On the prospects of mini nuclear power plants (MNPP) in the Far North of the Republic of Sakha (Yakutia)

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Abstract. The paper addresses the main directions of organic fuel delivery to the northern territories of the country including the Sakha republic (Yakutia) (variants of the Northern, Siberian and Far Eastern directions of fuel delivery). Consideration is given to the specific features of the multi-link, seasonal scheme of organic fuel delivery to the arctic areas. The dynamics of change in the fuel delivery costs is estimated. The comparative calculations for energy sources on organic fuel and mini nuclear power plants are made. The limit of efficiency and role of mini nuclear energy sources is determined.

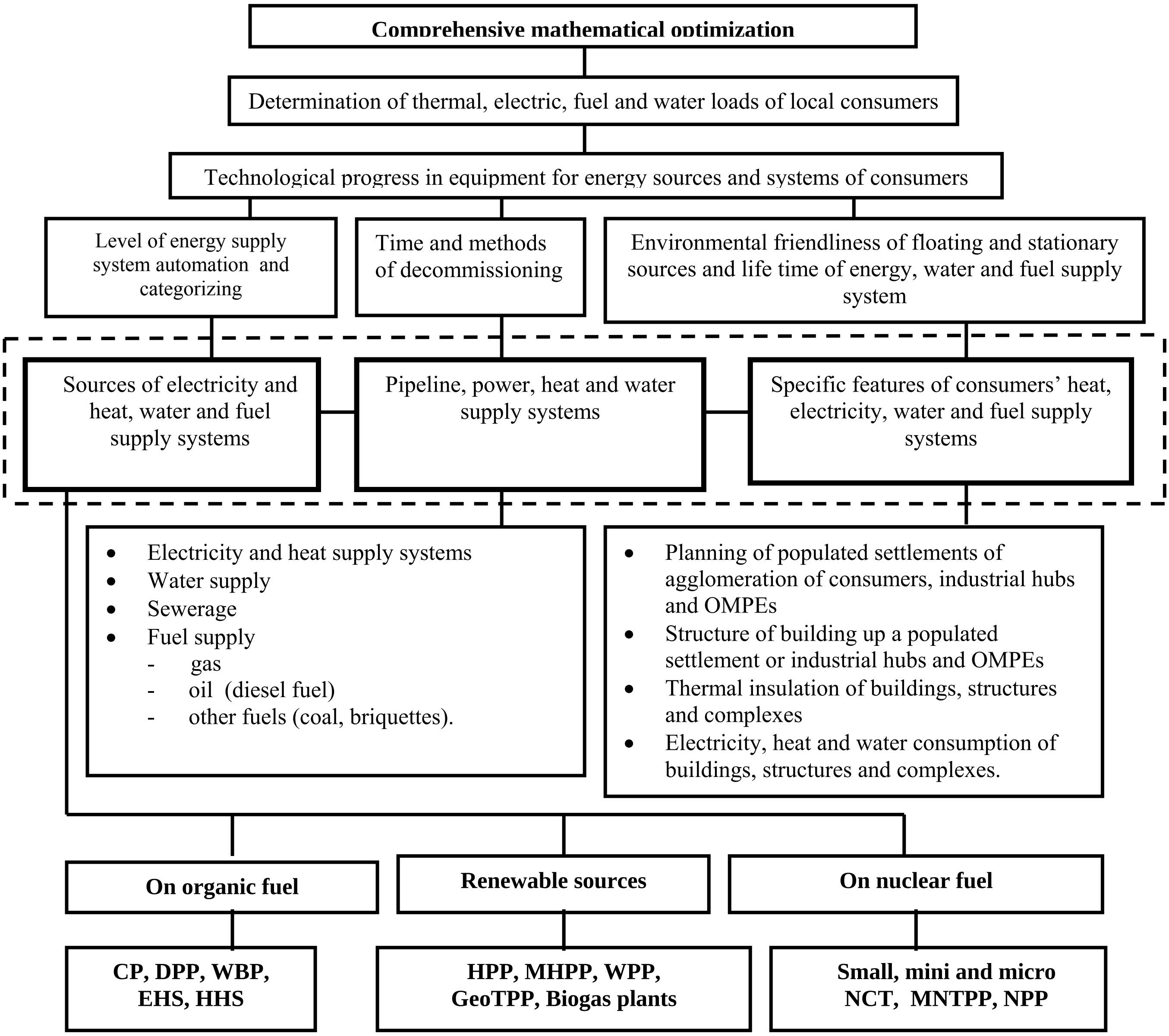
I. INTRODUCTION AND PRECONDITIONS

Currently the Government of the Russian Federation spends huge funds only to deliver fuel to the northern regions of Russia (average costs reach the value above RUR 45 billion). Fig.1 shows a general scheme of the northern delivery of liquid fuel to the republic of Sakha (Yakutia) – the northern variant along the NSR is more than 4500 km. Only to deliver **250 thousand tons of liquid fuel** to the arctic areas of the Sakha republic (Yakutia) in 13 areas the costs reach about **RUR 3.0 billion**, taking into account a multi-link and seasonal character of the organic fuel delivery (railway, river, sea, winter motor road). The use of principally new low-capacity nuclear power plants (LCNPP) of the last generation with energy units varying in electric capacity **from 100 kW to 1-35 MW and higher (LCNPP projects: "Elena", "Sakha-92", "Krot", "Angstrem", "Unitherm", "ABV-3÷12", "LBFR-10", "KLT-40C", "Kushva", "Utro", etc**.) can be a main and efficient way of decreasing the costs of fuel delivery to the areas of Russia's North. In the future their use will improve the situation with fuel delivery for 10 and more years ahead since **reactor refueling** will be carried out once a **decade or two** and more; small floating nuclear power plants (FNPP) will solve the problem of plants decommissioning according to the "green field" principle after the lifetime has expired (20-30÷40 and more years) [1-17].

Principles and methodology of determining the efficiency of MNPP (LCNPP) under the extreme conditions of the Far North.

