-27 and other nuclear waste from the Arctic seafloor. The institute's director, Sergei Malyshev, claimed the K-27 could be lifted by 2022.

Other radioactive contamination from marine nuclear power operations

- Andreyeva Bay (Kola Peninsula, Barents Sea):
  - This is the largest interim storage site for radioactive waste and spent nuclear fuel (SNF) in Europe. The site was constructed in the late 1950s – early 1960s on a former Russian Northern Fleet base located just 100 km (62 miles) from Murmansk and 45 km (28 miles) from the Russian-Norwegian border.
  - Since 1993, the base has ceased taking in SNF and radioactive waste for storage and the base was taken out of service.
  - Responsibility for cleaning up the base was transferred from the Navy to SevRAO.
  - The site holds about third of the radioactive waste found on the Kola Peninsula. The approximate radioactive material inventory was estimated by Nuvia Limited (UK) to be:
    - ~22,000 SNF elements, which is equivalent to 90-100 reactor cores or ~50 submarines worth of SNF.
    - Radionuclide inventory ~4×10^{18} Bq (about the same as in the remains of Chernobyl Unit 4 in its sarcophagus).
  - June 2017: The first batch of 470 SNF elements in shielded casks were transported by ship from Andreeva Bay to Murmansk, and from there they were transported by train to Mayak (near Chelyabinsk) for storage and reprocessing.
  - SNF and radioactive waste removal from, and cleanup of, Andreyeva Bay is expected to continue into the mid-2020s.

Other radioactive contamination from marine nuclear power operations

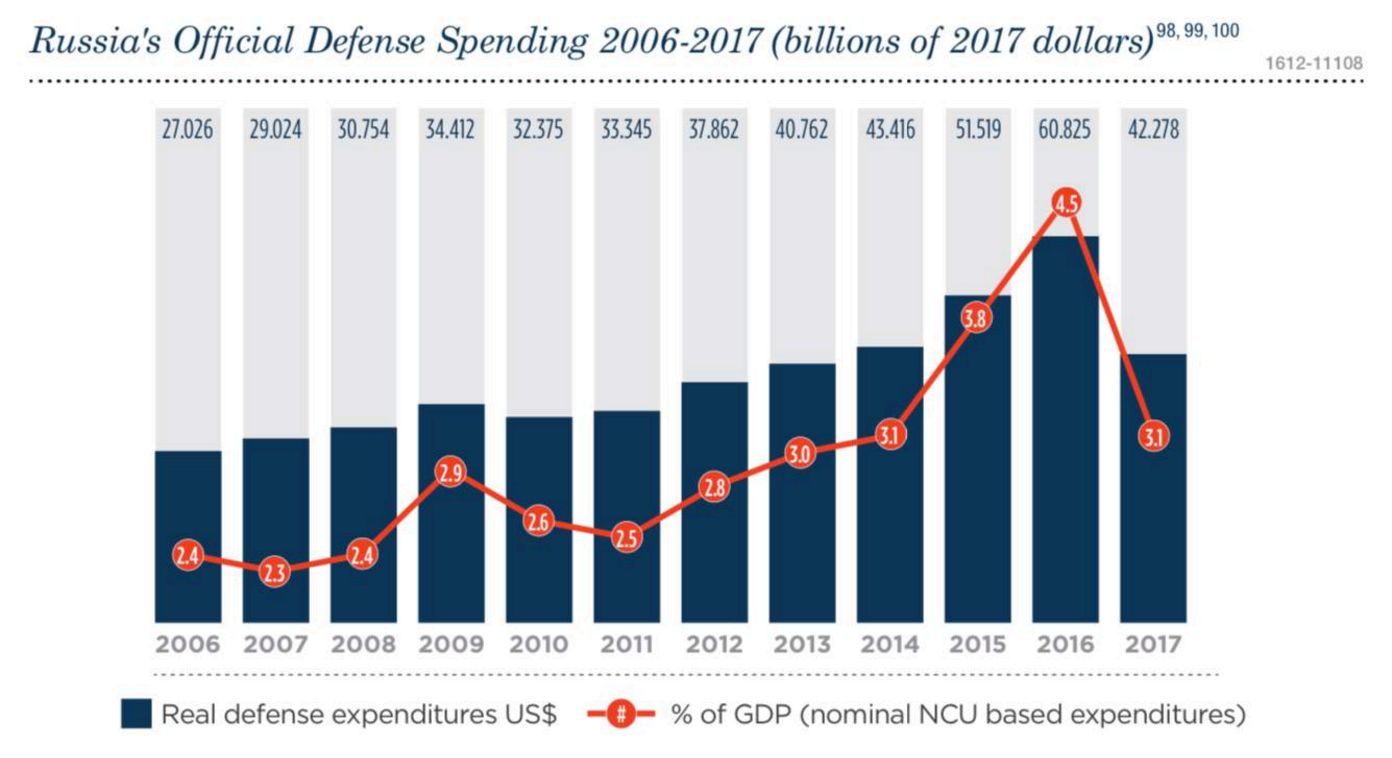
- Kara Sea (Arctic Ocean):
  - According to a report issued in 2012 by the Norwegian Radiation Protection Authority (NRPA), Russian nuclear waste in the Kara Sea includes:
    - 19 ships containing radioactive waste;
    - 14 nuclear reactors, including five that still contain spent nuclear fuel;
    - 735 other pieces of radioactively contaminated heavy machinery;
    - 17,000 containers of radioactive waste
    - Sunken submarine K-27
- Pacific Ocean:
  - Two Russian naval nuclear reactors without fuel were dumped in the Sea of Japan off Vladivostok
  - Various naval marine nuclear system components (i.e., steam generators, pumps) were dumped off Kamchatka

