IMPLEMENTATION OF THE PROJECT FOR THE CONSTRUCTION AND OPERATION OF A NUCLEAR HEAT AND POWER PLANT ON THE BASIS OF A FLOATING POWER UNIT WITH KLT-40C REACTORS

A.K. POLUSHKIN, E.A. KUZIN
JSC Malaya Energetika, Moscow

V.M. VOROBIOV
JSC Atomenergo, St. Petersburg

D.M. KLYKOV
JSC Iceberg, St. Petersburg

J.K. PANOV
OKBM, Nizhny Novgorod

Russian Federation

Abstract

This paper presents the results of research and development on floating nuclear power plant (FNPP) for electricity and heat production for remote locations and small island or coastal communities. Evaluations of construction period, social and economic factors as well as safety and operational issues of the non-self-propelled barge-mounted NPP is given.

1. INTRODUCTION

The development of small-scale power for isolated regions of Russia has long slipped the attention of the public and specialists. Development of the United Power System of Russia, creation of high capacity generating facilities and construction of giant power plants and complexes have been considered top priorities over the past years.

The decentralized power supply territory occupies about two thirds of Russia. It is mainly populated by small ethnic groups including the peoples of the North whose living standards are dozens of years backward as compared with those of such groups of population in the similar climatic zones of North America and Europe.

On the other hand, this territory is very rich in all kinds of mineral resources which are not mined at the present time as there are no required conditions or infrastructure, we mean power supply, communication and transport, first of all. For this is a very scarcely populated territory the border of which practically coincides with the permafrost zone boundary it is obviously impossible to solve a power development problem by means of large-scale network construction.

As a result of the defense industry conversion a number of small-scale power projects became available for civil applications. These Projects were developed for marine and submarine fleet, spacecraft and other scientific purposes, being notable for their novelty and advanced technological level in comparison with similar projects either in Russia or abroad.

At the present moment according to the IAEA surveys nuclear desalination - i.e. using nuclear reactors as sources of electricity or heat for desalination plants - is considered to be the most promising line of development. The present lack of potable water in some areas and increasingly serious and pressing water supply problem definitely act as a stimulant to the growing display of interest in this field.

According to the international organizations more than 50 countries in the world have to face a critical situation with potable water supply. This refers to the south of Europe, North Africa, East and West coast of the USA, coast of Brazil, Argentina, Chili, some regions of India, China, Egypt, Pakistan, Iran, Mexico. Kuwait, Saudi Arabia, United Arab Emirates, Bahrain, Yemen and other Arabian Peninsula countries, some of Caribbean Sea, Pacific and Atlantic Ocean islands are almost absolutely arid.

The main objective set at the beginning of this decade was to sort out electricity, heat and potable water production projects that are more suitable for decentralized power supply areas.

At the beginning of this process more than 20 small-scale nuclear projects were presented. They were divided into three groups:

- less than 10MW (heat);
- 10 - 50MW (heat);
- over 50MW (heat).

For the first group the winners were identified for heat plants and nuclear heat and power plants (NHPP) separately. "Elena" ranked first among heat plants and got a recommendation for the construction of the first production prototype. "Sakha 2" and "Krot" ranked second among heat and power plants.

For the second group the winners were identified for land-based heat plants, land-based NHPPs and floating NHPPs separately. "Ruta" project ranked first among land-based heat plants. The NHP Ruta has a good potential market in settlements that are connected to the central grid but have no fuel of their own for heat supply. "Angstrem" project ranked first among land-based NHPPs, and ABV 6 ("Volnolom") - among floating ones. It was recommended that the implementation of the latter should be started.

For the third group the winners were identified for land-based and floating NHPPs separately. NHPP 80 ranked first among land-based NHPPs, and KLT-40 - among floating ones. The plant is produced in lots for nuclear icebreakers and have already been examined and accepted by Russian State and international experts.

It was recommended that when selecting the type of a plant for the specific customer the judges of the competition should give preference to floating NHPPs (the winners are presented in Table 1).

