Floating Power Sources Based on Nuclear Reactor Plants

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I. INTRODUCTION

North regions and distant areas assimilated to them cover more than 50% of territory of Russia, where ~ 20 mln. people live. These regions are characteristic of remoteness from year-round water traffic arteries and railways. The richest mineral resources are found and developed there. 2/3 of the country natural – resources potential is concentrated in the North of Russia, the potential implementation requires considerable generating capacities. Integrated power system of Russia covers only about 15% of the country territory, therefore, northern regions of Russia are located in decentralized power supply area, where small-power sources operating at imported fossil fuel, mainly, prevail.

Creation of local nuclear power sources of rather small power is essential for these regions and is a component of general nuclear engineering development strategy in Russia.

This nuclear engineering direction can satisfy various heat and electricity consumers.

Concept of creating nuclear power plant with floating power source – FPM, delivered to operation location, built under factory conditions, tested and commissioned "ready-to-operate" to industrially developed area, at minimum scope of construction and mounting activities at the site, is very interesting from both technical and economic viewpoints [1].

Inconsiderable construction scope under North conditions, its territory vulnerability to anthropogenic loads, high ecological indices and possibility to relocate to the other site, if needed, are important advantages of NCGPP (nuclear co-generation power plant) based on FPM as compared to other power sources of comparable power [2].

Using this procedure, in accordance with Federal target program "Power efficient economy" for 2002–2005 for prospect till 2010, design of small-power nuclear plant (SPNP) based on floating power module (FPM) with KLT-40C reactor plants is developed.

Russia is a single country in the world, which posses power nuclear icebreaker fleet, which solves essential social and economic problems of its north regions, providing year-round functioning of main traffic artery of the country – Northern Sea Route [3].

Common nuclear transport and power complex, which consists of nuclear ships and nuclear co-generation power plants based on FPM with single-type RP, integrated by single maintenance infrastructure, will allow efficiently solving many problems of the Russian North and its assimilated area development at minimum expenditure [4].

It is planned to locate lead NPP at FSUE "PO "Sevmash" territory in Severodvinsk, Arkhangelsk region.

Design (feasibility study) of lead NCGPP is approved in the established procedure. Gosatomnadzor licenses for locating and constructing NCGPP with KLT-40C RP in Severodvinsk are obtained.

The second NPP can be located at ZATO territory in Vilyuchinsk, Kamchatka region. "Declaration of Intent" is approved by ZATO and region management in the established procedure.

Potential locations of similar NPP in Pevek, Dudinka, Onega, Nikolaevsk-na-Amure, Sovetskaya Gavan, Nakhodka, Rudnaya Pristan, Olga, Turukhanskaya GES construction area are determined.

