RITM
Reactor Plants for Nuclear-Powered Icebreakers
and Optimized Floating Power Units
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FROM PAST EXPERIENCE TO FUTURE PROSPECTS

Russia is the only country in the world that has a civilian nuclear maritime fleet. Nuclear-powered icebreakers ensure steady functioning of the Arctic transportation system for Russia to achieve its national objectives in the Arctic region.

In practice, the following tactics is adopted for operation of icebreakers — open-sea icebreakers, like Arktika, provide escort for convoys in deep-water areas. Limited-draft icebreakers, like Taymyr, provide escort for convoys in shallow waters. In this case, the convoys have to be transferred from an open-sea icebreaker to a shallow-draft icebreaker and the other way around, which results in that the convoy and the icebreakers have to spend the time standing, and it has a negative effect upon the economic efficiency of cargo transportation. In addition to that, practically all the currently operating nuclear icebreakers powered by the OK-900A reactor plants are nearing the end of their service life. In order to ensure the timely and adequate replacement for the decommissioned icebreakers, construction of new ships is in progress, so that the national objectives be achieved in terms of reinforcing and protecting the geopolitical interests of the Russian Federation in the Arctic region, and in terms of supporting the economic and business activities and living of population in the Far North regions of Russia.

The first Soviet nuclear-powered icebreaker Lenin was commissioned in 1959. It was the world’s first surface ship with a nuclear propulsion plant unmatched in terms of its power among the nuclear-powered icebreakers worldwide. As the power source, the OK-150 nuclear steam supply system (NSSS) was adopted. It was a reactor plant with a distributed layout, i.e., the main equipment of the circuit was placed in individual pressure vessels connected via long pipelines. Starting from 1964, the development commenced of the OK-900 nuclear steam supply system (NSSS) with a modular layout, i.e., every reactor plant incorporated a pressurized water reactor, four circulation pumps, four steam generators, pressurizers and other equipment. The reactor, the pumps and the steam generators had individual pressure vessels and were connected via short coaxial nozzles. The OK-900 NSSS was installed into the upgraded nuclear-powered icebreaker Lenin. In 1968, the USSR Council of Ministers made a decision to build the nuclear-powered icebreaker Arktika. The OK-900 NSSS was re-designated as OK-900A because of individual differences in its interfaces with the nuclear-powered icebreaker Arktika. In the next phase, civilian marine nuclear steam supply systems with the KLT-40 and KLT-40M single-reactor plants were developed for a nuclear lighter-aboard ship and for two limited-draft icebreakers designed to ensure safe waterways for cargo ships in the mouths of Siberian rivers.

Currently, Russian companies are developing new-generation multipurpose nuclear icebreakers powered by the RITM-200 reactor plant, which has an integral layout of its steam-generating unit (SGU).
NUCLEAR-POWERED ICEBREAKERS OF RUSSIA

- LENIN
  - 134 m
  - 19,240 t
  - 10.5 m

- ARKTIKA
  - 147.9 m
  - 21,000 t
  - 11 m

- SIBIR
  - 147.9 m
  - 21,000 t
  - 11 m

- ROSSIYA
  - 150 m
  - 23,000 t
  - 10 –11 m

- SEVMORPUT
  - 260.3 m
  - 61,000 t
  - 11.8 m

- SOVETSKIY SOYUZ
  - 150 m
  - 23,000 t
  - 10 –11 m

- VAYGACH
  - 151.8 m
  - 21,000 t
  - 8.1 m

- TAYMYR
  - 151.8 m
  - 21,000 t
  - 8.1 m

- YAMAL
  - 150 m
  - 21,000 t
  - 11 m

- 50 LET POBEDY
  - 159.6 m
  - 25,370 t
  - 11 m

9 nuclear-powered icebreakers & 1 lighter-aboard ship
20 reactor plants
JSC “Afrikantov OKBM” has been developing reactor plant designs for nuclear-powered ships since 1954.

Based upon the designs developed by JSC “Afrikantov OKBM”, the total of 20 nuclear reactors have been fabricated and successfully operated on 10 ships. Note that a part of reactor plant equipment was fabricated in the production facilities of JSC “Afrikantov OKBM”.