Based on the comprehensive – "system" approach and rating methodology (Fig.1) the IPTPN SB RAS determines efficient, dependable, highly automated and safe floating LCNPPs and the sites of their primary allocation over the territory of the Sakha Republic (Yakutia) in the future.

Rating methodology takes into account different construction periods, specific features of operation and decommissioning, as well as different energy technology options for power supply taking into account planning of residential territory in an industrial area and populated settlement, structure of building up of consumers – residential, industrial constructions, industrial hubs and ore mining and processing enterprises under the conditions of the Far North [1].



CP – cogeneration
DPP – diesel power plants
WBP – water boiler plants
EHS – electric heat system
HHS – house heat sources
NCP – nuclear cogeneration

MNPP – mini nuclear power plants
MNTPP – mini nuclear thermal power plants
HPP – hydro power plants, small and mini HPP (MHPP)
WPP – wind power plants
GEOTPP – geothermal power plants
Bioplant – biogas plants

The main principle at the Far North is: build - own – operate- utilize – state policy – system – complex"

Fig. 1. A general principle of mathematical modeling of local (isolated, industrial) power supply systems, taking into account ownership, planning and structure of building up of consumers in the settlement, complex, industrial hub – ORPE under conditions of the Far North.

II. NORTH DELIVERY AND FUEL RESOURCES

The specific features of a multi-link seasonal scheme of fuel delivery and potential sites of low-capacity nuclear power plants allocation are given as an example in Figures 2 and 3. Figure 4 shows the areas for possible construction of LCNPP in the settlement of Chokurdah, where the total length of the multi-link seasonal scheme of the liquid fuel delivery reaches up to 6490 km, including railway – 1280 km, river – 3600 km, sea – 1000, winter motor roads – 590 km, and the distance to the settlement of Chersky – Zeleny Mys – up to 8190 km.

In 1992 on the initiative of IPTPN SB RAS and with the support of the Government of the Sakha Republic (Yakutia) the Yakutian delegation and working group of 9 people, headed by A.P.Shadrin (IPTPN SB RAS), visited federal nuclear centers of the Ministry of Atomic Energy: Research and Design Institute of Electrical Engineering (RDIEE, Moscow) and Experimental Design Office of Machine Building (EDOMB, Nizhniy Novgorod).