TABLE I."SMALL-SCALE NPP-91" PROJECT COMPETITION WINNERS

Capacity	Less than 10MW(heat)		10-50MW(heat)			Over 50MW (heat)	
Plant Type	NHP	NHPP	NHP	Stationary NHPP	Floating NHPP	Stationary NHPP	Floating NHPP
Project	Elena	Cakha-92 Krot	Ruta	Angstream	ABV-6	NHPP-80	KLT-40

In 1995-1996 under the auspices of IAEA an options identification programmer for demonstration of nuclear desalination was completed. As regards small-scale reactors (100-200MW (heat)) for co-generation it was recommended that the power generating desalination complex on the basis of KLT-40C reactors proposed by Russia should be constructed. The above reactors have proved to be safe in operation for more than 150 reactor years.

At the beginning of the 1990s small-scale power plants market research was carried out in Russia as well as abroad.

In the framework of this activity Feasibility Reports for the Chukotsky Autonomous Region, Primorsky and Khabarovsky Regions were prepared. On consideration of small-scale nuclear power for the north of Russia over 250 possible sites were analyzed. The sites were assessed on the basis of the following criteria:

- settlements with very small population were excluded (less than 1000 people);
- settlements having their own fossil fuel were excluded;
- settlements without any potential for future development were excluded;
- settlements with limits related to the natural conditions were excluded;
- priority was given to large developing settlements with a complex and multistage fuel supply scheme.

26 sites were selected for possible location of small-scale nuclear power plants of various types.

For the sites selected a detailed analysis of regional energy markets was carried out, including, among other kinds of studies made for the Chukotsky Autonomous Region, the following:

- present conditions and social and economic development perspectives;
- conditions of natural ecosystems surrounding optional sites;
- electricity and heat consumption;
- technical and financial position of power sector enterprises;
- estimation of fuel resources availability and perspectives of their development;
- the existing plants reconstruction and revamping costs evaluation;
- evaluation of economic efficiency of fossil fuel, renewable resources and nuclear options.

The results of these investigations showed that the implementation of a Project for the construction and operation of a small-scale nuclear heat and power plant on the basis of a floating power unit with KLT-40C reactors (hereinafter referred to as the Project) allows - in the short run and with lower costs - to ensure safe and secure power supply in remote and isolated areas with extreme natural conditions and costly fossil fuel transportation.

Pevek, Chukotsky Autonomous Region, was recommended for the implementation of the pioneer project.

The results of the above work served as a reason for including the Project in the following State Programmes of Russia:

- "Fuel and Energy Programme for 1996-2000".
- "Programme for the Development of the Power Industry of Russia for 1998-2005 and up to 2010".

2. CONCEPTUAL POINTS.

2.1. Plant Description

The small-scale nuclear heat and power plant on the basis of a floating power unit with KLT-40C reactors (SS NHPP on the basis of a FPU with KLT-40C reactors) is designed for generation and supply of heat and electricity to the consumers (Figs 1 and 2).