NSSS FOR THE NUCLEAR ICEBREAKER FLEET

JSC “Afrikantov OKBM” is a chief designer of reactor plants for the nuclear icebreaker fleet.
New-generation multipurpose nuclear-powered icebreaker model

Generations of Marine Reactor Plants

As of now, 3 generations of reactor plants have been developed for the civilian nuclear fleet.

<table>
<thead>
<tr>
<th>Generation 1</th>
<th>Generation 2</th>
<th>Generation 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK-150</td>
<td>OK-900 (OK-900A)</td>
<td>RITM-200</td>
</tr>
<tr>
<td></td>
<td>KLT-40 (KLT-40M)</td>
<td></td>
</tr>
</tbody>
</table>

Distributed layout of the reactor plant
Reactor plant with the modular layout of the steam-generating unit (SGU)
Reactor plant with the integrated layout of the steam generating unit (SGU)

The nuclear-powered ship of the new design will be the largest and the most powerful in the world. Because of the increased beam, the multipurpose nuclear-powered icebreaker will be able alone to provide escort in the Arctic for tankers with the displacement of up to 70,000 tons. The icebreaker will be able to ensure waterways for ships in the ice up to 3 meters thick. The scheduled commissioning date for the prototype nuclear-powered icebreaker is 2020.

By 2021, the Russian fleet is to receive a series of new-generation multipurpose nuclear-powered icebreakers. They are designed to provide unassisted ice escort for ships, including large-capacity vessels, to lead convoys in the Western Arctic region all year around; and in the Eastern Arctic region, during the summer and autumn months. The nuclear-powered ships will be suitable even for shallow waters of the Gulf of Ob and Yenisei in the Dudinka direction. ROSATOM is now constructing new multipurpose nuclear-powered icebreakers.

### Main design characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length at design waterline, m</td>
<td>160</td>
</tr>
<tr>
<td>Beam at design waterline, m</td>
<td>33</td>
</tr>
<tr>
<td>Molded depth, m</td>
<td>15.2</td>
</tr>
<tr>
<td>Icebreaking capability, m</td>
<td>up to 3</td>
</tr>
<tr>
<td>Complement</td>
<td>75</td>
</tr>
<tr>
<td>Draft at design waterline (open-sea icebreaker mode), m</td>
<td>10.5</td>
</tr>
<tr>
<td>Minimum operating draft, m</td>
<td>8.5</td>
</tr>
</tbody>
</table>

The nuclear-powered ship of the new design will be the largest and the most powerful in the world. Because of the increased beam, the multipurpose nuclear-powered icebreaker will be able alone to provide escort in the Arctic for tankers with the displacement of up to 70,000 tons. The icebreaker will be able to ensure waterways for ships in the ice up to 3 meters thick. The scheduled commissioning date for the prototype nuclear-powered icebreaker is 2020.
Design Concept

In the course of the design work on the reactor plant for the new nuclear-powered icebreaker, an integrated approach was implemented to identify the basic parameters of the primary circuit, to select equipment and equipment layout, and to adopt the optimum configuration and parameters for the safety systems.

Fundamental Solutions

1. The nuclear propulsion plant incorporates two reactor plants based upon a 175 MWt integral pressurized water reactors and placed into two individual containments.
2. The steam is generated (248 ton/h in either reactor plant) through transferring the primary circuit heat to the secondary circuit feedwater and steam in a steam generator, i.e. by the traditional two-circuit schematic well-proven in the nuclear power industry.
3. The reduced neutron fluence to the pressure vessel makes it possible to extend the lifetime under irradiation for the steam-generating unit (SGU) and to reduce the hydraulic test temperature.
4. Passive and active safety systems are introduced.
5. Safety of the RTM-200 reactor plant is based upon the following principles:
   - high heat-storage capacity,
   - natural circulation of the primary coolant sufficient for shut-down reactor cooling,
   - minimum length of the primary pipelines,
   - outflow restrictors used in small nozzles,
   - compared to the modular schematic, the primary coolant volume is large in the reactor pressure vessel, which extends the time to core dewatering in primary circuit LOCAs.