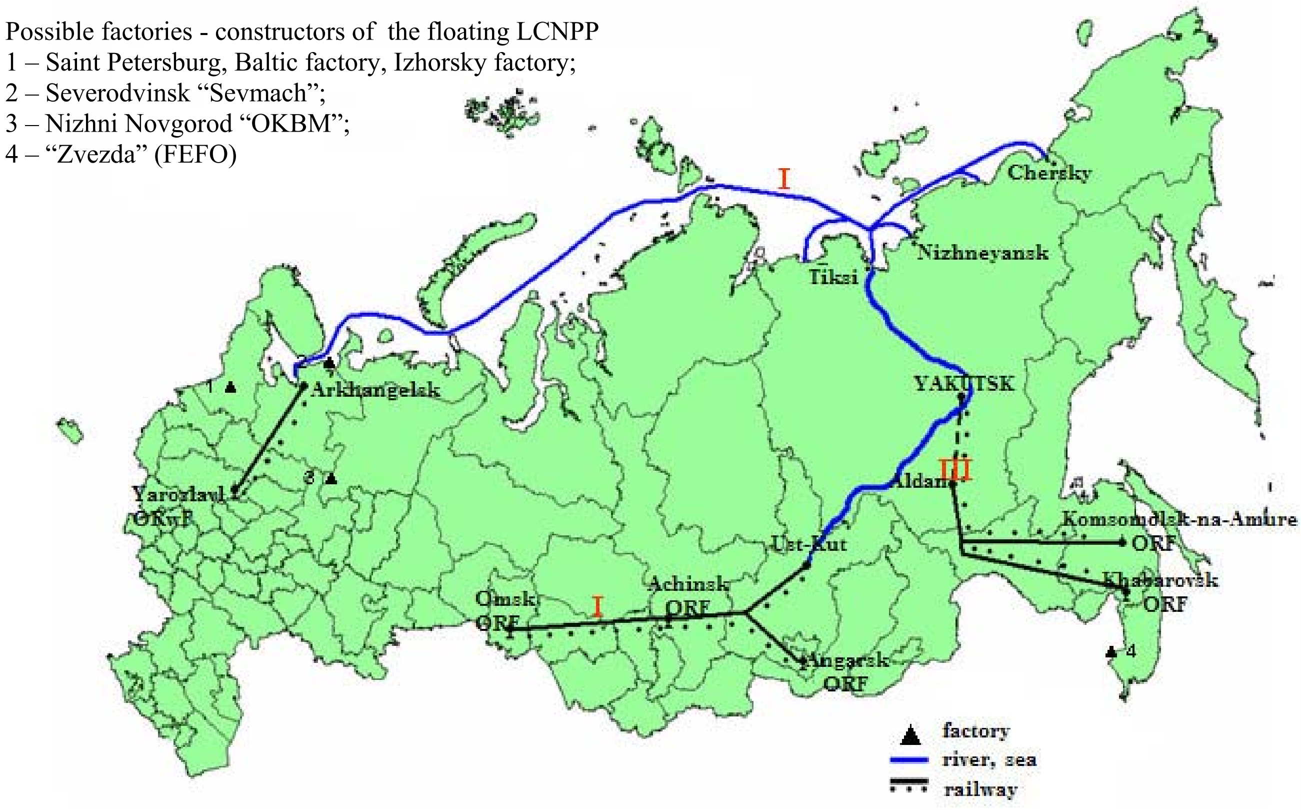
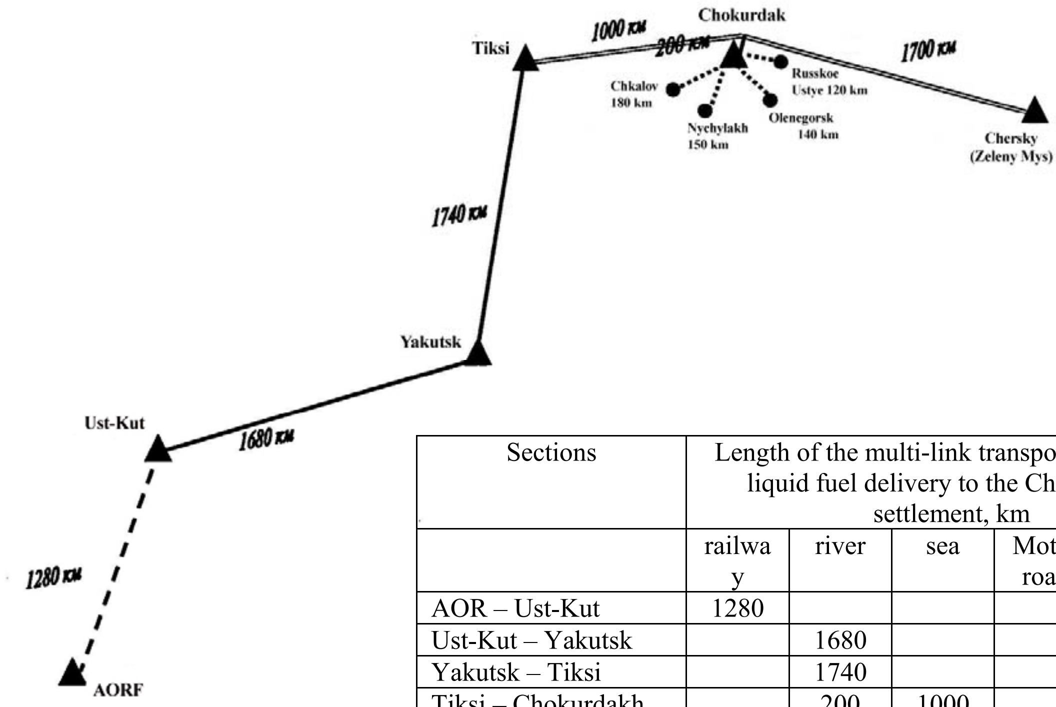


Fig. 2. A scheme of liquid fuel delivery to the Republic of Sakha (Yakutia) and potential factories – constructors of FLCNPP.
I – Northern variant (up to 10%); **II** – Siberian variant (up to 85%); **III** – Far Eastern variant (up to 5%).