Russian marine nuclear power current trends

- Defense budget
- Operations
- New build
- Refurbishment / modernization
- Phase-out / replacement of aging vessels
- New nuclear vessel development
- New marine reactor development
- New weapons system development / deployment
- Nuclear expansion in the Arctic
- Final disposition of retired nuclear vessels
- Cleanup of radioactive contamination from marine nuclear activities
- On-going monitoring of other sunken Russian nuclear submarine deep water sites
- Nuclear vessel leases to other nations
- Naval nuclear technical support for other nations

Russia current trends

- **Defense budget:**
  - Russian nuclear fleet operations, modernization and new construction will be adversely affected after the Russian Duma adopted an austere federal budget that reduces defense spending from a post-Cold War high of 4.5% GDP (about $60.825 B) in 2016 to 3.1% GDP in 2017 (about $42.278 B). The defense budget is expected to be about 2.8% GDP in 2018, and slightly less as a percent of GDP in 2019 – 2020.



Source: "Russia Military Power – Building a Military to Support Great Power Aspirations – 2017," Defense Intelligence Agency.

Russia current trends

- **Operations:**
  - The Russian Navy will continue to operate a fleet of nuclear-powered SSNs, SSBNs and SSGNs supplemented by a fleet of conventional attack submarines (SS).
    - There has been an increase in worldwide SSN & SSBN patrols after a significant decline in patrol activity in the decades following the dissolution of the USSR in 1991.
  - The Russian Navy also will continue to operate a limited number (1 or 2) of Project 1144.2 Orlan-class nuclear-powered guided missile cruisers.
  - Rosatom will continue to operate a fleet of nuclear-powered icebreakers to support increasing commercial utilization along the Northern Sea Route, with some older icebreakers retiring as newer icebreakers enter the fleet.
    - By 2021, when the last Project 22220 "universal" (deep-water & shallow-water) icebreaker enters service, the nuclear icebreaker fleet is expected to consist of:
      - Three new Project 22220 icebreakers: *Arktika (2019), Sibr (2020)* & *Ural* (2021)
      - Two Project 10580 shallow-water icebreakers*: Taymyr* (1989) *&* *Vaygach* (1990)
      - Two Project 10520 deep-water icebreakers: *50 Let Pobedy* (2007) & *Yamal* (1993)
      - One ice-breaking container vessel: *Sevmorput* (1988)
    - By the mid-2020s, the first of two new classes of nuclear-powered icebreakers will begin entering the Rosatom fleet:
      - Project 10510 (LK-110Ya) heavy, deep-water icebreakers
      - Project 10570 multifunction offshore nuclear-powered icebreakers
  - By 2021, Russia will begin operating its first floating nuclear power plant (FNPP), *Akademik Lomonosov,* in the Arctic far-east city of Pevek.

Russia current trends

- **Operations (cont'd):**
  - The Main Directorate of Deep-Sea Research (GUGI) in the Russian Defense Ministry Russia will continue to expand their unique operational responsibilities, which include:
    - Operating an expanding fleet of small, deep-diving nuclear submarines and much larger nuclear-powered "motherships" that conduct special operations in the Arctic and elsewhere.
    - Developing the very long range, nuclear-powered and nuclear-armed strategic torpedo known as Status-6 (or Kanyon), which in March 2018 was renamed Poseidon.
    - Developing a delivery capability for the Poseidon weapon. Currently, the experimental submarine *Sarov* is serving as a testbed for this weapon. Two submarines, *Belgorod* and *Khabarovsk*, are being built to serve as operational platforms for this weapon by the early 2020s.

