Status Report - ABV-6E (Russian Federation)

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1. Overview

- ☐ **In Operation**
- ☐ **Under Construction**
- ☐ **Described in**

Link to PRIS	--

- ☑ **New Concept**

Number of Units	--
Year	--

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	6
Gross Power Output (MWe)	--

1.1 Introduction

The ABV-6E is reactor plant (RP) as a part of nuclear power system (NPS) that produces 14 MW(t) and 6 MW(e) in cogeneration mode or 9 MW(e) in condensation mode. ABV-6E integral PWR adopts natural circulation of the primary coolant. The ABV-6E design was developed using the operating experience of PWR reactors and recent achievements in the field of nuclear power plant (NPP) safety. The main objective of the project is to develop small, shipyard fabricated, multipurpose transportable NPP for safe operation over 10 to 12 years without refuelling at the berthing platform or on the coast. Plant maintenance and repair, refuelling and nuclear waste removal will be carried out at dedicated facilities.

The ABV-6E RP is intended as a multi-purpose RP. The RP is designed with the capability of powering a floating power unit (FPU) as a part of floating nuclear power plant (FNPP) with a maximum length of 91.6 m, a beam of 26 m, a draft of 3.6 m and a displacement of 8100 t. Depending on the needs of the region, the FNPP can generate electric power or provide heat and power cogeneration or can be used for other applications. Besides, a land-based configuration of the plant is also applicable.

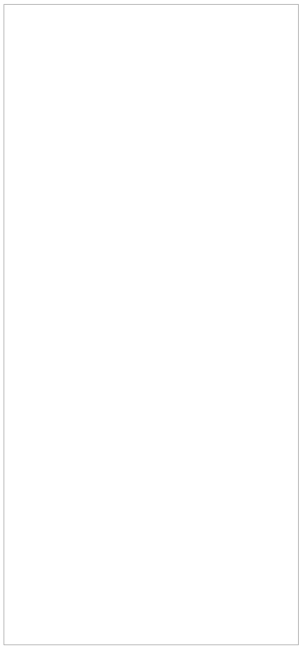


Figure 1. ABV-6E design concept

1.2 Development Milestones

2006	Feasibility study developed for construction of the floating NPP with ABV-6M for the Far North (settlement Tiksi, settlement Ust-Kamchatsk)
2007	Feasibility study developed for construction of the floating NPP with ABV-6M for Kazakhstan (City of Kurchatov)
2014	Final design is being developed for a transportable reactor plant ABV-6E under the contract with Minpromtorg (Russian Federation Ministry of Industry and Trade)

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

The ABV-6E is a pressurized water reactor (PWR); its design incorporates the following main features:

- Integral primary circuit layout with natural circulation of the primary coolant;
- Negative feedbacks and enhanced thermal inertia;
- Passive and self-actuated safety systems;
- Increased resistance to extreme external events and personnel errors;
- Use of nuclear fuel with the enrichment of less than 20%.

Figure 2. FPU and the reactor

FPU includes reactor, steam-turbine, part of electric power system and control systems. The RPV operates under conditions of 16.2 MPa in the reactor pressure vessel. The steam generators located inside the RPV generate 295°C steam at 3.83 MPa flowing at 55 t/h. The RPV head is located under biological shielding and the control rod drive mechanism is located above the shield outside the vessel.

1.6 Licensing Application Support Documents

1.7 Reactor Unit in PRIS

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose	Commercial – Electric/Non-Electric	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Baseload, Non-electric (heat and cogeneration)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Floating-Fixed	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)		e.g. Single Unit, Dual Unit, Multiple Unit (# units)

Core Coolant	H2O	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Reactor Core Size (1 core)	30 MWth <= Thermal power < 1000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	PWR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	H2O	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Integral	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Natural	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Rankine	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H2O	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Hexagonal	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle		e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Detailed Design	e.g. Conceptual, Detailed, Final (with secure suppliers)
Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)

Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	40	Years
Lifetime Capacity Factor		%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages		# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources		# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design		n Units/Modules
Capacity to Electric Grid	6	MWe (net to grid)
Non-electric Capacity		e.g. MW(th) heat at x °C, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	20000 (basic design)	m2 (rectangular building envelope)
Site Footprint		m2 (fenced area)
Emergency Planning Zone		km (radius)
Releases during Normal Operation		TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed		x – 100%, % per minute
Seismic Design (SSE)	7 per Richter scale (basic design)	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	16.2	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)		MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet

Primary Coolant Inventory (incl. pressurizer)		kg
Nominal Coolant Flow Rate (primary)		kg/s
Nominal Coolant Flow Rate (secondary)		kg/s
Core Inlet Coolant Temperature	250	ºC
Core Outlet Coolant Temperature	325	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	Reactor vessel	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	6000	mm
- NSSS Largest Component Diameter	2400	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight		tonne
Reactor Vessel Material		e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design		e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory		kg
Pressurizer Design		e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume		m3 / m3 (total / liquid)
Containment Type		Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume		m3
Spent Fuel Pool Capacity and Total Volume		Years of full-power operation / m3
Non Electric Application	heat and cogeneration	-
Core Delta Temperature	75	ºC

Fuel/Core		
Single Core Thermal Power	38	MW(th)
Refuelling Cycle	120-144	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	<20	%
Average Neutron Energy		eV
Fuel Cladding Material		e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”		Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit		kg
Total Fissile Loading (initial)		kg fissile material (specify isotopic and chemical composition)
% of fuel outside core during normal operation		Applicable to online refuelling and molten salt reactors
Fraction of fresh-fuel fissile material used up at discharge		%
Core Discharge Burnup	N/A	MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)		MWd/kgHM
Breeding/Conversion Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing		e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Control rods	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber		e.g. Gd2O3
Core Volume (active)		m3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary		n/(cm²*s)
Max. Fast Neutron Flux		n/(cm²*s)
Core Control Rod Absorber		-

Core Soluble Neutron Absorber		-
Safety Systems		
Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	Active/Passive	- / - / -
- core injection	Active/Passive	- / - / -
- decay heat removal	Passive	- /- / -
- containment isolation and cooling	Active/Passive	- / - / -
- emergency AC supply (e.g. diesels)	Active/Passive	- / - / -
DC Power Capacity (e.g. batteries)		Hours
Events in which Immediate Operator Action is required		e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time		Hours (that are assumed when following EOPs)
Severe Accident Core Provisions		e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)		x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions		e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)		x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (nth of a kind)		Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort		Person-years (PY) [DP&P]
Construction and Commissioning Effort		PY [C&C]
Material and Equipment Overnight Capital Cost		Million US$(2015) [M&E], if built in USA
Cost Breakdown	%[C&C]/%[M&E]	

- Site Development before first concrete		(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- Nuclear Island (NSSS)		
- Conventional Island (Turbine and Cooling)		
- Balance of Plant (BOP)		
- Commissioning and First Fuel Loading		
Factory / On-Site split in [C&C] effort		%/% of total [C&C] effort in PY (e.g., 60/40)
Nuclear System		
System Steam Flow Rate		kg/s
System Steam Pressure		MPa
System Steam Temperature		ºC
System Feedwater Flow Rate		kg/s
System Feedwater Temperature		ºC
Reactor Core		
Active Core Height		m
Equivalent Core Diameter		m
Average Linear Heat Rate		kW/m
Average Fuel Power Density		kW/kgU
Average Core Power Density		MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