Sections	Length of the multi-link transport scheme of liquid fuel delivery to the Chokurdakh settlement, km				
	railway	river	sea	Motor road	**TOTAL**
AOR – Ust-Kut	1280				**1280**
Ust-Kut – Yakutsk		1680			**1680**
Yakutsk – Tiksi		1740			**1740**
Tiksi – Chokurdakh		200	1000		**1200**
Chokurdakh – Naslegi				590	**590**
TOTAL	**1280**	**3620**	**1000**	**590**	**6490**

Fig. 3. An entire multi-link scheme of liquid fuel delivery and a distance to the northern Allaikhovsky Ulus, the Sakha (Yakutia) republic.

III. LOCAL PECULIARITY OF CLIMATE OF THE EXTREME NORTH

The Yakutian delegation, in particular the head of the thermal energy laboratory at the IPTPN SB RAS, Dr. Shadrin A.P., were the first to propose and develop jointly with EDOMB, RDIEE and FEI technical assignments and ideas on the LCFNPP project (Sakha-92) with an electric capacity of 1000 kW, on the basis of "ABV" and "Unitherm" reactors with a 10-20-year reactor refueling interval. Currently this condition principally distinguishes this project from the other FLCNPP projects.

The Sakha (Yakutia) republic showed the necessity of preparing jointly with nuclear centers the Federal "Research and Engineering Program" on using FLCNPP in the priority sites of possible allocation on the northern territories of the country and in the Sakha Republic for the perspective [2-10,15,16,17].

Fig. 5 shows, as an example, the change in the range of efficient application of floating LCNPP in the Far North of the Sakha Republic depending on the levels of thermal and electric load, specific features of fuel delivery schemes, the change in the delivered liquid fuel costs in the range from 15000 to 30000 RUR/t and dynamics of capital investments. Fig. 5 shows the real picture of change in the efficiency of FLCNPP in the Far North and its dependence on the transport conditions of fuel delivery. The efficiency of FLCNPP versus the variant of power supply on the organic fuel to be delivered to DPP, CP and WBP changes depending on the equipment mix, electric and thermal load, and standard sizes of nuclear reactors for small NPP.

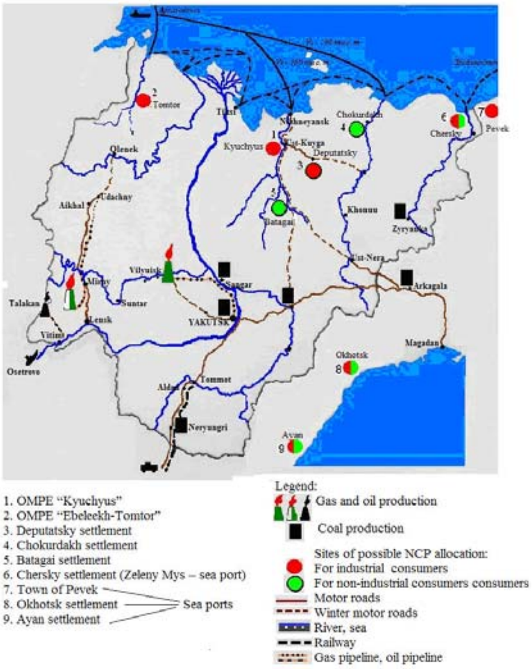


Fig. 4. A multi-link scheme of fuel delivery and small-scale nuclear energy

Based on the data obtained it is necessary and expedient in the years to come to make specific "target" calculations on the sites of primary use of FLCNPP of the last generation in the Sakha Republic, taking into account the multi-link scheme of fuel delivery to the region, and arrange a wide discussion on the use of FLCNPP among developers, project participants and interested ministries, stock companies and concerns of the country to assess the impact on the environment, first of all radiation impact of the involved enterprises in the Sakha Republic (YA): **JSC "ALROSA", OSC "Polus zoloto", JSC "Sakhaolovo", JCS "Sakhaenergo", and JSC "Yakutskenergo".** Here it is necessary to take into account the tendency towards a change in the prices of oil, oil products and natural gas for 10-20 years in Russia and in the world (Fig.6). The organic fuel price is forecasted to increase 2.5-3.0 times by 2050.