Technical Features

- The integrated pressure vessel of the steam-generating unit (SGU) allowed the reactor plant mass and overall dimensions to be reduced within the containment.
- The low-enrichment reactor core comprised of an array of fuel assemblies ensures long-time operation without recharging and satisfies the requirements of the nuclear weapon non-proliferation regime.
- The lifetime and service life of the main equipment are extended.
- Compared to the marine reactor plants of previous generations, more extensive time margins are provided in emergencies for the personnel to take corrective actions.

<table>
<thead>
<tr>
<th>Rated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary circuit operating pressure, MPa</td>
</tr>
<tr>
<td>Primary coolant temperature:</td>
</tr>
<tr>
<td>– core inlet, °C</td>
</tr>
<tr>
<td>– core outlet, °C</td>
</tr>
<tr>
<td>Primary coolant flow rate through the reactor core, t/h</td>
</tr>
<tr>
<td>Steam output, t/h</td>
</tr>
<tr>
<td>Steam parameters:</td>
</tr>
<tr>
<td>– temperature, °C</td>
</tr>
<tr>
<td>– pressure, MPa (abs.)</td>
</tr>
<tr>
<td>Hydrostatic test temperature at the end of service life, °C</td>
</tr>
<tr>
<td>Neutron fluence at the end of service life, n/cm²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main design characteristics per 1 Steam Generating Unit (SGU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGU type</td>
</tr>
<tr>
<td>Thermal power, MW</td>
</tr>
<tr>
<td>Capacity factor (as required in reactor plant specifications)</td>
</tr>
<tr>
<td>Continuous operation period, h</td>
</tr>
<tr>
<td>Initial core stored energy, TW-h</td>
</tr>
<tr>
<td>Fuel enrichment</td>
</tr>
<tr>
<td>Assigned service life:</td>
</tr>
<tr>
<td>– permanent equipment, year</td>
</tr>
<tr>
<td>– replaceable equipment, year</td>
</tr>
<tr>
<td>Assigned lifetime:</td>
</tr>
<tr>
<td>– permanent equipment, thousand hours</td>
</tr>
<tr>
<td>– replaceable equipment, thousand hours</td>
</tr>
</tbody>
</table>

*design prospects
The design employs a reactor core comprised of an array of fuel assemblies incorporating cermet fuel with the uranium content increased vs. the intermetallic fuel. The reactor core satisfies the requirements of the nuclear weapon non-proliferation regime (the enrichment is below 20%).

Steam Generator

The reactor plant employs a high-efficiency straight-tube steam generator (SG). The specific steam output of the steam generator is more than two times higher than that of the currently used coil-tube steam generators. The configuration of the steam generator cassettes makes it possible to arrange the cassettes compactly within the steam generating unit pressure vessel.

Pumps

The primary circuit circulation pump (PCCP) is of a traditional design, vaned, single-stage with a canned electric motor. The motor is single-wound. The pump rotation speed is controlled by changing the power supply current frequency.

Control and Protection System Drive Mechanisms

The group of safety control rod drive mechanisms is designed to scram the reactor and to keep it subcritical in an emergency. The group of compensating group drive mechanisms is designed to compensate for the excess reactivity in the startup mode, in the power operation mode and in the reactor shutdown mode. The control and protection system drive mechanisms in the RITM-200 reactor plant are developed based upon the drives used in the KLT-40S reactor plant.

