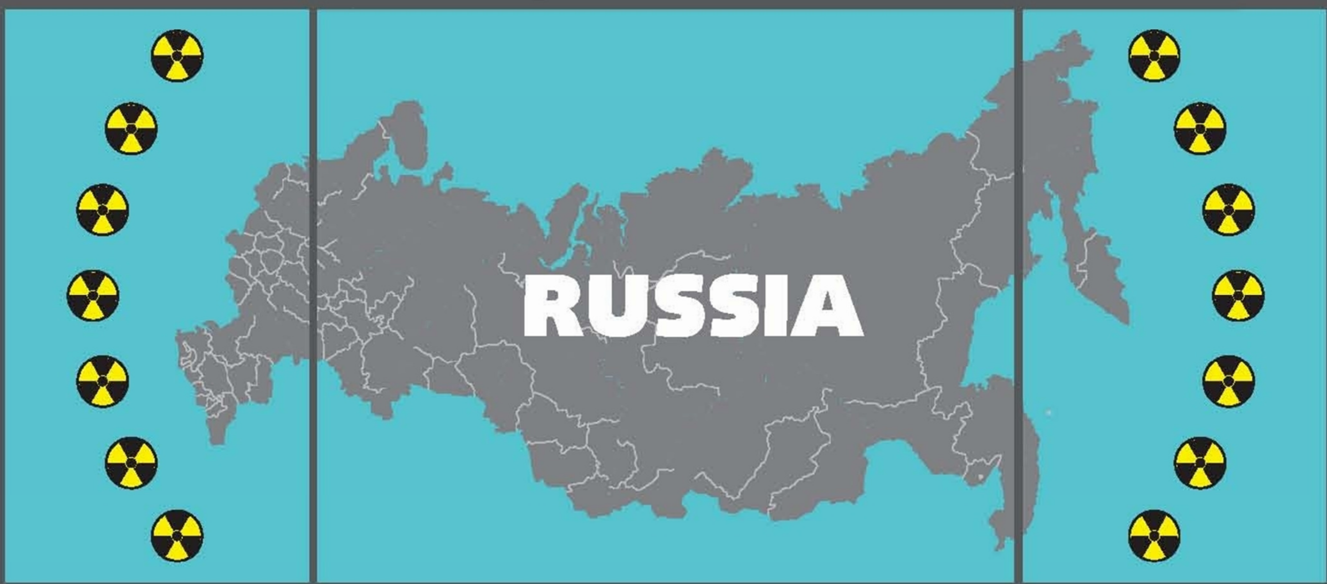
Bellona report 2011

Floating Nuclear Power Plants



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Floating nuclear power plants

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Foreword

The need for this report arose from the fact that in the past several years, the Russian State Nuclear Corporation Rosatom – the top authority governing the Russian nuclear industry, including its nuclear energy-generating sector – has been engaged in a massive propaganda campaign extolling the virtues of low-capacity nuclear power plants (LCNPPs), complete with a push to speed up construction of a pilot floating combined heat-and-power nuclear power plant (FNPP)[i], a variation on the basic LCNPP concept.

Low-capacity floating nuclear power plants have yet to see widespread application in the world. None of the countries with nuclear energy capabilities are using LCNPPs to any significant extent for either industrial or any other commercial purposes. What interest has been expressed in this type of nuclear power installations has always been on the part of the military and other special-activity entities – such as space agencies, special engineering services etc.

The idea of creating a large and diverse series of LCNPP installations was most enthusiastically promoted in the former USSR – and continues to be a popular topic in Russia. Back in Soviet times, small-scale nuclear energy installations were first designed for use in spaceships, tractor trucks, various surface and submersible watercraft, as well as on flatbed rail cars. The USSR also led the world in the number of nuclear-powered surface ships and submarines, equipped with nuclear reactors with capacities ranging between one and 160 megawatts.