At present the dynamics of electricity and heat consumption in the populated settlements of the northern territories in the FEFO, including Yakutia, Magadan oblast and Khabarovsk Krai, has been analyzed depending on the residential and industrial building. The materials of the "Program" on social and economic development of municipal entities in 13 arctic areas (Uluses), the Republican target program "Development of electric power industry in the Sakha Republic (Yakutia) for the period until 2010 and the forecast until 2015", the subprogram "Development of small-scale energy in the Sakha republic until 2015" and the Program on "Development of the productive forces in the Sakha Republic - transport and energy" for 2020 and for the period until 2030 are generalized.

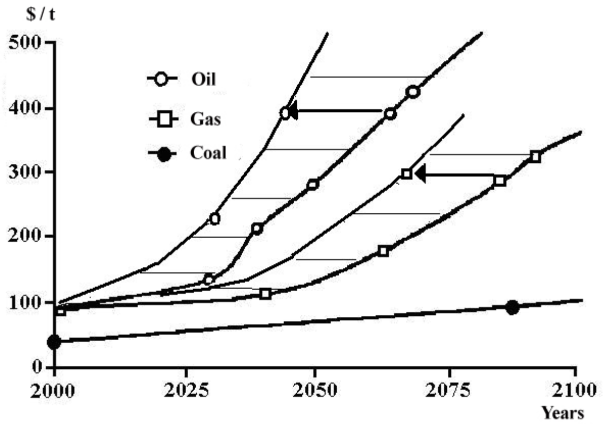


Fig. 6. A trend in the change of the organic fuel price in the world

(L.S.Belyaev, O.V.Marchenko et al. World energy and transition to the sustainable development. Publishing house "Nauka", Novosibirsk, 2000, p.29.)

IV. RESULTS CALCULATION'S OF ZONES OF EFFECTIVENESS FROM SUPPLY SMALL AES

Based on the system methodology the calculations were made to estimate the efficiency of different scenarios of electricity and heat supply to arctic consumers in the FEFO, taking into account the diesel fuel delivery scheme and its seasonal character and changes in the total costs including transportation, renting and guarding. The costs increased from 15000 to 30000 RUR/t and more [8].

For these conditions the efficiency of power supply scheme for diesel power plants (DPP) and water boiler plants was compared and the possibilities of applying alternative energy sources, for example, low capacity nuclear power plants, were estimated. Figs. 5(A) and 5(B) show as an example the **dynamics of**

change in the efficiency of FLCNPP, DPP and **WBP on liquid** (Variant A) and **solid** (variant B) **fuel**.

Bearing in mind the tendency towards the change in the world and Russia's prices of oil and oil products a staged application of a combined power supply scheme (on the basis of DPP and WBP, variants A and B) is suggested.

Figures 5(A) and 5(B) show the changes in the efficiency of different variants of power supply to the arctic consumers depending on the dynamics of change in the liquid fuel costs (from 15000 to 30000 RUR/t) and unit electric capacity of energy sources from 3 to 12 MW.

Real reliable, social, economic and environmental benefit from the use of FLCNPP is obtained even at a 3 MW unit capacity of an energy source, at a cost of organic fuel of 30000 RUR/t, and saving makes up from 1 to 600 million rubles at a unit capacity of 12 MW (Fig.5 A).

With the use of coal-fired water boiler plants the total efficiency is observed at an electric capacity of 9 MW and annual savings in the range 50 to 120 million rubles are obtained at 12 MW (Fig. 5 B).

Taking into account the current state of change in the price of 1 barrel of oil from USD 60 to 65 (and more in a perspective, taking into account transportation) we can state highly efficient use of FLCNPP with a long refueling interval (ABV, LBFR-10 and others) in Russia's arctic territories.

Extreme natural climatic conditions of living in the north of the country:

- Long heating period (7 -12 months), polar night, blizzard, low temperatures and wind loads.

