Technology Development and Design Approaches Including Economics of Small and Medium Sized Reactors

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OKBM Reactor Technologies: Experience and Development

Experience is the best of all evidences – F. Bacon

Foundation of proven technologies and development

Great experience in development and operation of marine reactor plants

- Key fields of activities:
  - Standardization of engineering decisions for the entire power range;
  - Increase of reliability, safety, manoeuvrability;
  - Reduction of the scope of maintenance, increase of service operation between repairs.

Great experience in development and operation of nuclear icebreakers reactor plants

- Total number of reactor plants is 20 pcs. (including 7 RPs installed on the acting nuclear icebreakers).
- More than 50 years of 3 generations of nuclear icebreakers operation in the Arctic region.
- Total operating time is more than 400 reactor-years.
- Four innovation RITM-200 RPs have been supplied for two multipurpose nuclear icebreakers.

Experience in development and fabrication of reactor plants for the floating nuclear power plants

- Two RPs have been supplied for the FNPP “Academician Lomonosov” confirming the efficiency of combining the functions of Chief Designer and Complete Supplier of KLT-40S RP.

Proven reactor technologies and innovation solutions are available.
"AKADEMIK LOMONOSOV":
Floating NPP Based on FPU with two KLT-40S

- THE DESIGN OF THE SMALL COGENERATION NUCLEAR POWER PLANT IS PILOT.
- THE FPU IS UNDER TESTS.
- KLT-40S EQUIPMENT SUPPLY WAS COMPLETED IN 2011.
- THE FNPP STARTUP IS EXPECTED IN 2019.
- SUPPLY TO CONSUMERS IS AS FOLLOWS
  - ELECTRIC POWER  20…70 MW
  - HEAT              50…146 Gcal/h

FLOATING POWER UNIT (FPU) with KLT-40S
Floating NPPs are a New Class of Power Sources

- The floating power unit “AKADEMIK LOMONOSOV” comprises two reactor plants, two turbine plants, electric-power system, refueling complex, nuclear fuel and radioactive waste storage, FNPP personnel living areas.

- An autonomous power unit is mounted on the non-self-propelled barge. The number of offshore facilities and requirements for them are minimal.

- The floating power unit will be delivered to the operation site by sea on a turnkey basis after completed acceptance tests.

- After completion of four fuel cycles, it will be transported to a specialized service site for maintenance.

- It is possible to change the floating power unit location site.

- After termination of the service life, the floating power unit is transported to its disposal site, thus leaving the “green field” site.
Optimization Areas to Increase Floating Power Unit (FPU) Competence

- **FPU with KLT-40S RP**
  - Total assigned life time - 40 years
  - Time to factory repair - 12 years
  - Time between core refueling – 2.5 – 3 years
  - Refueling complex and Spent Fuel storage on the FPU

- **Optimization of reactor plants systems**

- **Optimization of personnel living areas at FPU**

- **Elimination of refueling complex and storage of spent fuel and solid radwaste from the FPU**

- **Floating technical support and maintenance base with transportation to FPU location OR**
  - FPU operation without refueling at the location site, then transportation to service site for maintenance.
Offshore option: Advanced FPU with RITM-200M RP

- **Multipurpose icebreaker**
  - Service life – 40 years
  - 1 factory repair
  - Core power margin up to 7 TW·h
  - Reduction of RP R&D duration and cost due to standardization of RP for multipurpose icebreaker and FPU

- **FPU with RP KLT-40S**
  - Service life – 40 years
  - 2 factory repairs
  - Core power margin up to 3 TW·h
  - Refueling complex and Spent fuel storage at the FPU
  - Standardization of the main technical solutions and equipment for RP and FPU

- **Advanced FPU with RITM-200M RP**
  - Service life – 60 years
  - 2 factory repairs
  - Core power margin up to 11.5 TW·h
  - Refueling - once in 10 years during factory repair

- **Design options**
  - Non-self-propelled barge, fixed hydraulic structures
  - Self-propelled vessel, dynamic positioning in the open water area

- Ensuring of operation without refueling at location site till factory repair
Onshore option: Small Nuclear Power Plant with RITM-200 RP – a New Direction of Marine Reactor Technologies Development

**Multipurpose icebreaker**
- Service life – 40 years
- 1 factory repair

**Small NPP based on marine reactor technologies**
- Approved technical solutions
- Reduction of RP R&D duration and cost due to standardization of RP for multipurpose icebreaker and Small NPP

**Competitive advantages**
- Competitive technical and economic indicators
- Minimum foot print area
- Long operation period without refueling (10 years)
- Long service life of main equipment
- High maneuverability

**Small sized NPP**
- Service life – 60 years
- 2 factory repairs
## KLT-40S and RITM-200/200M Comparative Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>KLT-40S</th>
<th>RITM-200</th>
<th>RITM-200M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two RPs electric power (el.), MW</td>
<td>38.5 x 2</td>
<td>50 x 2</td>
<td>50 x 2</td>
</tr>
<tr>
<td>Total assigned service life, h/years</td>
<td>300 000/40</td>
<td>500 000/60</td>
<td>480 000/60</td>
</tr>
<tr>
<td>Assigned life time/service life till factory repair, h/years</td>
<td>100 000/12</td>
<td>170 000/20</td>
<td>160 000/20</td>
</tr>
<tr>
<td>Number of factory repairs</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Weight of two RPs in the containment, t</td>
<td>3743</td>
<td>2200</td>
<td>2600</td>
</tr>
<tr>
<td>Containment dimensions for two RPs LxWxH, m</td>
<td>12x17.2x12</td>
<td>6x13.2x15.5</td>
<td>6.8x14.6x16.0</td>
</tr>
<tr>
<td>Core refueling interval, years</td>
<td>2.5 (3.0)</td>
<td>5.7</td>
<td>10</td>
</tr>
<tr>
<td>RCP power, kW</td>
<td>4 x 152</td>
<td>4 x 97</td>
<td>4 x 97</td>
</tr>
<tr>
<td>Passive heat removal, h</td>
<td>24</td>
<td>∞</td>
<td>∞</td>
</tr>
<tr>
<td>Time until core uncovery in a passive accident scenario with primary leakage, h</td>
<td>10</td>
<td>72</td>
<td>72</td>
</tr>
</tbody>
</table>
Arrangement of KLT-40S, RITM-200 and RITM-200M RP in the Containment