The main argument used by proponents of LCNPPs in modern Russia is the need to solve energy supply issues in Russia's remote northern and far eastern regions. They calculate that even as expenditures incurred by various LCNPP projects – capital investment per unit of output expected to be produced – exceed by five times or more those that are required to launch a stationary 1,000-megawatt nuclear power plant, such projects still offer enticing prospects. The advocates of "minor-league" nuclear energy literally believe that money is no object where their pet idea is concerned – the important thing is to secure a claim on an energy market niche which may eventually generate lavish contracts, including international ones. Guided by this rationale, the State Corporation Rosatom is planning to offer its LCNPP (FNPP) projects to countries in Southern Africa, East Asia, South America etc. to solve problems with their energy supply and shortage of potable water.

The attitude toward these initiatives, both in Russia and elsewhere in the world, is that of ambivalence. It remains to be seen whether such projects deserve the generous bets placed on them either economically or from the point of view of security and safety – nuclear, first and foremost. For the time being, LCNPP advocates have yet to base their claims of economic and energy practicality and overall indispensability of these installations, or their assurances of LCNPPs' reliability and safety across the board, on any serious foundation. Answers are still pending with regard to most of the issues raised by experts from various non-governmental organisations back in 2000, when they carried out an independent analysis of the FNPP concept and prepared the results for publication in the brochure entitled "Russia's Floating Nuclear Power Plants: A Threat to the Arctic, World Ocean, and Nuclear Non-Proliferation" (http://www.bellona.ru/reports/floatnpp, in Russian).

[i] The design organisation behind the FNPP project analysed in this report, Joint Stock Company Afrikantov OKB Mechanical Engineering, terms these installations "small-power ship-based floating nuclear cogeneration plants." For more information, please see http://www.okbm.nnov.ru/english/lomonosov. – Translator.

The present report is an estimative analysis of a document called "Declaration of Intent to build an LCNPP on the basis of a floating power-generation unit with reactor plants of the type KLT-40C[ii] for operation in the closed administrative territorial entity[iii] of the town of Vilyuchinsk, Kamchatka Region."

This is why, when presented in this report, our assessments of this or that factor that has a bearing on an FNPP and its subsequent operation, are bound to be "tied" to one project's planned location – Vilyuchinsk. But much of what will be said in this report will hold true for other regions as well where a floating nuclear power plant may be slated for deployment in the future.

This report is meant for industry specialists, decision-makers, and potential FNPP buyers or recipients as well as the public. We have tried to expose all issues we find problematic with the FNPP concept. However, we chose not to go back to the events that took place in the FNPP project development before the year 2000 since those have largely been covered in "Russia's Floating Nuclear Power Plants: A Threat to the Arctic, World Ocean, and Nuclear Non-Proliferation," a publication that had been prepared with Bellona's participation.

We thank our contributors – experts from Greenpeace, environmentalists based in Kamchatka, economists, and all those who have rendered their invaluable help in making this report happen.

Introduction
(a brief history and certain highlights and episodes from the story of FNPP development)

The idea to create floating nuclear plants for commercial use first emerged in the United States in 1974. The first plant was to be built on the Eastern Seaboard, with four such installations deployed in the Atlantic Ocean 18 kilometres northeast of Atlantic City in New Jersey. Yet the project was abandoned – for reasons of both the exorbitant costs and pressure from public protests.

There had also been a number of earlier projects, developed as part of the American and Soviet defence programmes. The US Department of Defense had built the Sturgis, a 10-megawatt floating nuclear power plant that it operated during the Vietnam war, between 1967 and 1976, in the Panama Canal. Then in the early 1980s, the Soviet military commissioned a project to build Volnolom (Wavebreaker) 3, an FNPP with a 12-megawatt pressurised-water reactor of the type ABV-6, for subsequent use at the Ministry of Defence's test range on Novaya Zemlya. However, work on this project was ceased at an early stage of development.