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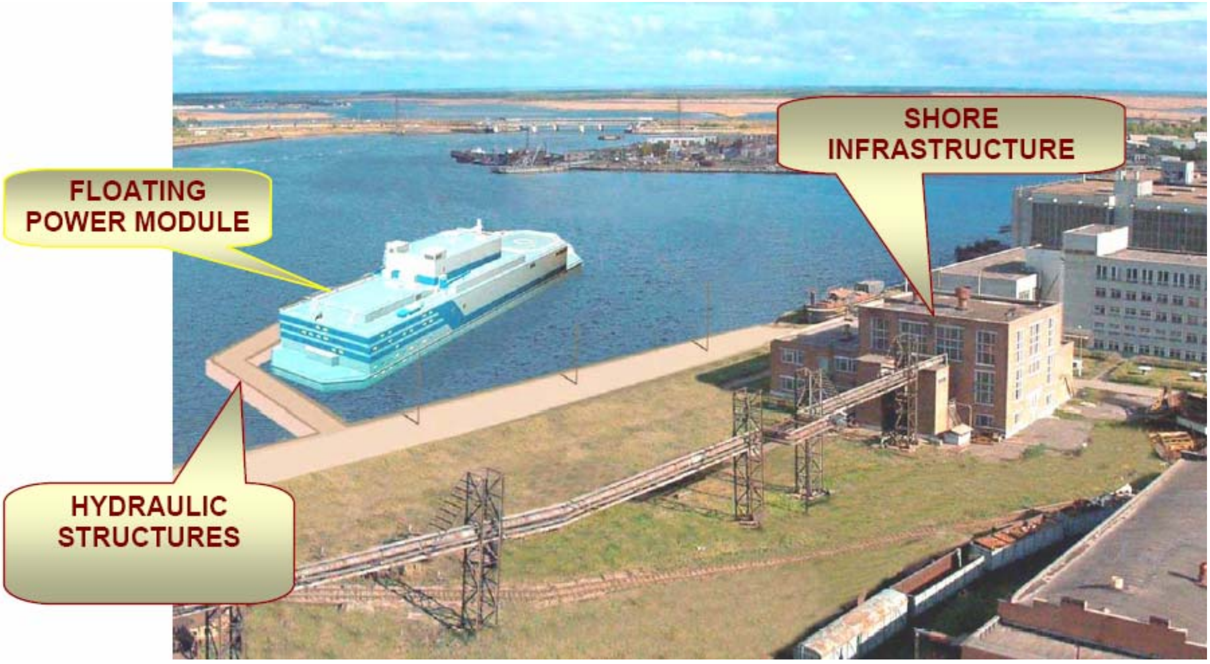

Fig. 1. General view of NPP.

II. CHARACTERISTICS OF NPP

General view of NCGPP based on FPM is given in Fig.1.

FPM is a determining NCGPP component, because it generates electric power and heat and generates them via shore infrastructure to consumers.

TABLE I

MAIN CHARACTERISTICS OF SP NCGPP BASED ON FPM WITH KLT-40C RP

Characteristic	Value
Installed power	
Electric power (at generator terminals), MW	2×35
Thermal power generated for heat supply system, GKal/h	2×25
Maximum electric power (at generator terminals), MW	2×38.5
Maximum thermal power (with actuated high-pressure heater and peaking heaters), GKal/h	2×73
House load electric power consumption, MW	4-6
House load thermal power consumption, MW (therm.)	~ 3.2
Square of shore territory, hectare	1.5
Square of water area, hectare	6.0
Number of attending personnel (watch), persons	58
Construction duration, years	4-5

Hydraulic structures are intended for safe FPM installation and dismantling.

Shore infrastructure consists of constructions and special devices intended for receipt and transfer of electric power and heat to consumers.

Main characteristics of SP NCGPP based on FPM with KLT-40C RP are presented in Table I.

Floating Power Module is a flush deck dumb vessel of rack-mountable type with rectangular vessel bypass and multi-layer superstructure. Main technical characteristics of FPM are presented in Table II.

TABLE II

MAIN TECHNICAL CHARACTERISTICS OF FPM

Characteristic	Value
Type	Dumb rack-mountable vessel
Register class of Russia	KE*[2]A2
Length, m	140
Width, m	30
Depth, m	10,
Draught, m	5.6
Water displacement, t	21 000
FPM operation time, year	40
Delivery date, year	4-5

TABLE III

MAIN TECHNICAL CHARACTERISTICS OF KLT-40C RP

Characteristic	Value
Thermal power of the reactor, MW	150
Primary circuit parameters	
Temperature at the reactor inlet, ºC	280
Temperature at the reactor outlet, ºC	317
Primary pressure, MPa	12.7
Secondary circuit parameters	
Steam power, t/h	240
Steam pressure downstream SG, MPa	3.72
Temperature of superheated steam, ºC	290
Temperature of feed water, ºC	170

FPM consists of accommodation module arranged at the stern and power module arranged in the central and forebody. Power module includes two KLT-40C RP, two steam generator plants and electric power system.

Power module is intended to generate electric and thermal power. The module includes two reactor plants, two steam generator plants and electric power system. Equipment layout principle is based on block one (1 reactor + 1 turbine+ 1 generator).