**KLT-40S**
- RP weight in the containment: 1870 t
- RP dimensions in the containment: 12 x 7.9 x 12 m

**RITM-200**
- RP weight in the containment: 1100 t
- RP dimensions in the containment: 6 x 6 x 15.5 m

**RITM-200M**
- RP weight in the containment: 1300 t
- RP dimensions in the containment: 6.8 x 6.7 x 16.0 m
1. The RP has integral design with forced circulation of the primary coolant and external gas pressure compensation system.

2. Composition of the RP systems is designed basing on
   • previous plant generation developing experience,
   • current regulatory requirements,
   • reduction of weight-dimensional characteristics and reduction of liquid radwaste amount.

3. The main design approach is a rational combination of passive and active safety systems and optimal use of the normal operational systems and safety systems.
   • Passive pressure reduction system and cooling down system are introduced (efficiency of the systems is confirmed by bench testing);
   • Pressure compensation system is divided in two independent groups to minimize diameter of potential coolant leak;
   • Main circulation path of the primary circuit is located in a single vessel;
   • Optimized scheme of primary coolant circulation is introduced, which ensures advanced vitality of the plant during MCP failures.
The safety concept of the reactor plants is based on state-of-the-art defense-in-depth principles combined with developed properties of reactor plant self-protection and wide use of passive systems.

Properties of intrinsic self-protection are intended for:

- power self-limitation and for
- reactor self-shutdown,
- limitation of primary coolant pressure and temperature,
- limitation of heating rate,
- primary circuit depressurization scope and outflow rate,
- fuel damage scope,

thus, maintaining reactor vessel integrity in severe accidents and ensuring the “passive reactor” concept, which is resistant to all possible disturbances.

The RP designs were developed in conformity with Russian laws, norms and standards for marine nuclear power plants and fully meet all safety principles reflected in IAEA guidelines.
KLT-40S, RITM-200/200M SAFETY BARRIERS

1 – FUEL COMPOSITION
2 – FUEL ELEMENT CLADDING
3 – PRIMARY CIRCUIT
4 – RP CONTAINMENT
5 – PROTECTIVE ENCLOSURE
RITM-200/200M Decay Heat Removal System (DHRS)

Application of combined systems with heat transfer to water and air with no time limitations

Pneumatically driven valves of DHRS passive trains are opened by hydraulically operated distributors ensuring the core cooldown
Pumps and valves are connected to emergency diesel generators.

At least one of two pressurizers performs the function of a hydraulic accumulator.

The water of the hydraulic accumulators is used for the hydraulic tests that allows to reduce liquid radioactive waste amount.
KLT-40S, RITM-200/200M System of Emergency Pressure Decrease in Containment

System of Emergency Pressure Decrease in Containment is based on the passive operating principle and:
- interconnects areas in the containment
- condensates the steam on heat exchangers in the containment and ensures pressure decrease due to barbotage
Retention of the molten corium in the reactor vessel

Results of the severe accident analysis:

- Absence of submelting of the RPV wall
- Reliable heat removal from the reactor bottom outer surface is ensured
- Reactor mechanical properties are maintained at the level sufficient to ensure load bearing capacity despite temperature difference
- Radiation dose for population in case of beyond design accident with severe core damage does not exceed 5 mSv
Resistance to External Impacts for Offshore Options (KLT-40S, RITM-200M)

The RP is substantiated to be resistant to external impacts:

- Rolls and tilts in accordance with the requirements of the Russian Maritime Registry of Shipping;
- Impact resistance of not less than 3 g;
- Reactor shutdown and containment preservation in case of flood, including in case of turnover;
- Crash of an aircraft.

The performed comprehensive analysis of the FPU resistance in case of natural impacts has demonstrated that there are no radiation consequences:

- In case of a seismic impact of up to 10-12 degrees with vertical acceleration not exceeding 1.8 m/s^2;
- Within 24 hours for sure after full FPU blackout;
- In case of a tsunami due to appropriate location site selection and the use of purpose-built hydraulic structures.
Radiation and Environmental Safety

- POPULATION RADIATION DOSE RATE UNDER NORMAL OPERATION CONDITIONS AND DESIGN - BASIS ACCIDENTS DOES NOT EXCEED 0.01% OF NATURAL RADIATION BACKGROUND
- POPULATION IS ALLOWED TO LIVE IN THE EMERGENCY PLANNING ZONE (NO COMPULSORY EVACUATION)
Conclusion

- JSC “Afrikantov OKBM” – a ROSATOM subsidiary, RPs chief designer – has developed and is implementing innovative reactor plant designs of different capacity and siting options: onshore and offshore.

- AKADEMIK LOMONOSOV FNPP (2 x KLT-40S) startup is expected in 2019.

- RITM-200/200M provide effective technical and economic parameters, and referenced technical solutions with confirmed safety features ensured by many years of successful experience.