- Short navigation periods in the northern rivers and northern seas, complex multi-link transportation conditions for fuel delivery with rent, guidance and reloadings (railway, river, sea, winter roads), the need to deliver fuel for the second year of the energy facility operation (taking into account seasonal character), i.e. in

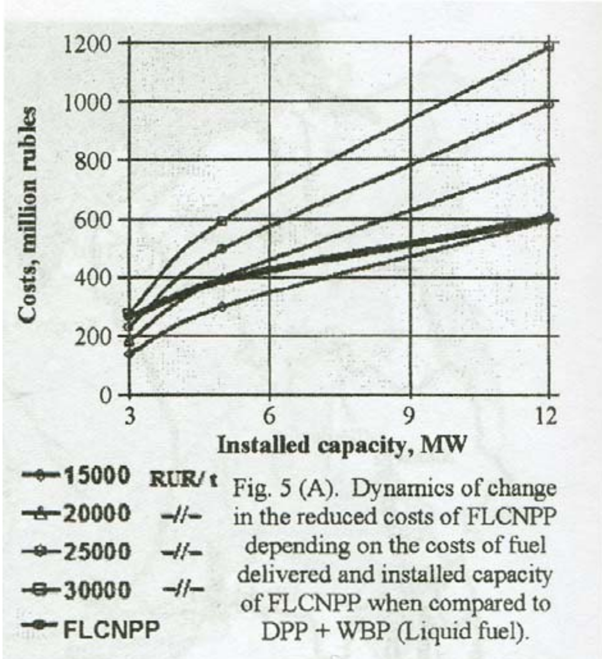


Fig. 5 (A). Dynamics of change in the reduced costs of FLCNPP depending on the costs of fuel delivered and installed capacity of FLCNPP when compared to DPP + WBP (Liquid fuel).

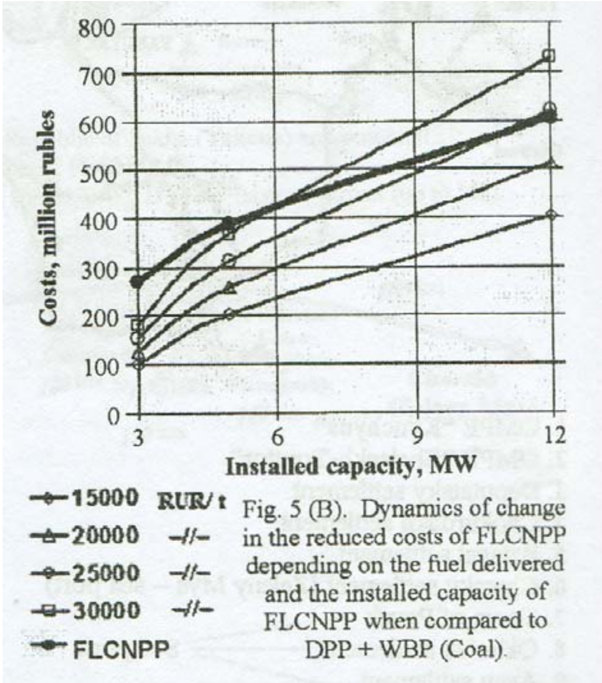


Fig. 5 (B). Dynamics of change in the reduced costs of FLCNPP depending on the fuel delivered and the installed capacity of FLCNPP when compared to DPP + WBP (Coal).

fact the facility should be provided with a fuel volume sufficient for two years;

- Relatively low electric and thermal loads of arctic consumers, industrial hubs and OMPEs;