Reactor compartment and spent fuel storage compartment are protected by structural shockproof guard against external impacts (collisions, grounding). Structural FPM layout includes spent fuel assembly (SFA) storages, storage of SFA, liquid (LRW) and solid (SRW) radioactive waste and reactor refueling complex itself, which provides refueling without involvement of special process recharge bases during overhaul period.

The design implements technical solutions (creation, protection guard, independent ventilation system), which exclude radioactivity release into environment.

KLT-40C Reactor Plant developed by FSUE "OKBM", is an upgraded transport reactor plant of KLT-40 type, which successfully operates for many years without any accidents at nuclear icebreakers under severe conditions of the Russian North. Operating time of similar marine installations being used in presently operating nuclear icebreakers amounts to more than 265 reactor-years. Main technical characteristics of KLT-40C Reactor Plant are presented in Table III.

III. TECHNICAL CONCEPT

Construction of reactor plant based on the following:

- use of proven marine block reactor technologies;
- use of technology and experience in operating reactors of VVER type;
- use of technologies and experience in development of NPP for district heating of cities.

When KLT-40C RP was designed, special attention was paid to safety of the plant and nuclear co-generation power plant as a whole. It is expressed in orientation to verified technical solutions:

- use of the vessel light-water reactor mastered at maximum extent in the world practice;
- use of reliable and developed elements in RP with account of elimination of "weak points" based on experience of analog operation;
- use of independent multi-channel systems of emergency reactor shutdown and passive and active heat;
- guaranteed safety (shown at the analog occurred during nuclear submarine "Kursk" accident).

KLT-40C RP safety systems are designed using rational combination of active and passive systems and needed element redundancy (Fig. 2).

KLT-40C RP is two-circuit plant with light-water reactor, which is connected to coil steam generator and primary circulation pumps by main “pipe in pipe” nozzles.

Main RP equipment: reactor, steam generator and pumps are structurally combined by main nozzles and form steam generating unit.

Layout of main RP equipment is shown in Fig. 3.