The distinctive features of the drive mechanisms in the RITM-200 reactor plant are:

- extended lifetime and service life
- increased travel length of the reactivity control members

Steam Generating Unit (SGU)

Underlying the RITM-200 reactor plant design is an integrated type steam generating unit (SGU) utilizing forced circulation. The SGU steam generator casettes are placed inside the pressure vessel, and the primary circuit circulation pumps (PCCP) are in individual external hydrochambers. The SGU has scaled-up initial core stored energy. Compared to modular-type SGUs currently used in nuclear-powered ships with their steam generators placed in separate pressure vessels, the new SGU type features greater compactness. Additionally, in order to minimize the overall dimensions, a more compact steam generator design has been used, a core comprised of an array of fuel assemblies has been introduced, which has a higher uranium content, and the equipment has been arranged more densely in the compartment. The compactness of the steam-generating unit makes it possible to reduce the SGU mass and overall dimensions, which cuts down the scope and duration of installation activities done in the shipyard and enhances the manufacturing quality of the SGU thanks to the fact that all activities are completed at a machine building plant. At the same time, the disposal of the facility is simplified thanks to the possibility of unloading the entire SGU with a minimum scope of dismantling activities to be done.

Main Equipment

| Quantity (Q-ty) | Reactor core | 1 |
| Steam generator | 4 |
| PCCP | 4 |
| Drive mechanisms: | 12 |
| – CGDM | 6 |

Reactor Core

Lifetime, h
Service life, year
Dimensions: OD×H, mm
Initial core stored energy, TW-h/m³
Number of fuel assemblies
^{235}U load, kg
Average fuel enrichment, %
Average ^{235}U consumption, g/MW-day

Steam Generator

Number of SG cassettes
Heated length, mm
Heat exchange surface area, m²

Pumps

Number of SG cassettes
Heated length, mm
Heat exchange surface area, m²

Control and Protection System Drive Mechanisms

The group of safety control rod drive mechanisms is designed to scram the reactor and to keep it subcritical in an emergency. The group of compensating group drive mechanisms is designed to compensate for the excess reactivity in the startup mode, in the power operation mode and in the reactor shutdown mode. The control and protection system drive mechanisms in the RITM-200 reactor plant are developed based upon the drives used in the KLT-40S reactor plant.

The distinctive features of the drive mechanisms in the RITM-200 reactor plant are:

- extended lifetime and service life
- increased travel length of the reactivity control members

General view of SGU
Serial Production of Reactor Plants for the New-Generation Nuclear-Powered Icebreakers

>15 companies in cooperation

10 reactor plants for a series of icebreakers

6RPs have been manufactured and supplied to the object

- Regular manufacturing cycle
- Repetition and periodicity of manufacturing process
- Stable cooperation between enterprises

1 — Assembly of reactor plant tube units and devices
2 — Corrosion resistant surfacing by welding on the shell with nozzles
3 — Forging of a workpiece on the automatic forging machine
4 — Hardening process for the shell workpiece
5 — Machining of slanted holes to install steam nozzles
6 — Pressure vessel ingot cast
7 — Corrosion resistant surfacing by welding on the shell with preheating
8 — Upright positioning and installation of the reactor plant pressure vessel into a special building berth
9 — Moving the finished pressure vessel into the shipping package
10 — Transportation of the reactor plant SGU pressure vessel
11 — Installation of the RITM-200 reactor plant
Competitive Advantages

- Compared to the previous generation, the technical and economic performance and safety have been substantially enhanced; the mass and size characteristics have been considerably reduced, which made it possible to develop a double-draft icebreaker.
- Multiple uses are possible in ships, floating structures and within power sources for various applications.
- There is a potential for the reactor plant upgrading and for creating a power range family of this type of reactor plants with broadening the spheres of reactor plant applications.

RITM-200 reactor plant

<table>
<thead>
<tr>
<th></th>
<th>OK-900A</th>
<th>RITM-200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assigned lifetime of the main equipment, h</td>
<td>100,000 (177,000*)</td>
<td>320,000</td>
</tr>
<tr>
<td>Assigned service life of the main equipment, year</td>
<td>25 (33*)</td>
<td>40</td>
</tr>
<tr>
<td>Mass of 2 reactor plants within the containment, t</td>
<td>2,603</td>
<td>2,200</td>
</tr>
<tr>
<td>Overall dimensions of the reactor plant containment L×W×H, m</td>
<td>7.6×13.3×20</td>
<td>6×13.2×15.5</td>
</tr>
<tr>
<td>Initial core stored energy, TW·h</td>
<td>1.8</td>
<td>4.5 (7**)</td>
</tr>
</tbody>
</table>

*maximum value reached during operation
**maximum design value

Reactor Plant Safety

Radiation and Environmental Safety

The exposure dose for the crew during normal operation and in design-basis accidents is less than 0.01% of the natural radiation background.
The exposure dose to the population in a design-basis accident with severe core damage is below the values that require any protective actions to be taken.
The outside seawater activity associated with reactor plant operation is around 0.1 Bq/L, which is 100 times lower than the regulatory value for the potable water activity.