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Plant Layout

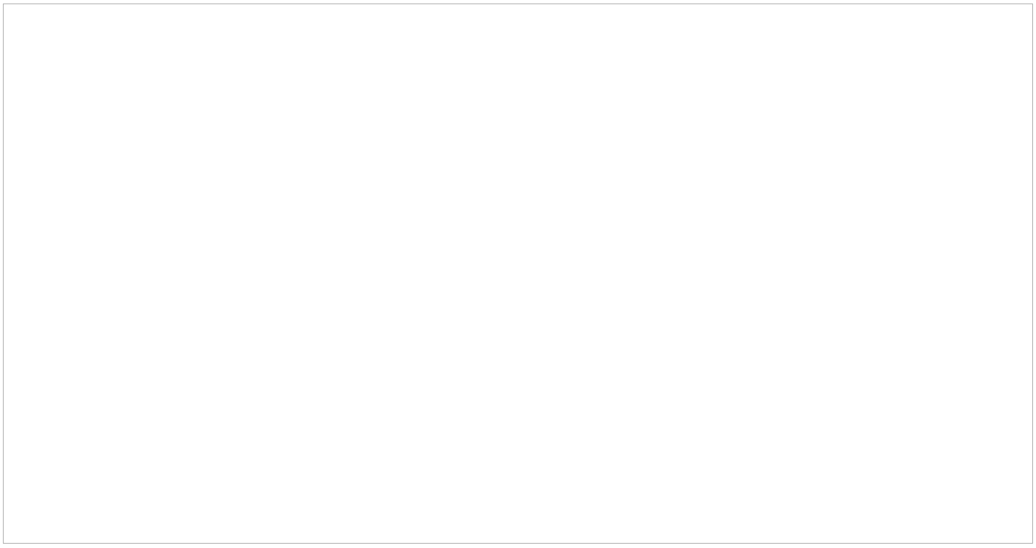


Figure 3. Plant layout

4.1 Site Requirements during Construction
4.2 Site Considerations during Operation
4.3 Grid Integration

5. Technical NSSS/Power Conversion System Designn

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Reactor Core

The core comprises 121 hexagonal fuel assemblies (FA) of cassette type with active part height of 900 mm, similar to the FAs in KLT-40S. Cermet fuel is used with less than 20% enriched 235U. Special stainless steel is used as fuel cladding.

Reactivity Control

Reactivity control without boron solution in the primary coolant and compensation of reactivity changes in power operation is achieved by mechanical control and protection system (CPS). These inherent safety features ensure automatic power regulation in a steady state operation, self-limiting power rise in case of positive reactivity insertions, automatic control of the reactor power and primary coolant pressure and temperature in transients, as well as the emergency shutdown of the reactor core including the cases with a blackout and RPV flip-over (with account of the time that the vessel flip-over process takes).

Reactor Pressure Vessel and Internals

The RPV is a welded cylindrical ‘container’ with an elliptical bottom. At the top of the vessel there are pipes for feedwater supply and superheated steam removal, as well as those for the connection of the primary circuit systems and the auxiliary process systems. The RPV head consists of a load-bearing slab, a shell attached to this slab and sealed by a weld, and a top slab welded to the shell. The cavity

between the top slab and the load-bearing slab is filled with serpentine which acts as a biological shielding, and the heat insulation is located at the top. The posts of the CPS drives and thermal converters, etc. are welded to the load-bearing slab and penetrate through the cover. Points of penetration through the top slab are sealed. Fuel assemblies are located in the in-vessel shaft. The protective tubes and devices provide the necessary coolant flow rate distribution between the fuel assemblies and an arrangement of connectors for joining the absorber elements of fuel assemblies into CPS control rods and connecting the CPS control rods to CPS drives.

Reactor Coolant System

Core heat removal is based on conventional two-circuit methodology. The core is cooled and moderated by water through natural circulation of coolant in the primary circuit. Hot coolant is cooled in a once-through steam generator, where slightly superheated steam is generated, then supplied to the turbine. This design eliminates large-diameter pipelines in the primary circuit and main circulating pumps. The steam generator (SG), arranged in the annular space between the vessel and the in-vessel shaft, is a once-through vertical surface-type heat exchanger generating steam of the required parameters from heat of the primary circuit coolant. The SG is divided into four independent sections; feedwater supply and steam removal from each section is carried out through the pipes in the reactor vessel. Counter flow circulation is used, i.e., the primary circuit coolant moves downward in the inter-tube space, while the secondary circuit coolant is moved upward in the tubes. In case of inter-circuit leaks, it is possible to cut off any section automatically or remotely. Identification of the leaking section is carried out with the use of the detection blocks of the radiation and process control system. Finding and disabling a faulty module is carried out during reactor shutdown.