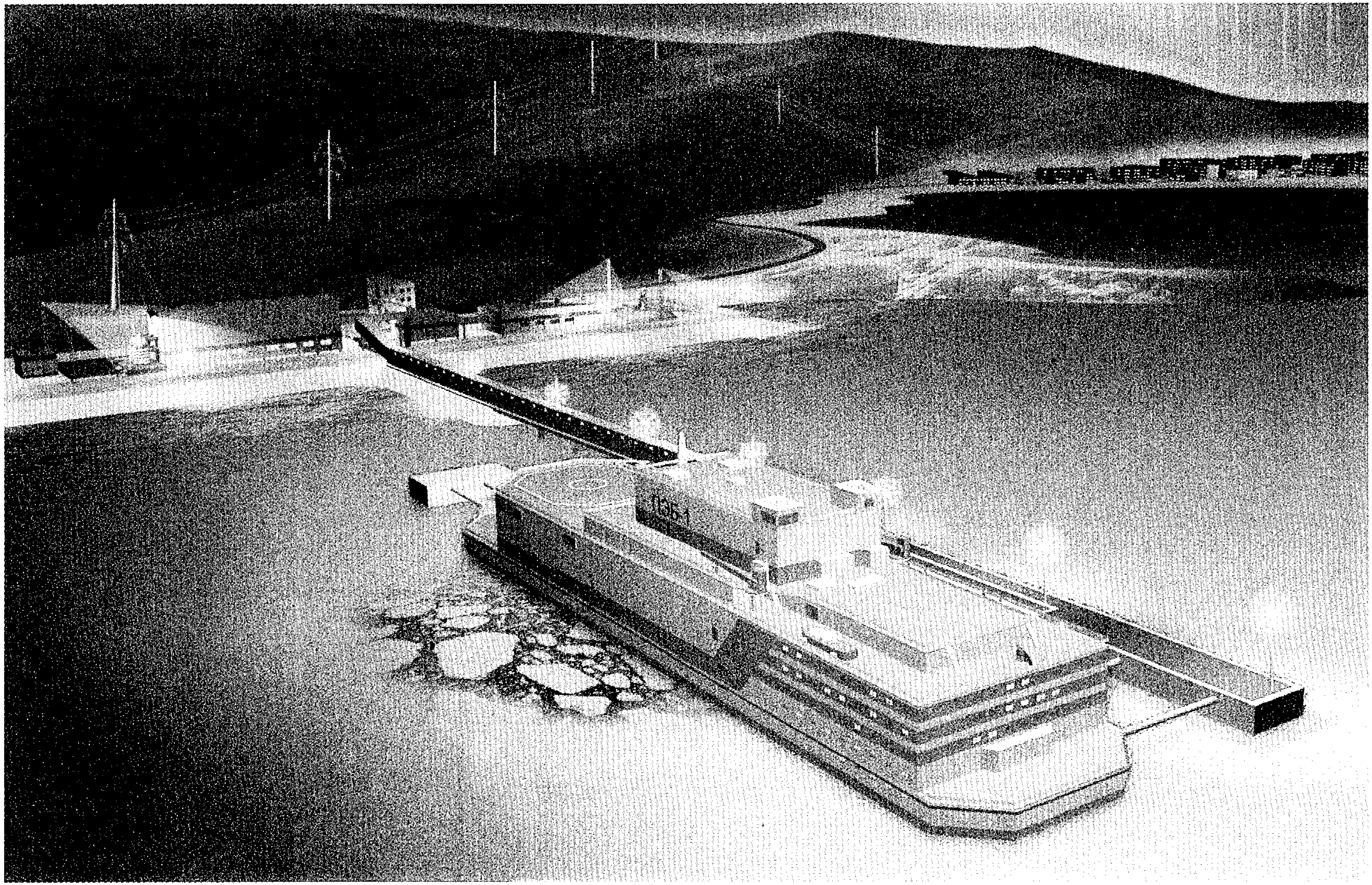

FIG. 1. PEVEK Project from nuclear icebreakers to nuclear power stations.