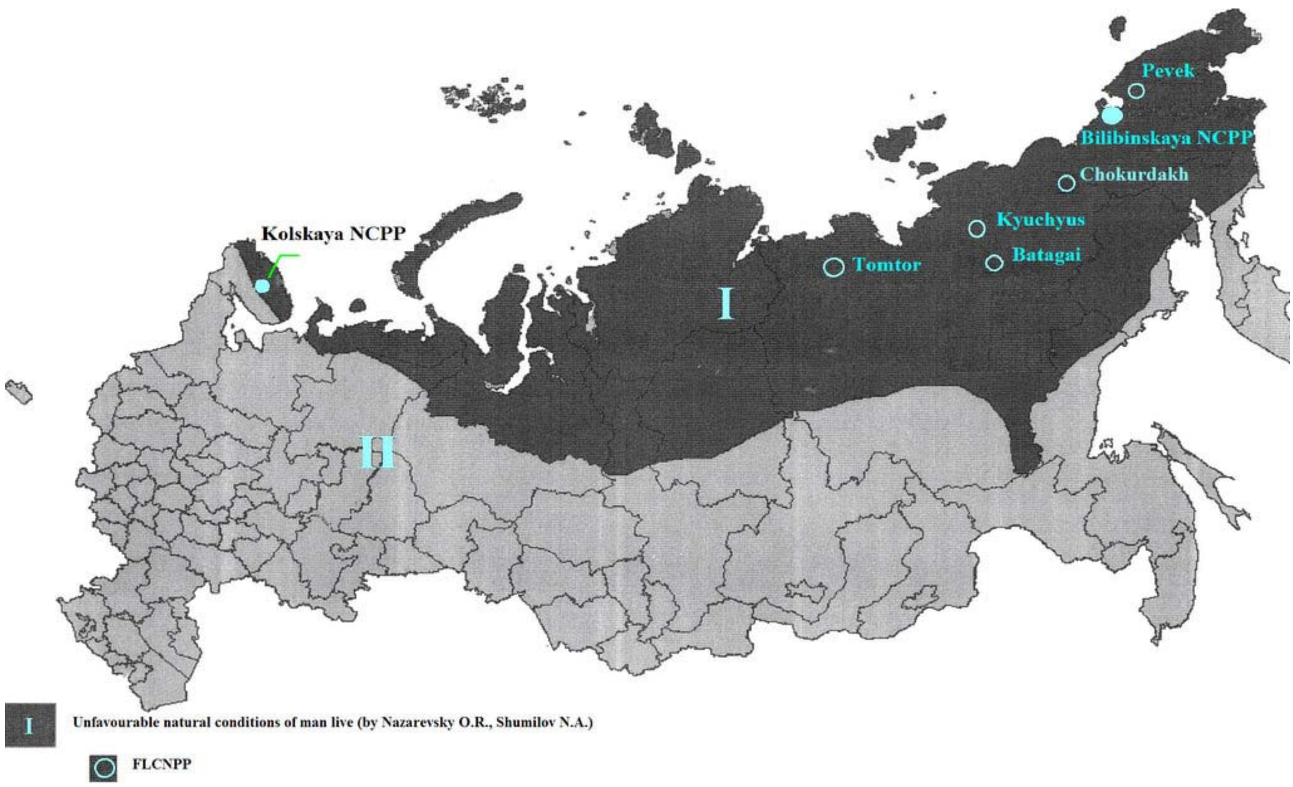


Fig. 7. Territory with unfavorable natural conditions for living of people and the first main NPPs – Kolskaya, Bilibinskaya NCPP, Pevek FLCNPP (KLT-40), Kyuchyus, Tomtor, Batagai, ABV, LBFR-10, etc.

Fig. 4 shows division into zones in terms of unfavorable climatic conditions for living and allocation of the first – basic nuclear power plants of large, small, mini and micro capacity in the Far North – Kolskaya NPP, Bilibinskaya NPP; in the future, nuclear power plants at Ore Mining and Processing Enterprises: in the settlements of Ust-Kuiga (gold), Chersky, the town of Pevek (gold, tin), the town of Okhotsk, the settlement of Tiksi, the settlement of Ayan – sea ports, fishing and fish processing, the settlements of Batagai, Chokurdakh, Kyusyur (non-industrial consumers) and others.

The calculations performed were used to determine the efficiency, reliability and safety of small nuclear power plants of new generation of types “Elena”, “Sakha-92”, floating “ABV-3-12”, “LBFR-10”, “Angstrem” and others in the conditions of the Sakha Republic (Yakutia). In Fig. 4 the sign (●) indicates possible and priority sites for allocation of LCNPP (stationary or floating) until 2025 depending on the mix of equipment, level of industry and nuclear energy - machine building development. The floating low-capacity nuclear power plants of top priority for the Sakha republic (Yakutia) include those to be constructed in the areas:

- engaged in development of **rare-earth metals, alluvial and root diamonds** (niobium, the settlements of Tomtor, Ebeleeh, Anabar, Molodo, etc.);
- developing **gold and tin deposits** (Kyuchyus, the settlements of Ust-Kuiga, Deputatsky, etc.);
- with **ports and non-industrial consumers** (Chersky, Zeleny Mys, Tiksi, Pevek, Okhotsk and Ayan, Batagai, Chokurdah).

Thus, in the future, allocation of nuclear cogeneration plants with a total capacity of up to 175 MW can:

- Replace 420 thousand t of coal and 250 thousand t of liquid fuel to be delivered from remote regions, i.e. up to RUR 3-4 billion per year;

- Replace 69 trips of dry cargo carriers (with a capacity of 2510 t each) and 82 trips of tankers (1500 t), 160 trips of tank trucks, 49 trips of large capacity motor transport;

- Release 2290 people of maintenance personnel in the transport sector;

- Save considerable capital investments into berths, liquid fuel reservoirs and coal storage facilities.

The feasibility of applying LCNPPs is determined by the objective factors including natural climatic, economic and social efficiency, environmental protection, manpower training, possibility of manufacturing the main and special equipment for small-scale nuclear energy, state policy of development, designing and creation of efficient use of low-capacity nuclear power plants and their utilization, i.e. decommissioning after the rated service life has expired, public attitude to small-scale nuclear energy sources in the country and in the world, and formation of the market of domestic and foreign demand and investing [6,7,8].