The first civilian FNPP project appeared in Russia in the beginning of the 1990s. But at the time, Russia – a newly independent state that was going through a painful transition period from a Soviet dictatorship to a country with a market economy and democratic path of development and was struggling through economic, social, and political hardships – had no energy nor money to spend on

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[ii] Here and elsewhere in the text, letter and letter-numerical combinations used in original Russian designations – such as those of government documents, reactor models and the like – are rendered into English using simple Russian-to-English transliteration rules, unless common translated abbreviations exist as English equivalents. The English designation of the reactor model to be employed in the FNPP concept detailed in this report alternates between KLT-40S and KLT-40C in the project developer's materials (see, for instance, here http://www.okbm.nnov.ru/english/lomonosov) and other documents. The IAEA's Advanced Reactors Information System (ARIS) lists this model as KLT-40S. The combination KLT-40C will be used in this report. – Translator.

[iii] Known under the Russian abbreviation of ZATO, "closed administrative territorial entities" are restricted-access areas used for classified military or nuclear research. As part of the USSR's atomic-drive legacy, they have been serving as a kind of "reservations" created for the country's scientific community by the top Soviet nuclear authority in the mid-20th century to conduct highly sensitive research and experiments. There are 42 such towns spread across Russia with a combined population of over two million; most of these locations are known by combinations of a name and digit only, such as, for example, Krasnoyarsk-66. – Translator.

extravagant nuclear toys; the project was put on the back burner until the year 2000. Still, the idea was kept afloat between 1990 and 2001, including by some in the government. Every now and again a statement would be made by a high-ranking official, or a government document – directives, instructions, programmes, and the like – issued that even authorised government spending on FNPP development[iv].

In 2001, the project was once again reanimated. Still, in the past ten years, the story of developing floating nuclear power plants in Russia has been one fraught with impediments and even scandals. In 2002, Rosatom's predecessor, the Ministry of Atomic Energy (Minatom), and the now-defunct federal Russian Shipbuilding Agency agreed on a technical design for the project, which was followed by a search for a buyer, expected to pay for the construction, and a primary contractor, to build the prototype.

In 2006, the Severodvinsk-based shipyard Sevmashpredpriyatiye (Sevmash)[v] won the tender for the construction of the first FNPP. On August 8 that year, Rosatom signed a shipbuilding contract with Sevmash. On April 15, 2007, the keel-laying ceremony took place at the shipyard. The plan was to build the first vessel by 2010 for further use in Severodvinsk. There was also talk of building, within the next ten years, seven floating nuclear power plants in all for Russia's most energy-starved regions as well as for development of oil deposits on the shelf. This was mentioned, in particular, in statements made by Deputy Prime Minister Sergei Ivanov and Rosatom's head Sergei Kiriyenko. The idea got enough traction that Rosenergoatom – Russia's nuclear power plant operator company, which is wholly owned by Rosatom – and Sevmash even signed in April 2007 a declaration of intent based on which Sevmash was to build another six floating reactor units: Rosatom believed that only a large enough series (no fewer than seven floating reactors) would create viable economic prospects for this project. Kiriyenko himself freely admits to this line of reasoning behind the idea.

As of today, it remains unclear who might potentially become the buyers or investors into these costly energy sources. The main stumbling block at the moment, for investors or future customers, is that one is yet to see a comprehensible and transparent feasibility study for the project that would outline its economic and other important aspects (safety and regulatory framework, among others) in any convincing way. One has to keep in mind, moreover, that a floating nuclear power plant is not just a source of heat and power, but also a complex facility that comes packed with a host of various issues that need careful handling – such as radioactive waste, nuclear materials and technologies, operational regulations that must govern procedures involving nuclear and radiation hazards, specially trained personnel, etc. All this must be taken into account by the would-be buyers and investors as they make their decisions about buying or renting such an energy site.

Furthermore, potential investors are presumed to pursue an interest in investing into novel and promising projects. Rosatom does present its FNPP project as an innovation, but the technologies that will be employed when building the reactor plants and other equipment to be used in the FNPP are in fact obsolete, while the operational reliability of the equipment is not quite up to par. That can be confirmed by the decades-long history Russia has had operating its nuclear icebreakers and nuclear-powered submarines and surface ships – experience that, to put it mildly, leaves something to be desired.