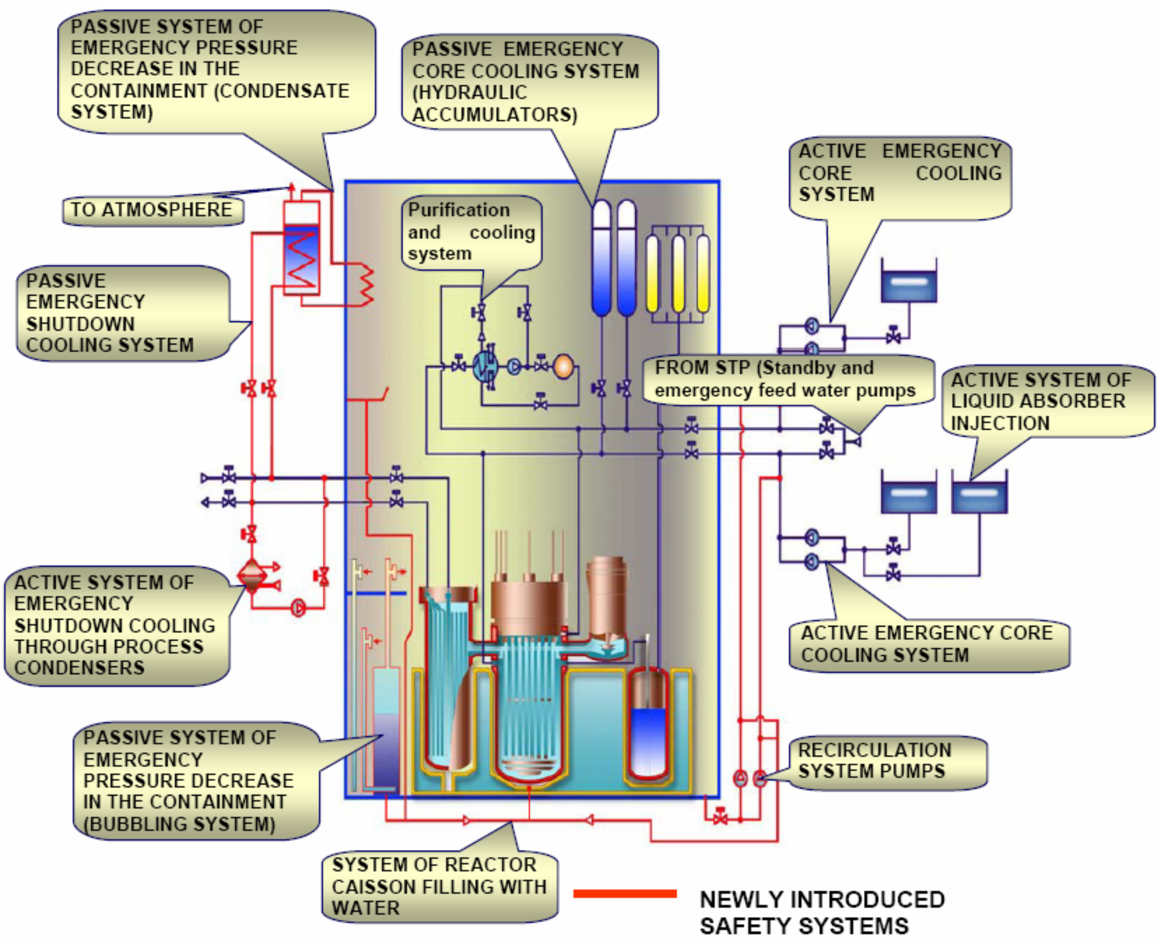

Fig. 2. Principle scheme of KLT-40C RP.

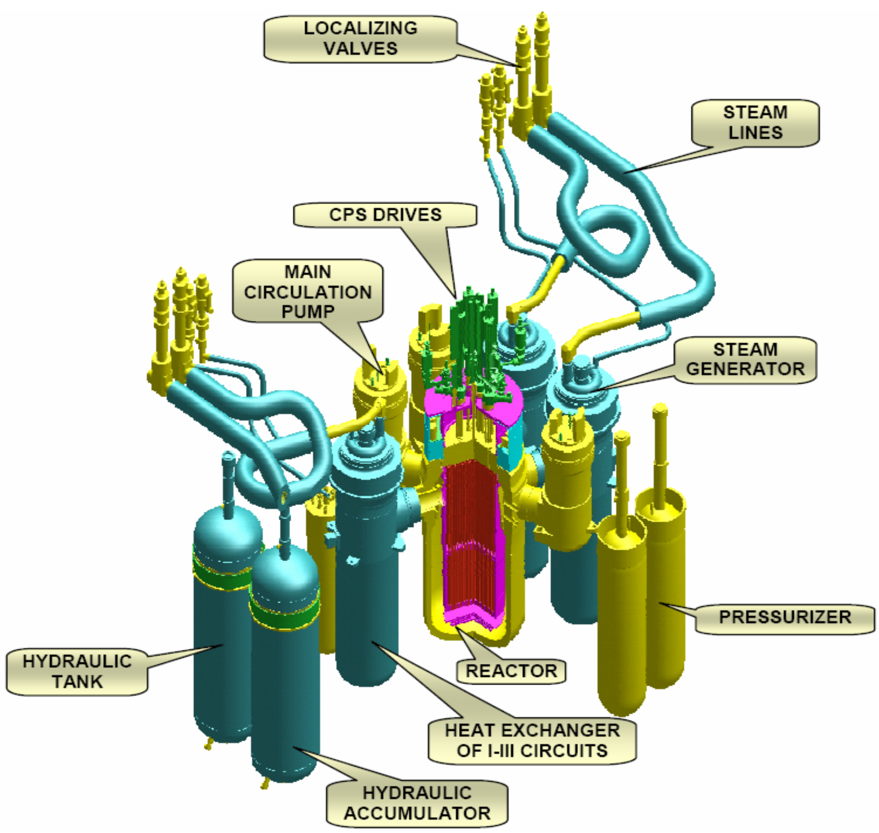

Fig. 3. KLT-40C RP layout.