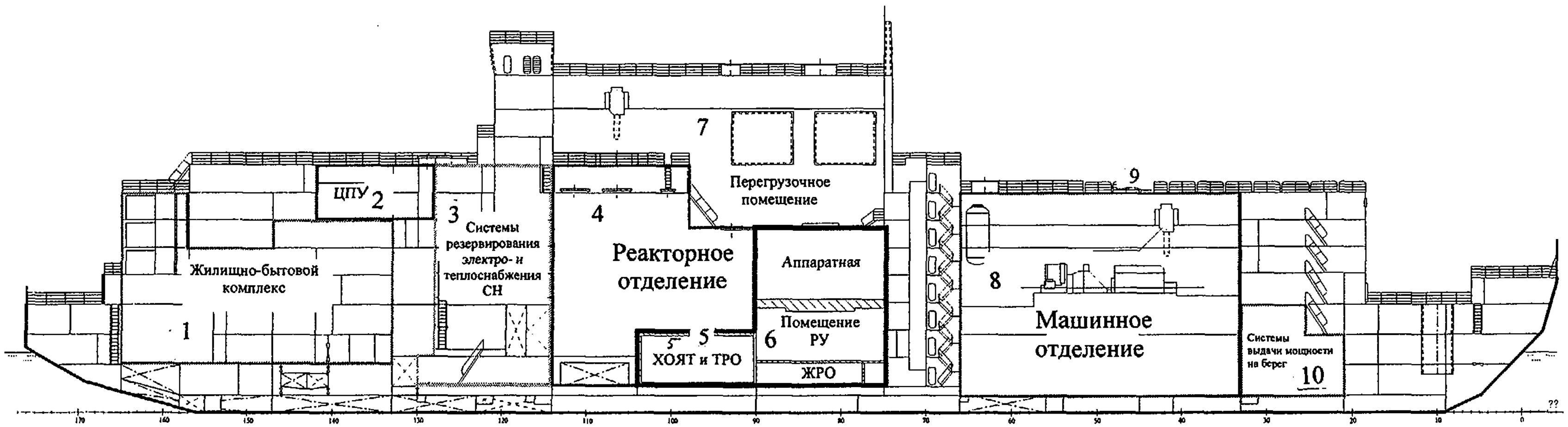

Fig. 2 FPU longitudinal cut-away view:

1 – living section
2 – control room
3 – auxiliary compartment
4 – reactor compartment
5 – spent fuel and waste storage
6 – reactor division
7 – refueling compartment
8 – turbine-generator compartment
9 – helicopter landing site
10 – compartment for electric transformer and switchgear

SS NHPP on the basis of a FPU with KLT-40C reactors consists of a floating power unit, hydraulic structures and a shore-based infrastructure.

The floating power unit is to generate heat and electricity and supply electricity and heat supply water to the shore-based facilities.

The hydraulic structures are designed to connect the FPU to the shore. Mooring facilities provide technical connection between the FPU and the shore. Vessels for supplying the Plant with material and equipment or other maintenance means can be moored to the FPU.

The shore-based structures comprise facilities for the transmission of heat and electricity to consumers and office and other buildings.

Basic characteristics of a small-scale nuclear heat and power plant on the basis of a floating power unit with KLT-40C reactors are given in Tables 2-5.

TABLE II.BASIC CHARACTERISTICS OF A SS NHPP ON THE BASIS OF A FPU WITH KLT-40C REACTORS

Nominal Co-generation Operation Nnom, MW Qnom, Gcal/hour	2x35 2x25
Nominal Heat Generation Operation, Nnom, MW	2x35
Maximum Electric Generating Capacity, MW	2x38,5
Maximum Heat Generating Capacity, Gcal/hour	2x41,8
Auxiliary Electricity Consumption, MW	4-6
Auxiliary Heat Consumption, MW (heat)	3,2
Water into the Heat Supply System, m^3/hour	2x240
Intermediate Circuit Water Temperature Curve for nominal operation, ^{0}C	130/70
Intermediate Circuit Water Temperature Curve for peak load operation, ^{0}C	170/70
Water Pressure in the Intermediate Circuit, MPa	1,6
Shore Territory, hectares	1,5
Surrounding Water Area, hectares	6,0

The FPU is being manufactured at a special shipbuilding dock with a very strict control of the quality of production in compliance with the quality assurance procedures established for nuclear vessels. As soon as the required testing is completed the FPU is to be towed to the site complete and ready for operation.

The FPU accommodates two KLT-40C reactor plants with pressurized water reactors, two steam turbine plants with TK - 35/38 - 3.4 turbines of a co-generation type and TAG8123EUL5B electric generators, facilities for nuclear fuel management and solid and liquid radioactive wastes storage, ecological section.

The FPU ecological section is designed for discharge water and oil contaminated water treatment, solid domestic and food waste collection, treatment and disposal.