Finally, it is a common assumption that a vigorous spread of floating nuclear power plants across the globe will open up broad possibilities for terrorists and opportunists of all sorts chasing nuclear materials and technologies for personal profit. These considerations will prompt special security

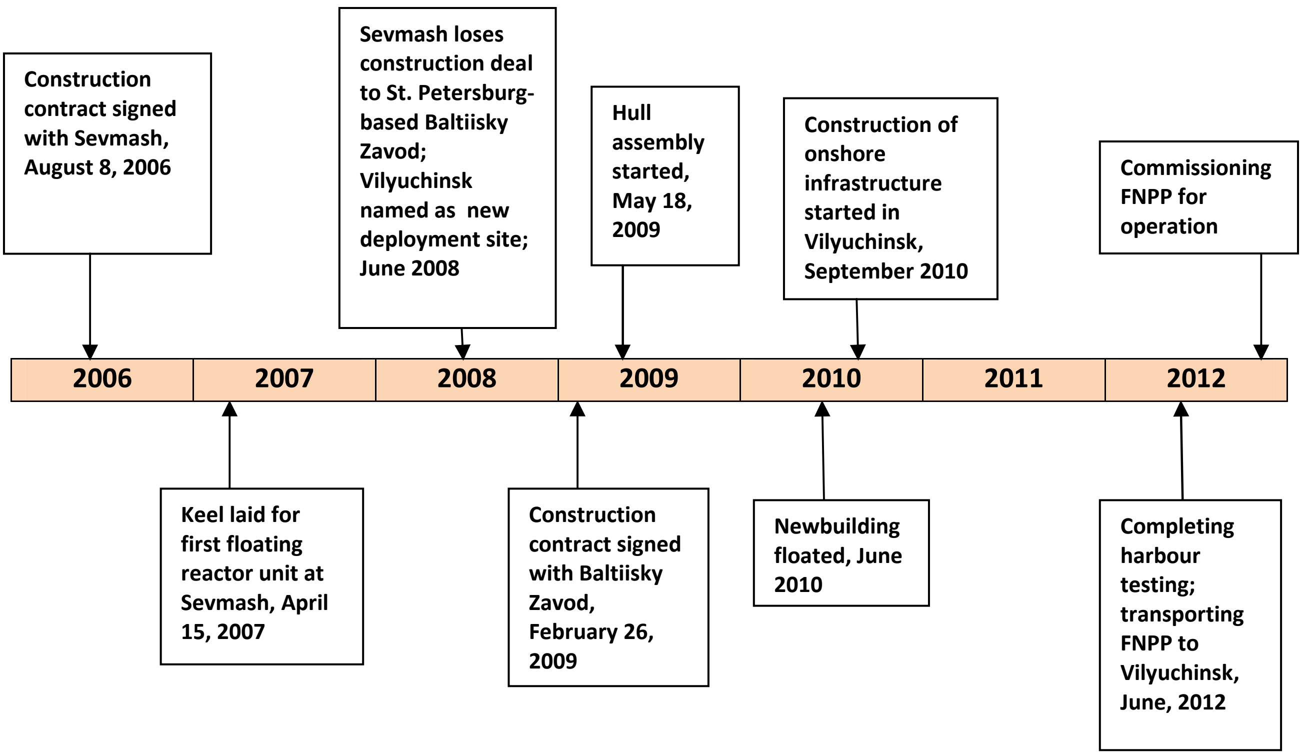
[iv] See Chapter 1 of "Russia's Floating Nuclear Power Plants: A Threat to the Arctic, World Ocean, and Nuclear Non-Proliferation" (http://www.bellona.ru/reports/floatnpp, in Russian).

[v] For more information on the enterprise, please see http://www.sevmash.ru/eng/. – Translator.

measures to be enforced on an international scale. Both private and state-owned investors with an eye on a floating nuclear power plant will have to be aware of the difficulties they will face if they agree to participate in such a project.