Russia current trends

- **New build:**
  - After about two decades of inactivity, there has been a significant increase in nuclear ship new-build activity.
  - Project 885 and 885M Yasen multi-purpose SSNs
    - The first all-new Project 885M Yasen-M boat, *Kazan*, is scheduled for delivery later in 2018.
    - Five more Yasen-M boats are under construction and are expected to be delivered between 2019 – 2023 at a rate of about one per year.
  - Project 995 and 955A Borei II SSBNs
    - Five Project 955A Borei SSBNs subs are under construction. At least one is scheduled for delivery later in 2018, with the remaining boats expected to be delivered between 2018 – 2020.
  - LK-60-class "universal" icebreaker
    - The lead ship, *Arktika,* was launched in 2017.
    - The next two ships are scheduled to be completed in 2019 and 2020.
  - *Akademik Lomonosov* floating nuclear power plant (FNPP)
    - This FNPP was completed in 2018 and moved to Murmansk for reactor core load and testing. It is expected to be ready for deployment to Pevek in 2020.
  - Project 09851, *Khabarovsk*, special operations submarine
    - A 2014 contract between shipyard Sevmash and the Rubin Design Bureau is reported to cover construction of the Project 09851 submarine.
  - Project 2195.6 - Leader-class destroyer
    - Lead ship expected to enter service in the 2023 – 25 timeframe. A nuclear version is expected.

Russia current trends

- **Refurbishment / modernization:**
  - Russia has been overhauling and modernizing all classes of its older operating nuclear vessels, thereby significantly extending their service lives.
  - Some Project 1144.2 Kirov (Orlan)-class guided missile cruisers
    - Only one CGN is in service (*Pyotr Veliky*), one is being modernized for return to service in about 2020 (*Admiral Nakhimov*), and two are in reserve storage and have not yet been funded for modernization (*Admiral Ushakov* & *Admiral Lazarev*).
    - *Admiral Nakhimov* modernization is expected to include conversion to carry SS-N-26 (P-800 Oniks) and SS-N-27 (Kalibr) cruise missiles.
    - *Pyotr Veliki* is expected to enter an extended modernization overhaul after *Admiral Nakhimov* returns to service.
    - The poor physical condition of *Admiral Ushakov* and *Admiral Lazarev* may preclude their modernization. The alternative is scrapping.
  - In 2015, *IHS Jane's Navy International* reported that the Russian Navy was in the process of modernizing and overhauling 12 multi-purpose nuclear-powered submarines (Akula & Sierra SSNs, Oscar-class SSGNs as well as at least one Delta III SSBN). In September 2015, Russian Defense Minister Sergei Shoigu reported that six boats were already undergoing modernization at the Zvezda shipyard at Bolshoy Kamen on Russia's Pacific coast (2 x Akula, 3 x Oscar, 1 x Delta III).
  - Project 945 Sierra-class SSNs
    - Sierra-class subs are being refurbished under Project 945M. The two Sierra I subs are expected to be back in service in 2016. There are plans to also refurbish the two Sierra II subs.
    - Justified by the unique value of their titanium hulls and deep-diving capabilities.

Russia current trends

- **Refurbishment / modernization (cont'd):**
  - Some Project 971 Akula-class and Project 671RTM Victor III-class SSNs
    - Update electronics and sonar systems, add ability to handle SS-N-27 (Kalibr . Club) cruise missiles.
  - Some Project 949A Oscar II-class SSGNs
    - These SSGNs are being overhauled and modernized to carry non-nuclear SS-N-26 (P-800 Oniks) and SS-N-27 (Kalibr / Club) cruise missiles.
  - Project 09852 PLA carrier (former Oscar II SSGN)
    - Modification schedule not known.
- **Phase-out / replacement of aging vessels:**
  - Some Project 671RTM Victor III SSNs, Project 971 Akula SSNs, and Project 649 / 649A Oscar SSGNs
    - To be replaced by the multi-purpose Yasen-M
  - Project 667 Delta III SSBN, and later Delta IV SSBNs
    - To be replaced by Borei / Borei II.
    - New R-29RMU2 Layner SLBM, introduced to the Delta IV fleet in 2014, is expected to ensure the viability of the Delta IV SSBNs until at least 2030
  - Arktika-class and Taymyr-class icebreakers
    - To be replaced by LK-60 icebreakers starting in 2017