TABLE III. BASIC TECHNICAL CHARACTERISTICS OF THE FPU

Type	Non-Self-Propelled Vessel
Russia's Register Class	KE✪[2]A2
Length, m	140,0
Width, m	30,0
Hull Height, m	10,0
Draught, m	5,6
Displacement, tons	21 000
Cabins for Personnel, main/reserve	64 (single)/10 (double)
Design Service Life, years	40

TABLE IV.OPERATION OF FPU WITHOUT THE REPLENISHMENT OF:

Nuclear Fuel (time between refueling), years	2,5 – 3
Fossil Fuel (emergencies, transportation), days	30
Fresh Water, days	20
Provisions, days	60

TABLE V.FPU SAFETY PARAMETERS

Total Design Service Life, years	40
Design Lifetime before Overhaul , years	10-12
Docking Periodicity, years	10-12

The Project for KLT-40C reactors provides for new technical solutions as compared to the existing transportable reactor plants:

- system of residual heat removal in case of beyond design basis accidents with complete 24-hour blackout;
- containment excess pressure reduction system with passive bubbling and condensation subsystems;
- emergency core cooling system with a passive subsystem and returning coolant leakage back into the circuit;
- reactor containment cooling system for beyond design basis accidents;
- no-waste technology system;
- direct-acting device for beyond design basis accidents localization.

2.2. Project Concept

MARKETING CONCEPT

- Increase energy sales by introducing a well-balanced tariff policy stimulating the development of mining industry in the Region.
- Effect integration with BiNHPP, FIPP and NPTN in order to establish an optimum dispatching schedule for ChBPS.
- Enter into agreements with large consumers and the authorities of the Region with the object of ensuring timely payments for the energy sold to the consumers (solving the "non-payment" problem).
- Actively develop and expand sales market for the energy generated by the NPP by displacing fossil fuel power generating sources.

COMMERCIAL CONCEPT	–	Implement the Project using "Build-Own-Operate" scheme, which will allow to remove the heavy burden of intensive capital investment from energy consumers while, at the same time, the Company retains the rights of property.
OPERATING CONCEPT	–	Operate the NHPP with specially staffed and trained watch crews of highly qualified specialists, which guarantees safety and efficiency of operation and relieves the social burden in the area of NHPP location.
TECHNICAL CONCEPT	–	At all stages of implementation, such as design and engineering, equipment manufacturing, construction and operation, apply technical solutions proved by many years of trouble-free operation, which will allow to reduce the amount of work, including assembly, installation, erection and repair work at the site, and also to a maximum possible extent assure safe nuclear waste and spent fuel management in order to ensure nuclear and radiation safety of the NHPP.
SOCIAL AND ECONOMIC CONCEPT	–	Safe and secure power supply of consumers, reduction of fossil fuel requirements and, as a result, of the volume of fuel transportation under the severe conditions of the Arctic.
	–	Reduce the need for budgetary appropriations for the power sector, create conditions prerequisite for the development of industrial and agricultural sectors with high potential and simultaneously reduce the number of people employed in coal mining industry, transport and power industry.
	–	Improve social and ecological conditions in the Region where the Plant is to be located.

2.3. Project Implementation Model

It is proposed that the Project should be implemented using BOO (Build - Own - Operate) model.

Rosenergoatom Concern will finance the construction of the floating power unit, act as the owner and operating organization of the SS NHPP and sell the heat and electricity generated.

A long-term power purchase agreement for selling (buying) energy at a certain tariff will be signed with consumers. The principal provisions of the power purchase agreement - such as the term of validity, tariff rates, risk insurance terms, guarantees etc.- are supposed to be defined when negotiating to agree upon the Feasibility Study results to substantiate the required investment.

The construction period was calculated on the basis of data on the construction of single elements similar to that of the same kind of plants with geographical, climatic, hydrological and other conditions taken into account.

The period of hydraulic structures and shore-based facilities construction stipulated in the Project is 2-3 years.

The main FPU equipment manufacturing period stipulated in the Project was defined on the basis of norms and standards established for nuclear vessels with the following taken into account:

- in prospect - construction of a series of SS NHPPs in order to ensure the continuity of operation of the plant at a certain site;
- time required for manufacturing of certain types of equipment and organization of a continuous production process at the manufacturing plants.

The Plant construction period is 6 years with an allowance for 1 year of assembly, erection, startup and adjustment.