In early 2008, a conflict disrupted Rosatom and Sevmash's cooperation following the latter's failure to keep construction on schedule. Sevmash had also insisted that Rosatom raise the price of the FNPP construction contract up from RUR 9.1 billion to RUR 12 billion, citing rising costs of component parts, energy supply, associated services etc. Rosatom refused, saying that the working project and the costs had been agreed upon by its predecessor, Minatom, and the Shipbuilding Agency, then adjusted accordingly in 2007, and signed by all project participants, including Sevmash. Thus, the corporation said, it had no intention to revise the agreements already concluded. The squabble led Rosatom to seek the government's approval to transfer the construction of the floating reactor unit to the St. Petersburg-based Baltiisky Zavod (Baltic Shipyard)[vi] – a request fulfilled in 2008.

At the same time, a decision was made that the flagship FNPP would not be built for Severodvinsk, as had earlier been the plan, but for the needs of the far-off region of Kamchatka Krai[vii]. The choice to deploy the FNPP at the submarine base in Vilyuchinsk seems to be a questionable one, from the economic point of view, since neither the tiny Vilyuchinsk, nor, for that matter, the sparsely populated Kamchatka – a 182,400-square-mile peninsula in the Russian Far East, wedged between the Pacific Ocean to the east and the Sea of Okhotsk to the west – need an additional 70 megawatts of energy. The only reasonable explanation one can glimpse behind this strange decision is that no one in the military garrison that Vilyuchinsk is will be likely to protest at the positioning of the FNPP in the waters of a naval base, as well as that personnel with necessary qualifications to work at a nuclear power plant, including those with expertise needed for technical maintenance, can be drafted from among the submariners stationed at the base.



[vi] For more information about the yard, please see http://www.bz.ru/en/about.html. – Translator.
[vii] Or Kamchatka Region, *krai* being a common Russian word for "land" or "region," used often to denote a subordinate territorial entity of the Russian Federation, such as Kamchatka. – Translator.

On the other hand, if Rosatom is planning to use its first FNPP as an ex-display model to attract potential investors, then the choice of both the location and the deployment conditions may indeed have been an unfortunate one – consider the remoteness of the area, the restricted-access military garrison, and all the other prerequisites that not every potential buyer, especially a foreign one, can easily reproduce at home, such as an enclosed harbour, the security, the technical support, qualified personnel etc. Today, the need is clear to analyse and assess what exactly stands behind these decisions and what the future of this controversial idea to build a large series of floating nuclear power plants holds.

On June 30, 2010, Baltiisky Zavod in St. Petersburg held a festive ceremony to mark the floating of the *Akademik Lomonosov* (Academician Lomonosov, Project 20870), the flagship vessel that will accommodate the first floating nuclear energy-generating unit. Rosatom's head Kiriyenko, among a group of high-ranking officials who took delivery of the vessel, called the event "a day of celebration for the entire Russian atomic industry," expressing confidence that twenty-two months thence – or in the spring of 2012 – Russia's first ever floating nuclear power plant would be seen off on its journey to Kamchatka.

1. Project 20870: Main characteristics and technical specifications

The floating nuclear heat-and-power- generating unit of Project 20870 belongs to a class of low-capacity nuclear power plants. The FNPP project comprises:

- a floating power unit with two modified naval propulsion reactor plants of the type KLT-40C and two steam-turbine plants of the type TK-35/38-3.4c;
- offshore facilities to secure the generating unit in its place of stationing or undock it for release and to transfer the energy and heat produced onshore;
- onshore facilities to transfer the heat and power received from the generating unit on to the grid for further delivery to the end user.

The hull of the generating unit houses the reactors and the steam-turbine plants. This is also where storage facilities will be provided to accommodate fresh and spent nuclear fuel assemblies and solid and liquid radioactive waste, as well as the power supply system, the automatic control system dubbed Laguna (Lagoon), the vessels' service systems and equipment, and the living quarters and work areas. [1]

The chief project developer is the St. Petersburg-based engineering firm Aisberg (Iceberg).[viii] The Nizhny-Novgorod-based Afrikantov Experimental Design Bureau for Mechanical Engineering (OKBM Afrikantov) is in charge of designing and producing the reactors, the refuelling equipment, as well as the equipment to be used in the fuel and waste storage facilities. The steam turbines will be designed and produced by Kaluga Turbine Works.[ix] The production and supply of the ship's service systems is the responsibility of the Baltiisky Zavod shipyard. Altogether, judging by the primary contract and subcontract agreements alone, some 136 entities are involved in the engineering and production stage of the project. All the equipment to be housed in the FNPP hull will be assembled at the shipyard in St. Petersburg. According to project documentation, the construction of the floating unit is to last four years at the shipyard, after which it will take a year to tow the unit to the deployment site and conduct all necessary pre-launch works. The FNPP's operating period between yard overhauls is twelve years [1].