IV. ECOLOGICAL SAFETY OF NPP

NCGPP based on FPM is pollution-free power source.

Usual waste is isolated and reprocessed in ecological NPP module.

Radiation NCGPP impact on the residents and environment during normal operation and design-basis accidents does not contribute much to natural radiation background. When FPM is decommissioned after expiration of operating time, it is transported to its disposition and burial location, keeping "green lawn" in NCGPP operation area.

NCGPP with KLT-40C RP as compared to similar power plants operating at fossil fuel (black oil or coal):

- saves 300 thousands of tons of conventional fuel per year;
- maintains 400 mln. m^3 air oxygen per year;
- does not release harmful substances into atmosphere: sulfurous anhydride, nitrogen oxides, vanadium pentoxide, etc.

No harmful contribution to natural radiation background (hundredth of percent) during normal operation and design-basis accidents, as well as attained safety level, which avoids necessity to evacuate the residents at any accidents, allow locating NCGPP close to settlements. Undoubted advantages of NCGPP based on FPM with KLT-40C RP concern ecological indices as compared to fossil fuel power sources.

V. TECHNICAL AND ECONOMIC INDICES

Construction cost of NCGPP based on FPM in Severodvinsk (mln.$):

- NCGPP as a whole - 297, including FPM- 253.
- Prime cost of:
- - electric power, cent/kW·h - 5.0;
- - heat, $/Gkal - 4.8
- Pay-back period of the design - 8-11 years
- Construction period of NCGPP based on FPM - 4-5 years.

VI. PROSPECTS OF USE

Potential of the market in Russia, where it is possible to use NCGPP based on FPM, is evaluated in 250 locations.

Investigations carried out by IAEA recently, on small power reactors and seawater desalination issues, showed that the most prosperous direction in this field is use of reactor plants as power sources [5].

IAEA experts recognize FPM with KLT-40C RP as the most suitable for creation of demonstration nuclear desalination complex.

Demand market of FPM with KLT-40C RP inside the complex, which generates electric power and desalinated water, is great – that are Indonesia, China, India, countries of the Near East, Mediterranean, Africa, South America. Taking into account this fact, it is possible to organize international cooperation on investment for creating nuclear complex based on FPM with KLT-40C RP.

VII. DESIGN STATUS

Power module design is approved by joint resolution No SR-1052-2002 dated October 23, 2002 of Minatom of Russia, "Rosenergoatom" trust and Russian shipbuilding agency.

The following Rostechnadzor licenses are obtained:

- for locating nuclear co-generation power plant of small power based on floating power module with KLT-40C reactor plants in Severodvinsk, Arkhangelsk region;
- for constructing FPM with KLT-40C RP;
- for constructing nuclear co-generation power plant of small power based on floating power module with KLT-40C reactor plants (SP NCGPP based on FPM with KLT-40C RP) in Severodvinsk, Arkhangelsk region.

Positive conclusion of Ministry of Natural Resources of the Russian Federation and state service of environment protection (Rosecologiya) is obtained.

It is recommended to approve the design by results of State design review.

VIII. FLOATING POWER SOURCE BASED ON INTEGRAL REACTOR PLANT

Advantages of integral reactors (IR) can be maximum compactness of steam generating unit:

- minimization of equipment units and boundary of the primary pressure with isolation of main primary coolant part in one vessel;
- reduction of the primary circuit branching;
- avoiding large diameter nozzles at the reactor vessel;
- possibility to use built-in pressurizer system, which excludes external pipelines;
- additional possibilities to increase safety level;
- reduction of scope of mounting activities at the ship.

Creation of integral reactors supposes solution of main problem – provision of high lifetime reliability of all reactor vessel elements, that is provided by reduction of accessibility to these elements for repair and replacement as compared to block plants. Accumulated experience allows stating that provision of the needed reliability level of equipment and its elements for IR is not a problem for designer.