Today it is well known that the Japanese firm "Toshiba" has developed the project of low-capacity NPP for power supply to the American Indian village Galena with a population of more than 700 people by the Yukon river. The LCNPP has a capacity of about 10 MW and will operate without refueling for about 30 years. The plant is planned for start-up by 2010-2015 (Nuclear Energy Bulletin, April 2005, p.83).

Taking into account the market of floating and stationary LCNPPs it is expedient to create a special department in the concern "Rosenergoatom" with a status of Ministry of "Small-scale nuclear energy", including the following areas: **DPP**, **Small (coal-fired) CPs** and combined **DPP +WPP and LCNPPs** with fast neutron and thermal reactors.

V. CONCLUSIONS AND PROPOSALS

- The analysis of the performed calculations on the basis of the comprehensive, integration and rating methodology resulted in determination of **top priority** projects to be implemented. These are **"ABV", "LBFR-10", "Unitherm", "Elena", "Sakha-92", "Kushva", "Utro" and "KLT-40C"** of the last generation. They were determined taking into account high safety, technology, economics, environmental friendliness and social conditions. Here it is important to emphasize that the principal novelty of the FLCNPP for the Far North is long-term refueling interval varying from 10 to 20 years and more, an integral layout of the main equipment (reactor, steam generators) and natural or forced heat carrier circulation in the "first" loop of the plant ("ABV", "LBFR-10", "Unitherm", "Elena" and others).

- Division of the country's territory into zones in terms of climate favorableness, navigation seasons, heating season, multi-link character of fuel transportation, development of unique deposits and consideration for the world tendency towards the rise in the prices of oil, oil products and natural gas over 2-3 decades predetermines the perspective development and use of small nuclear power plants like mobile transportable plants with 100% of factory readiness and with periodical maintenance (by rotational team or satellite methods).

- According to the tentative estimates currently the northern territories of the FEFO in Russia including for the Sakha Republic require RUR 25 billion including more than RUR 3 billion annually only for organic fuel delivery.

- The Russian Federation is the only country in the world that has nuclear transport energy technologies for creation of low-capacity floating and stationary NPPs. There is a nuclear ice-breaker fleet. Since 2007 the first head-end floating nuclear power plants have been constructed – "KLT-40C" in Severodvinsk and Vilyuchansk, technical projects have been implemented in the towns of Pevek, Ust-Kamchatsk, etc.

- IPTPN SB RAS, ESI SB RAS, IINEI RAS, JSC "Malaya Energetika", NIKIET, OKBM, FEI, OKB "Gidropress", CNII named after A.N.Krylov, etc., believe it is expedient to perform R&D by 2010 to substantiate the use of perspective floating LCNPPs to provide production of unique mineral resources competitive in the world market, taking into account technological progress in the energy technologies of nuclear fuel and nuclear machine building. Towards this end it is necessary to hold a working meeting in the Sakha Republic and involve research, design and production organizations, as well as interested ministries, joint stock companies and concerns in order to coordinate and substantiate technical, economical, environmental (radiation) conditions of using FLCNPPs and implement the "basic" project on floating low-capacity NPPs with reactors "ABV-3-12 MW", "LBFR –10", "Unitherm", "Angstrem" and others, to determine demand in the energy market of local (isolated) industrial consumers in Russia and APR countries.

- It is expedient to raise a question on creation of a special "vertical" structure - Department or Committee for **Small-Scale Nuclear Energy** in the framework of the Federal Agency for Nuclear Energy in order to coordinate, fund and supervise development of energy machine building for small-scale nuclear energy.

- The nearest objectives (until 2015) for further R&D works on efficient and radiation-safe application of FLCNPPs are the analysis of experience in designing and construction of the **first head-end floating LCNPPS in Severodvinsk and Vilyuchansk** in order to apply the experience on efficient and safe use of nuclear power plants in the Far North.

- Taking into account huge damage (more than RUR 300 billion, according to the conservative estimates) due to the consequences of emergency on the fourth block of Chernobyl NPP it is expedient to raise the question within the concern "Rosenergoatom" and "Gosatomnadzor of Russia" on creation of a special department – **a center on the supervision of decommissioning, nuclear and radiation safety of population and environment under the conditions of cold climate** and develop the law "**On small-scale nuclear energy",** and on the parallel formation of a structure for radio environmental monitoring of the sites to be used for construction of small NPPs in the Russian Federation.

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VII. BIOGRAPHIES

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