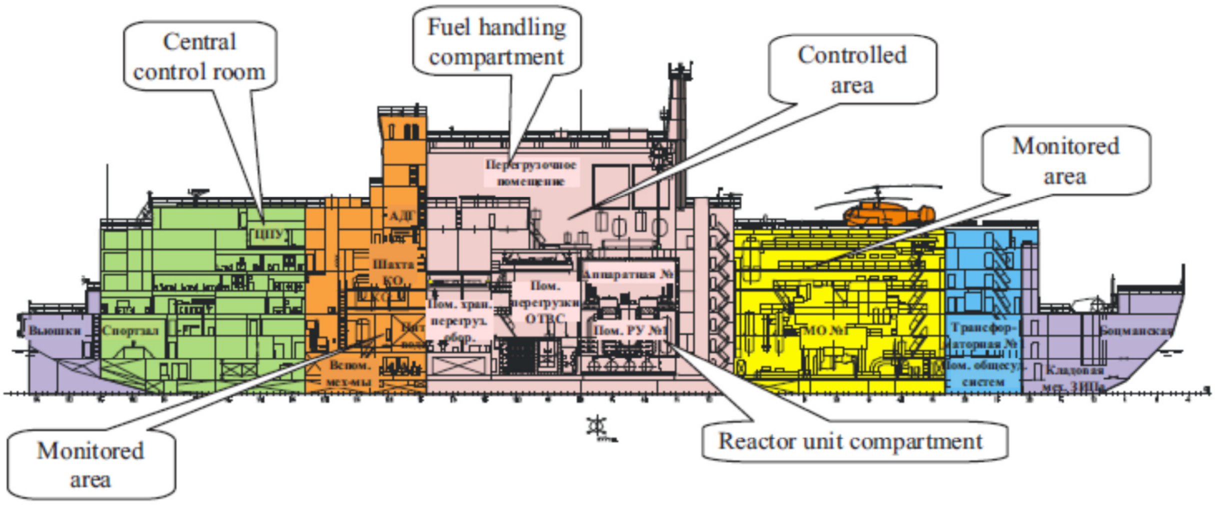
[viii] More information about this firm is available at its website at http://www.iceberg.sp.ru/ (in Russian). – Translator.

[ix] For more information about the enterprise, please see its website at http://www.ktz.kaluga.ru/english/default.htm. – Translator.

It is at this point still an open question where the potentially dangerous works associated with nuclear hazard that are involved in the construction and launch of the FNPP will take place – those that will be required to deliver nuclear fuel to the floating unit and to load it into the reactor, or to achieve first criticality and then increase the power load to projected capacity. The problem is that in the early 1990s, a mayoral decree banned all potentially nuclear-hazardous works within the city limits of St. Petersburg, and neither Baltiisky Zavod nor Admiralteiskiye Verfi (Admiralty Shipyard)[x] – another major shipyard in St. Petersburg, which also has an extensive history of building nuclear-powered fleet – have performed such works ever since. At any rate, official statements have it that when the nuclear battlecruiser *Pyotr Velikiy* (Peter the Great) and the nuclear icebreaker *50 Let Pobedy* (Fiftieth Anniversary of Victory) were being completed at the end of the 1990s at Baltiisky Zavod, all potentially nuclear-hazardous works involved in the construction were carried out outside St. Petersburg's city limits.

1.1 The hull of the floating power unit: Design and main characteristics

Because the nuclear power plant in question is a floating facility, the generating unit's hull and all of its characteristics, including its seakeeping qualities, are among the most important project elements that have a critical bearing on the site's future safety, including nuclear and radiation safety.