2.4. NHPP Operating Model

The operating model was developed on the basis of design performance characteristics of the complete operating cycle of the NHPP.

The Project provides for the installation of facilities for nuclear refueling and spent nuclear fuel storage on board the FPU without using special service vessels. Radioactive production waste is also stored on board the FPU. Thus, the design autonomous operation period (operation without supplies replenishment) of the FPU is determined by the capacity of spent nuclear fuel and radioactive waste storage tanks and periodicity of docking. With ~0.54 load factor, which corresponds to the pessimistic consumption forecast, the autonomous operation of the FPU is ensured by four nuclear core sets and makes 13-15 years. After the lapse of this period the FPU is replaced with a similar one.

As an FPU can be replaced the NHPP operation can continue as long as you like within the limits of hydraulic structures and shore-based facilities service life.

The following procedures are provided for during the Plant operation:

- 50% two-month load decrease for reactor plants refueling taken in turn every 2-3 years;
- complete interruption of power supply every 13-15 years for FPU replacement.

After the replacement the FPU with full radioactive waste and spent fuel storage tanks is to be towed to specialized repair works at the dock for overhaul, fuel unloading and hull docking.

The overhaul includes the following:

- unloading of spent nuclear fuel from reactor plants and spent nuclear fuel storage facilities;
- complete control of central power compartment equipment and steam turbines and a range of work in order to provide their further operation;
- control of the craft and general ship systems with necessary repair and preventive maintenance;
- FPU hull checkup and repair;
- carrying out a range of work for the FPU to meet the regulatory safety requirements;
- refueling;
- complex testing of all FPU systems and equipment;
- preparing the FPU for transportation to the site.

The overhaul period stipulated in the Project is 1 year with an allowance for transportation time. The Project provides for two overhauls and three operating cycles.

After the completion of the third operating cycle the FPU is to be decommissioned, i.e. towed from the site to the premises of the specialized dock for dismantling and disassembly of ship nuclear equipment.

The practical implementation of the accepted model is ensured by FPU mobility.

The Project technical decisions and the FPU operating model allow to:

- carry out all refueling between overhauls onboard the FPU;
- store all radioactive waste and nuclear fuel onboard the FPU;
- assure high quality of repair work;
- ensure safe and secure FPU decommissioning.

3. CONSTRUCTION PERIOD

The construction period was calculated on the basis of data on the construction of single elements similar to that of the same kind of plants with geographical, climatic, hydrological and other conditions taken into account.

The remoteness of the Region and its severe climatic conditions determine the seasonal character of equipment deliveries and construction work. The period of hydraulic structures and shore-based facilities construction stipulated in the Project, therefore, is 3 years.

The period of the main FPU equipment manufacturing was defined on the analogy of nuclear icebreakers.

The total FPU construction period is 5 years. Transportation of the FPU to the site and startup and adjustment take 0,5÷1 year. The plant construction period from obtaining the construction license is 6 years. With design and development taken into account the investment period makes 7 years.

The approved production and technological NHPP construction scheme consists of three main stages (see Fig.3):

FPU Manufacturing:

- manufacturing of the FPU hull at a specialized shipbuilding yard;
- simultaneous manufacturing of the central power compartment equipment and its sectional assembly as part of the FPU;
- manufacturing and testing of turbine generators at a specialized plant and their subsequent delivery to the manufacturer of the FPU to be assembled and mounted;
- assembly, mounting and testing of the FPU including reaching the design capacity at a shipbuilding yard;
- construction of the hydraulic structures and shore-based facilities on the site before the FPU arrival;
- Putting NHPP into Operation:
- towing the complete and ready FPU to the site;
- assembly, startup and adjustment of the whole complex of the FPU elements together with the shore-based power transmission network;
- putting the Plant into trial-commercial operation.