Russia current trends

- **New nuclear vessel development:**
  - Project xxxx Husky 5th generation multi-purpose nuclear submarine design and development is in progress
    - The project is in the early design stage. Design details are not available.
    - The lead ship is expected no earlier than the mid 2020s.
  - Project 2195.6 – Leader (Lider)-class destroyer
    - Two versions are expected: one with a gas turbine power plant; one with nuclear power.
    - Construction of the first unit is expected to start in 2019, with completion in about 2025.
  - Rosatomflot announced plans to build two new classes of nuclear-powered icebreakers, with the first units entering service in the mid-2020s.
    - Project 10510 (LK-110Ya) large polar icebreaker with 2 x RITM-400 reactors,
    - Project 10570 multi-function icebreaker to support off-shore activities on the Arctic shelf and in shallow seas.
  - Project 23000E - Shtorm nuclear-powered aircraft carrier
    - In 2015, an aircraft carrier design was displayed by the State Unitary Enterprise Krylov Shipbuilding Research Institute.
    - Two versions are expected: one with a gas turbine power plant; one with nuclear power.
    - Russia currently does not have a shipyard capable of building this type of ship.
    - Construction of a Russian aircraft carrier in the next decade seems unlikely, particularly considering the reduced defense budget expected in the next several years.
  - Next-generation floating nuclear power plant (FNPP) designs are being developed.
    - Rubin Central Design Bureau developed a design for a FNPP with 2 x RITM-200M reactors.
    - Atomenergo and Gidropress developed a design for a FNPP with 2 x SVBR-10 reactors.

Russia current trends

- **New marine reactor development:**
  - The first OKBM Afrikantov RITM-200 reactor will become operational in 2018.
    - First deployment will be in the LK-60-class icebreaker lead ship, *Arktika*.
  - A 4th generation naval reactor was expected to be used in the Project 885M improved Yasen (Yasen-M) and Project 995A improved Borei (Borei A) submarines.
    - With Russia's practice of basing many naval reactors on icebreaker reactors that have operated successfully, it is possible that the new 4th generation naval reactor will be based on the RITM-200.
    - New reactor introduction has been delayed. The lead Project 995A Borei, *Knyaz Vladimir (Prince Vladimir),* was launched in 2017 with an updated variant of the OK-650 PWR.
  - Russian reactor suppliers are developing a large number of diverse, small reactors designed for deployment into remote regions, including the Arctic and underwater. These reactors can deliver 6 – 80 MWe, and most also are capable of delivering process heat end users on shore, on above-water industrial platforms, or on the seabed. Most of the reactors are designed for autonomous operation.
    - OKBM Afrikantov: KLT-40S, RITM-200M, ABV-6E and Aisberg PWRs, and an autonomous HTGR.
    - Nikiet: SHELF PWR
    - OKB Gidropress: SVBR-75/100 and SVBR-10 LMRs
  - World Nuclear Association (WNO) claims that a Russian 5th generation naval reactor will be a supercritical water reactor (SCWR) with a single supercritical water/steam circuit. It is expected to run 30 years without refueling.
    - WNO did not identify the reactor designer
    - WNO claims a full-scale prototype was being tested early in 2013

Russia current trends

- **New weapons system development / deployment:**
  - RSM-56 Bulava SLBM:
    - This is a new class of strategic missile with independently targeted warheads capable of maneuvering during hypersonic flight enroute to the target.
    - First deployed on Borei-class SSBNs in 2014. Will not be used on Delta III and IV SSBNs.
  - Non-nuclear cruise missiles:
    - The Oscar II-class SSGNs and some Kirov-class guided-missile cruisers are being modernized to carry the latest generation of cruise missiles, including:
      - SS-N-26 (P-800 Oniks)
      - SS-N-27 (3M-54 Kalibr / Club)
      - Tsircon hypersonic missile
    - The Klub and Tsircon are designed for use in standardized vertical launch systems and can be deployed on many Russian submarines.
  - Status-6 (Kanyon) nuclear-armed, nuclear-powered strategic torpedo
    - This is a new class of strategic weapon with no Western counterpart.
  - Conventional Prompt Global Strike (CPGS):