5.1 Primary Circuit
5.2 Reactor Core and Fuel
5.3 Fuel Handling
5.4 Reactor Protection
5.5 Secondary Side
5.6 Containment/Confinement
5.7 Electrical, I&C and Human Interface
5.8 Unique Technical Design Features (if any)

6. Technology Readiness

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Design and Licensing Status

The final design of ABV-6E has been accomplished. The design has not been licensed yet.

6.1 Deployed Reactors
6.2 Reactors under Licensing Review

7. Safety Concepts

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Engineered Safety System Approach and Configuration

Safety of the ABV-6E RP is of utmost importance considering its close proximity to public area and at the same time far-off location from main technical bases, which could provide timely technical support. In view of its small power the emergency systems are simpler and often do not require active systems performance. Land-based and floating power units use the advanced active and passive safety systems for emergency cooling over an unlimited time during design-basis and beyond design-basis accidents. Low thermal capacity of reactor allows use of natural circulation in the primary coolant circuit and passive safety systems as primary safety systems. The autoprotective features of the NPP have been improved for deployment in far flung territories.

The safety systems include:

- Passive heat removal system;
- Passive core cooling system;
- Reactor caisson water flooding system;
- Backup liquid absorber injection system

Decay Heat Removal System

In emergency modes, a combined-type residual heat removal system (RHRS) is used to remove decay heat. This system functions on natural physical processes and - because there is an air heat exchanger cooled by the atmospheric air - ensures that the decay heat is being removed from the reactor for an unlimited time in all types of accidents. Because of this, and considering the measures taken to enhance the reliability of the passive RHRS, there are no active RHRS channels in the ABV 6E reactor design, which allows the output of emergency power supply sources to be reduced. The passive RHRS is made of two independent channels connected to two SGs each. Either channel, independently of the operability of the other channel, is capable of performing the RHRS functions, i.e. of maintaining the parameters of the primary circuit in the design limits for an unlimited time.

Emergency Core Cooling System

The emergency core cooling system (ECCS) is designed to compensate for the primary coolant leak and to cool the reactor core in case of LOCA. The ECCS comprises of the high-head pumps that inject water into the RPV if power supply is available, and the hydro-accumulators that supply water under the action of the compressed gas.

Containment System

The metal-and-water shielding (MWS) tank is a substantial structure for the equipment of the RP. RPV, two pressurizers and the cooler of the purification and heat removal system are enclosed inside the dry caissons of the MWS tank. The passive reactor caisson water flooding system is designed to protect the RPV against melt-down in severe beyond-design-basis accidents associated with core damage. The system feeds the primary coolant condensate to the RPV caisson. It is also possible to supply water from the fresh water intake and pumping system. The structure of the reactor caisson ensures the stable heat exchange between the RPV and MWS tank.

Plant Safety and Operational Performances

The NPP with ABV-6E generates electricity and heat in the power range of 20–100%Nnom with the continuous operation time of 26 000 hours. The NPP is designed for the manoeuvring rate of up to 0.1%/s. As a protection against the external events, the NPP is equipped with both ground and waterside security structures. The structures are designed for the sites in the Arctic zone with the frost penetration as deep as 2 m. The FPU and NPP design is intended to withstand the 10-ton aircraft crash. As the analysis of emergencies has shown, the radiation and ecological impact to the personnel, public and the environment during normal operation, abnormal operation, including the design-basis accidents, does not lead either to the excess of the radiation doses established for the personnel and public, or release of any of radioactive content in the environment. This impact is also limited in beyond-design-basis accidents.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

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8.1 Fuel Cycle Options
8.2 Resource Use Optimization
8.3 Unique Fuel/Fuel Cycle Design Features

9. Safeguard & Physical Security

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9.1 Safeguards
9.2 Security
9.3 Unique Safeguards and/or Security Features

10. Project Delivery & Economics

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10.1 Project Preparation and Negotiation
10.2 Construction and Commissioning
10.3 Operation and Maintenance