Integral reactor of up to 200 MW thermal power can be used as promising option for floating power source [7, 8].

OKBM optimizes lay-out diagram of the reactor, dimensions of steam generator, core, in order to obtain the best RP characteristics. Steam generating unit is assembled at machine engineering factory and transported to shipyard or construction site by railway.

Fig. 4 shows one of integral reaction options inside containment.

Based on this reactor JSC "TsKB "Lazurit" (Nizhny Novgorod) develops design of floating power module (Fig. 5) intended to generate electric power, which manufacture is adjusted to shipyard capabilities in Nizhny Novgorod region, providing possibility to transport it by the Volga river in northern and southern directions.

Characteristics of FPM with FSUE OKBM RP are given in Table IV.

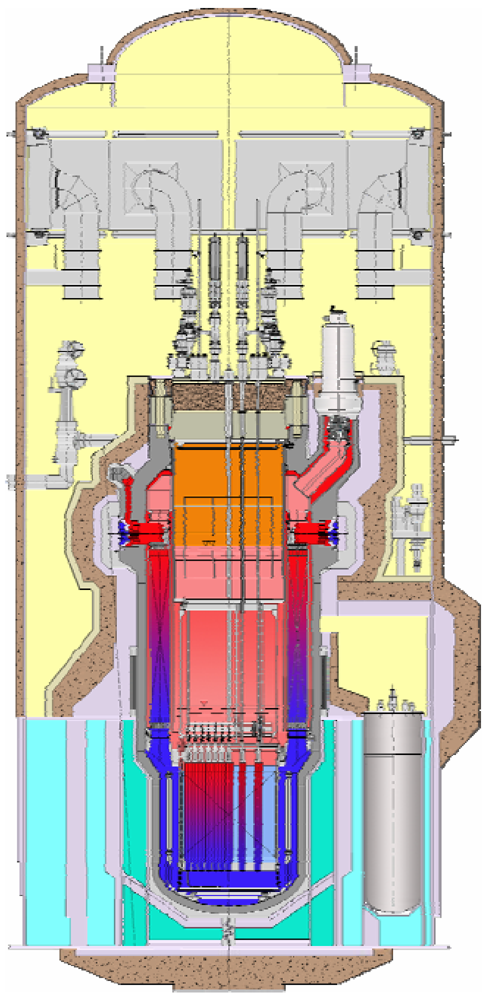

Fig. 4. RITM-200 RP.