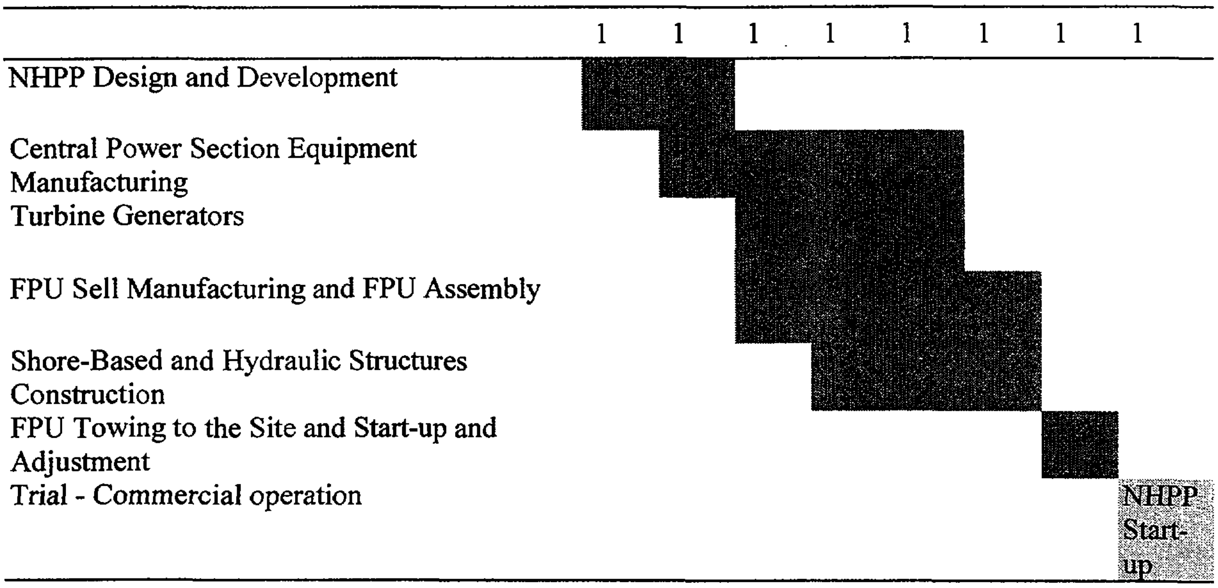

Fig.3. NHPP Production and Technological Construction Scheme

The FPU construction at specialized works in a dock ensures maintaining technological discipline and control of the quality of work carried out at all stages of construction and testing technological cycle.

4. SOCIAL AND ECONOMIC EFFICIENCY OF THE PROJECT

According to the expert estimations, the GDP growth over the construction period will make about 3900 – 5200mln rubles, even under the most pessimistic conditions, i.e. exceed the amount of investment 1,06÷1,42 times.

Creation of additional jobs machine engineering plants and shipbuilding yards in the European part of Russia will bring about GDP growth no less than 4 times over the amount of capital investment.

The construction of a NHPP in Pevek is a key component of the Programme for the Chaun-Bilibinsky Power System. The implementation of the Programme will make a considerable - 2.5-3 times - increase in mining industry output possible, which, in its turn, will bring about the revival of business activity and multiple increase in budget revenues at all levels. The reduction of fossil fuel requirements will relieve the social burden of the ChAR by cutting down the number of people employed in the coal mining and transport industry.

5. RISK ANALYSIS.

The Project sensitivity evaluation shows that the most significant factors affecting the Project parameters are the volume of energy sales, tariffs and construction cost.

– *The energy sales volume* depends on the results of implementation of the Programme for Chukotka gold mining industry development to a considerable extent. The intensification of gold mining and the development of other mineral resources, namely metals, can be considered a top priority not only at the local, but also at the federal level, especially taking into account the Russia's gold and foreign exchange reserve deficit. So the risk associated with the lack of demand for electricity that will be produced by the NHPP is entirely determined by the government policy in this field.

- all the above said equally refers to *tariff rates*, as the local power industry system has no internal market mechanisms to fix prices. Tariffs are established by the authorities. Their level is determined by production and transmission costs and the policy of local authorities. Taking into account the fact that the authorities are interested in the implementation of the Project and ready to participate in financing, tariff policy is anticipated to support and promote the Project in order to improve its technical and economic performance.
- *The cost factor* is of particular importance under the conditions of the economic crisis. On the one hand, price rise makes the Project more costly which can put the main obstacle to its implementation; on the other hand, the same rise is a cause of increase in energy tariffs. Under the conditions of inflation and political instability non-fulfilment of obligations to repay foreign currency credits, but in the given Project this risk is reduced to a minimum as the foreign currency component of construction cost is only 10%.