The radwaste volume is reduced by:
- the use of the core comprised of an array of fuel assemblies — the amount of solid radwaste reduces because no replacement is required for the reactor core pull-out assembly throughout the entire service life of the reactor plant,
- increased refueling intervals — the frequency of radwaste supplies accompanying the refueling is reduced,
- the non-waste technology system — the amount of liquid radwaste reduces by the primary water circulation arranged in closed paths during maintenance operations with the primary circuit system.

Safety Barriers

1 — fuel composition
2 — fuel cladding
3 — primary circuit
4 — reactor plant containment
5 — safety enclosure

Defense-in-depth (5 barriers preventing radwaste propagation)

Engineering Solutions Different from Those in Current Reactor Plants:
- passive emergency pressure release systems and emergency shutdown reactor cooling system (the effectiveness of the systems has been verified by rig testing)
- external systems connected to the top part of the SGU
- the primary coolant circulation path in a single pressure vessel
- collector circuit used for the primary coolant circulation

It is highly significant for ensuring reactor plant safety that passive and self-actuated safety systems and devices are used, which limits adverse effects of failures in external systems, power supply and of human errors. The design employs the passive devices and systems that function using natural processes and do not require any external power supply. They include:
- emergency core cooling system with hydroaccumulators that injects water to the reactor by the pressure produced by the gas blanket; one of the pressurizer groups is used as a hydroaccumulator
- containment with an emergency pressure release system capable of functioning in a passive mode
The promising areas for the development of the Northern Sea Route in Russia include providing year-round navigation of ships from the Barents Sea to the Sea of Okhotsk and operating in shallow-water areas in the Arctic Ocean basin. Achieving the objective of keeping drilling rigs is entrusted to the advanced off-shore nuclear icebreaker having the draft of 8.5 m and powered by the RITM-200B reactor plant. The objective of providing year-round navigation along the Northern Sea Route is entrusted to the nuclear-powered icebreaker Leader that is capable of going through the ice up to 4 m thick and leading large-capacity ships.

JSC “Afrikantov OKBM” has accumulated in the development of marine reactor plants the experience of using integral configurations of the primary circuit equipment; compact once-through steam generator; core comprised of an array of fuel assemblies with extended lifetime and service life; maximum unification with the RITM-200 reactor plant in terms of the refueling complex.

Based upon the RITM-200 reactor plant, the concept of RITM-200M reactor plant design has been developed for an optimized floating power unit (OPU). The OPU is an energy generating facility in the form of a non-self-propelled ship that incorporates two RITM-200M power plants. Such mobile power unit can generate electricity or ensure cogeneration of electricity and heat for household and industrial consumers.

While ensuring independence from the limitations of traditional energy-carrier resources, these power units will be a powerful factor in sustainable development of any region that is not covered by the unified power system and that requires reliable and economically acceptable energy carriers.

The developed reactor plant designs have good prospects for being used both in nuclear-powered icebreakers and in land-based/floating small-sized nuclear power plants.

The experience that JSC “Afrikantov OKBM” has accumulated in the development of the marine reactor plants enables development of reactor plants for floating power units (FPU).
WORLD’S FIRST MULTIPURPOSE NUCLEAR-POWERED ICEBREAKER

- June 16, 2016 — the prototype nuclear-powered icebreaker Arktika launched
- 2022 — the nuclear fleet will receive three multipurpose nuclear-powered icebreakers Arktika, Sibir, Ural. It is planned to construct two more serial icebreakers of this design by 2027.
JSC “Afrikantov OKBM”

IN THE NUCLEAR ENGINEERING INDUSTRY
SINCE 1945