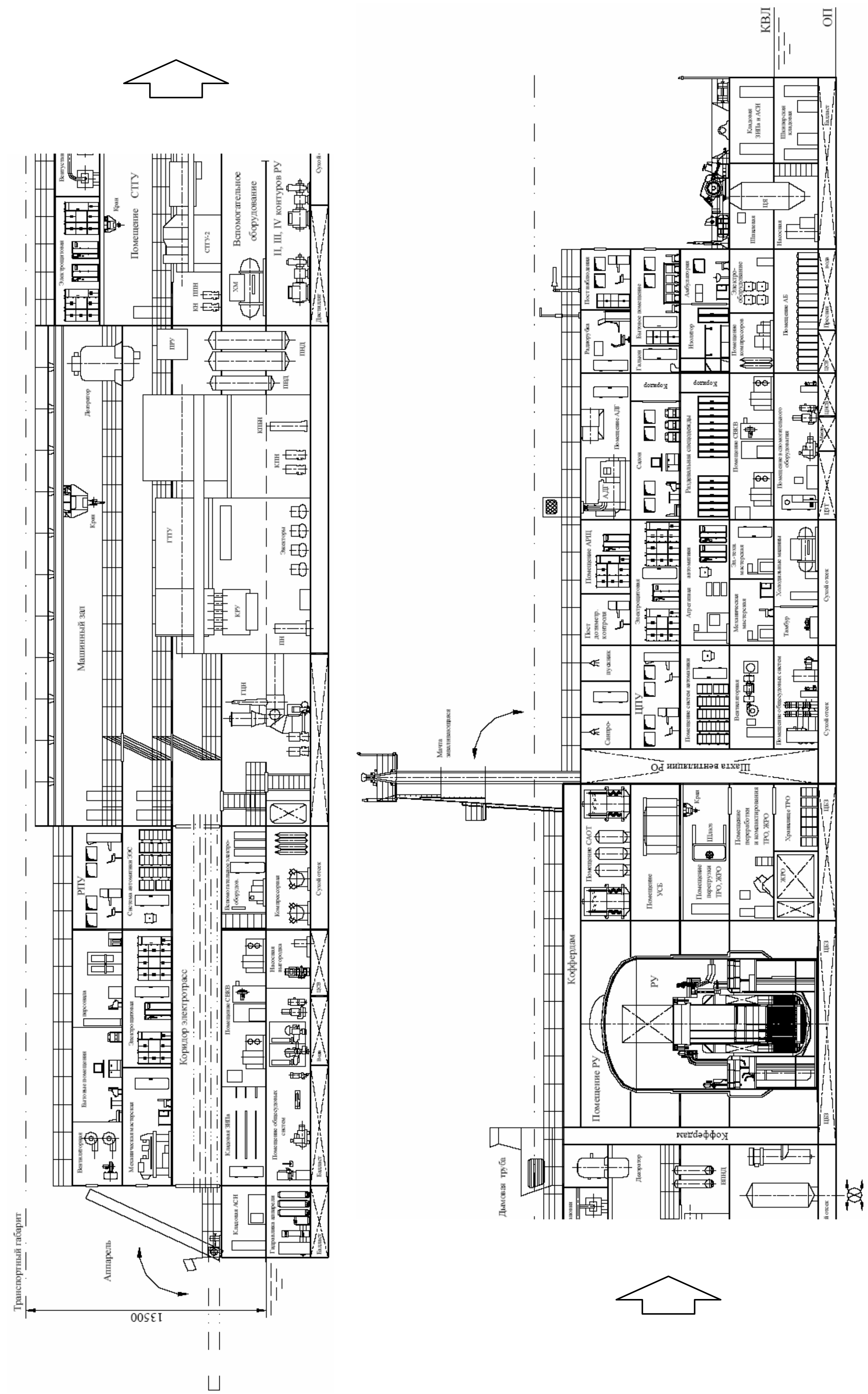

Fig. 5. FPM with RITM-200 RP.

TABLE IV

COMPARATIVE CHARACTERISTICS OF FPM WITH OKBM RP

Parameter, characteristic	Value	
	"Lazurit" FPM	"Aisberg" FPM
Nominal electric power (at TG terminals), MW	40	77
Number of reactor plants, pcs	1	2
Reactor plant type	IR	KLT-40C
Overall length, m	130	140
Width, m	14	30
Depth, m	6	10
Total displacement, t	6330	21000
Draught in working position, m	3.5	5.6
Draught during transportation, m	3.2	5.6
Personnel, men	30	58
Construction cost of lead FPM, mln. $	93.5*	253**
Refueling period, years	10	2-3
Service life, years	60	40

* - in costs of 2002

** - in costs of September of 2005

IX. CONCLUSION

1. NCGPP based on FPM with KLT-40C RP, which is upgraded analog of nuclear icebreaker plants, can be created at minimum expenditure and for a short period of time, which is safe and the most suitable electric and thermal power source for technical and economic indices, for conditions of North and its assimilated distant regions, even if there are own power sources.

   Minimum impact to ecological system during construction and ecological cleanness during operation, as well as high competitiveness for technical and economic indices as compared to alternative power sources of comparable power are important advantages of NCGPP based on FPM in various regions of Russia.

   Use of FPM with KLT-40C RP is very promising and recognized by IAEA for generation of electric power and desalination of seawater in various regions of the world.

2. FPM with integral reactor plants start new direction in ship nuclear engineering. Detailed development of this direction is present OKBM main goal.

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