It should be noted that this Project is to be the first one of a series of floating nuclear power projects. Some of them are to be exported as floating power stations with desalinating plants. Company's activity diversification, getting access to international markets, complex approach to the management of a series of Projects for the construction of a series of floating power plants allow to reduce risks of each single Project considerably.

Thus, the main risk factors are to a certain extent manageable and their possible negative impact upon the Project can promptly be eliminated. The risks will be managed by an organization to be established under the framework of the Programme for the ChBPS Development. This organization is to integrate the interests of large industrial consumers, primary power generating companies, power transmission companies and the authorities of the Region.

6. PROJECT STATUS

At the present time the Feasibility Study for the Project for the construction of a NHPP on the basis of a FPU with KLT-40C reactors in Pevek, Chukotsky Autonomous Region, is completed.

Two materials, namely "A Report on the Present Situation and Conditions of Power Industry in the Chaun-Bilibinsky Power System of the Chulotsky Autonomous Region" and "The Programme for Power Stabilization and Development in the Chaun-Bilibinsky Power System of the Chukotsky Autonomous Region up to 2015", were developed.

The preliminary agreement has been reached on the approval of Pevek site for the NHPP to be constructed.

The Feasibility Study accompanied by the above materials was submitted to the Federal Executive Authorities for expert evaluation, approval and licensing (expert opinion of the Federal Medical and Biological and Extreme Problems has been already obtained).

Declaration of Intention of the construction of a NHPP on the basis of a FPU with KLT-40C reactors in:

- the city of Dudinka, Taymyr (Dolgano-Nenetsky) Autonomous Region;
- the city of Viliuchinsk, Kamchatka Autonomous Region.

During the period May 11 - 21, 1999 an expert of ECTI acting in the framework of TACIS Programme assessed and evaluated the Project. The expert particularly pointed out that the floating application as part of a nuclear power plant benefiting from all the advantages of power generation proved by many years of experience of icebreakers operation can be considered as innovative at the world level, as the first Project of this kind implemented in the world. In case of its successful implementation with all safety and nuclear fuel and radioactive waste management requirements met during the operation the Project will be the first reference to demonstrate the opening new possibilities and perspectives as regards the potential development of isolated and remote northern territories of Russia and foreign countries.

7. CONCLUSION

The Project is oriented towards secure and efficient power supply and offers thoroughly selected optimum solutions of energy supply problem; transparent tariff policy and the consequent solution of the "non-payment" problem; optimization of the existing electricity and heat generation and distribution patterns.

In case of the Project successful implementation final consumers will benefit from the stable and efficient operation of the power supply system and thus, become more confident for paying energy bills. As a result they could be less reluctant to energy saving measures and behavior.

The Project, when implemented with successful operation, will constitute the first world reference for security of energy supply to very isolated areas with extremely severe conditions, allowing stabilization, economic development and social welfare for regions similar to the Chain-Bilibinsky District and ChAO.

Besides, it will also create conditions prerequisite for the efficient use of financial resources, stable operation and efficient performance of the economic systems of the region and local improvement of wealth and welfare.

Replication of this reference Project for new sites will open the market for the key component of the station, which is a small-scale floating nuclear power unit with KLT-40C reactors, reducing production investment and logistics costs that will drop by serial effect for the implementation of the given Project as well as for any further ones of this series.

The Project implemented will allow to reduce fossil fuel consumption fuel transportation costs; reduce the negative impact upon the environment; improve social and economic conditions in the Region; develop the scientific and technical potential of the country; retain the existing and create new jobs in the European part of Russia; expand nuclear industry's importing and international cooperation in the field of nuclear energy use; contribute to improvement of the positive image of nuclear energy for civilian application.