Picture 1. The hull of the floating power unit with two KLT 40-C reactor plants [1].

The floating energy generating unit represents a flush-deck, flat-bottomed, non-self-propelled vessel of the berth-connected type (that is, its main operational mode is that of long-term mooring at dockside) with rather square hull lines and a large multi-level superstructure. The stated sea class is KE* [2] A2. The KE* designation indicates that the vessel is a non-self-propelled floating facility with a combined prime engine power capacity of 100 or more kilowatts which has been built or manufactured in accordance with the rules and under the supervision of a classification body recognised by the Russian Maritime Register of Shipping and has been surveyed and received its classification certificate at the stage of construction and manufacturing. The symbol [2] stands for "two-compartment unsinkability standard" and means the vessel will remain afloat and will not lose stability and buoyancy even if, in the event of water permeating the hull, two of its adjacent compartments get flooded. The A2 (or AUT2) notation is what is called a "distinguishing automation mark" and means, according to the Russian

[x] For more information about Admiralty Shipyard, please see http://www.admship.ru/en. – Translator.

Maritime Register of Shipping's guidelines, that the "automation extent of the machinery installation is sufficient for operation of the machinery installation by one operator from the main machinery control room with unattended machinery spaces." In other words, the level of automation of the LCNPP's Floating Generating Unit's KLT 40C Reactor, as per the Russian Maritime Register of Shipping's classification, corresponds to A2 Class, which certifies that the reactor machinery can be operated by one operator from the central control room without any other servicing personnel present in the rooms accommodating the ship's power equipment. [3].

The main characteristics of the floating generating unit are specified in Table 1.

Table 1.

Floating generating unit: Main characteristics

	Parameter	**Value**
1.	Vessel type	Non-self-propelled, berth-connected
2.	Class notation	КЕ * [2] А2.
Vessel's dimensions and main operational characteristics:		
3.	Displacement, thousand tonnes	21.5
4.	Main dimensions, metres (m):	
	• Length OA	140
	• Beam	30
	• Draught	5.56
	• Height	10
	• Superstructure height	*around* 30
5.	Crew, per shift	70
6.	At-sea endurance, in days:	
	• By nuclear fuel reserves (i.e. self-sustaining period between refuels)	2.5 to 3 years
	• By fossil fuel consumption (emergency operation modes, towage trip)	30
	• By potable water reserves	20
	• By food reserves	60
7.	Service characteristics:	
	• Full projected service period	35 to 40 years
	• Full projected service period before yard repair	10 to 12 years

	• Duration of yard repair	1 year
	• Dockage frequency	Every 10 to 12 years
	• Full projected service period before main equipment overhaul	240,000 to 300,000 hours
8.	Resources required for operation:	
	• Non-recoverable water consumption for service water supply (non-recoverable water intake), cubic metres per year (m^3/year)	3,650
	• Potable water, cubic metres per day (m^3/day)	18
	• Waste water, cubic metres per day (m^3/day)	25
	• Power supply for internal use, megawatts (MW)	9.3

The generating unit's hull is all-welded and divided by bulkheads into compartments that form two distinct blocs, one housing the living quarters and the other the vessel's equipment and machinery (see Picture 1). The latter includes, in particular, the two reactors and two steam turbines, as well as auxiliary systems and equipment ensuring safe operation of the generating unit. The reactor compartment and the compartment designed for management of nuclear fuel are located in the middle section of the hull [1]. These compartments are separated from the rest by impermeable bulkheads that also play the role of physical and biological protective shields.

The bow accommodates compartments with turbogenerators and electrical engineering equipment; auxiliary installations and the living quarters are in the stern. The stern section of the living area contains the sleeping quarters and related amenities as well as equipment and utilities for accommodation of and personal use by the crew.

Altogether, a crew on the order of 140 are expected to work on board the FNPP, with two shifts of 70 personnel working on a rotational basis. Each shift is further divided into three watch teams since operating and servicing the vessel continues around the clock. Additional workforce will be employed to provide the administrative, engineering and maintenance staff, security, and personnel in onshore services.