Prospects for 2018 - 2030

- **Nuclear expansion in the Arctic**
  - Marine nuclear power is a key element in Russia's plans for developing its Arctic region. No other Arctic nation has similar plans for using marine nuclear power in the Arctic.
  - Russia's aging nuclear-powered polar icebreaker fleet is being modernized with more capable, nuclear-powered vessels that are designed for maintaining year-round, open sea lanes for large vessels using the Northern Sea Route. The net result should be greater international traffic transiting the Northern Sea Route and improved domestic and international service for cities and other sites along the route.
  - Russia's soon-to-be-deployed first floating nuclear power plant (FNPP) will be a proof-of-concept unit for delivering industrial-scale power in remote locations. FNPPs, Transportable Reactor Units (TRUs) and seabed-sited nuclear power complexes being designed and developed now will give Russia diverse means for deploying the electric power, process heat and fresh water infrastructures needed to enable Arctic economic and military development.
    - The small nuclear units can be sized or grouped to meet local demands and, thereby, reduce dependency on fossil fuels in remote, hard-to-supply sites.
    - The smaller nuclear units also enable deployment of a variety of autonomous civilian and military systems that have significant power demands.

Prospects for 2018 - 2030

- **Nuclear expansion in the Arctic (cont'd):**
  - Nuclear submarines will continue to have greater year-round freedom of navigation in the Arctic than any other class of vessel.
    - Russia, the US and the UK will continue to operate SSNs in Arctic waters, and Russia will continue using the Arctic as a patrol zone for some of their SSBNs.
    - Russia's large number of small, deep-diving, nuclear-powered submarines and associated nuclear-powered "motherships" gives them unique capabilities for underwater exploration, seabed infrastructure development and maintenance and other activities.
  - If Russia's 2015 Extended Continental Shelf (ECS) claim is upheld by the Commission on the Limits of the Continental Shelf, Russia will have an established Arctic infrastructure with the the means to enforce an expanded exclusive economic zone (EEZ).
    - No other Arctic nation has comparable means to operate in the Arctic region with nuclear- and conventionally-powered Arctic-capable civilian and military vessels.
    - The general decline of the US and Canadian conventional icebreaker fleets opens great opportunities for Russia to dominate the Arctic region.

Russia current trends

- **Final disposition of retired nuclear vessels:**
  - The existing program managers, SevRAO (Northern Fleet) and DalRAO (Pacific Fleet), will continue managing the disposition of retired naval vessels.
  - Japan continues to support Russian efforts to dismantle decommissioned Pacific Fleet nuclear vessels and nuclear support ships and provide equipment and funding for completion of the future Long-Term Storage Facility for nuclear vessel reactor compartments at Cape Ustrichny, near Vladivostok
  - After completion of the Pacific Fleet's future Long-Term Storage Facility, sealed reactor compartments currently in "afloat storage" will be moved to more secure storage sites on land.
  - Retired icebreaker *Arktika* likely will become a museum ship in St. Petersburg.
  - Russia's first nuclear-powered vessel, submarine K-3 likely will become a museum ship.
- **Cleanup of radioactive contamination from marine nuclear activities:**
  - International pressure is mounting on Russia to deal with the radioactive contamination it created in the Arctic region from oceanic dumping of radioactive waste, reactor cores, and other radioactive items, and from three sunken nuclear submarines:
    - K-27, at a depth of 33 m (108 ft.)
    - November-class K-159, at a depth of 248 m (814 ft.)
    - Mike-class K-278, at a depth of 1,680 meters (5,510 ft.)
  - In addition, Japan continues to demand cleanup of Pacific Fleet radioactive waste and items dumped in the Sea of Japan.

Russia current trends

- **On-going infrequent monitoring of other Russian sunken nuclear submarines in deep-water sites:**
  - November-class K-8, Bay of Biscay, at a depth of 4,680 m (15,350 ft.)
  - Yankee-class K-219, mid-Atlantic, at a depth of 6,000 m (18,000 ft.)
  - Currently there is no indication of significant radioactive contamination of the ocean environment.
- **Nuclear vessel leases to other nations:**
  - Negotiations for an additional Akula-class SSN lease to India were concluded in early 2015, with the expected of the transfer of the former *Iribis* to the Indian Navy in 2018.
  - In July 2015, Russia and India were reported to be in discussions regarding a lease of a current-production Yasen-class multi-purpose SSN.
- **Naval nuclear technical support to other nations:**
  - Likely support to India for continuing development of the reactor and submarine systems for their Arihant-class SSBN.