The generating unit will have an ice-strengthened hull and special means of towing for towage in ice conditions by a nuclear-powered icebreaker of the kind such as the NS *Rossiya* (Russia)[xi], as well as means of docking/undocking (fixing/unfixing) at the site of deployment. The main hull and the load-bearing structures of the superstructure are done in steel with high brittle-fracture resistance to ensure integrity in conditions of low temperatures. Electrochemical protection and ice-resistant paint coating protect the underwater part of the hull from corrosion [2].

Every twelve years, the floating unit is to be towed to a shipyard for yard and dock repairs. During yard repairs, the reactors are refuelled and radioactive waste is unloaded from the vessel. The repairs are to take one year, after which the unit is sent back to resume operation.

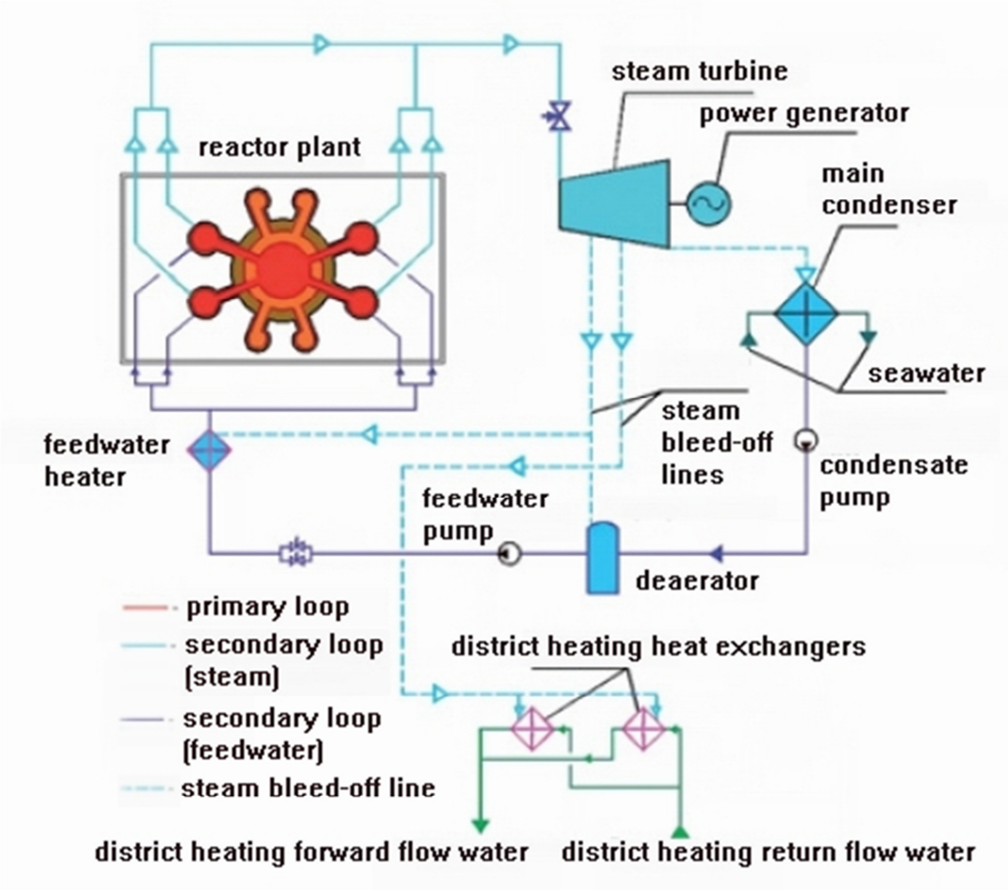
[xi] The NS *Rossiya*, Project 10521-1, built 1985, is a Russian nuclear icebreaker of the Arktika class. For more details, see vessel specifications in the Russian Maritime Register of Shipping (http://www.rs-head.spb.ru/app/fleet.php?index=810688&type=book1&language=eng). – Translator.

In all, the projected useful life span of the FNPP is to total around 40 years – with three 12-year operating cycles alternating with one-year yard repair periods.

1.2. FNPP's energy systems

The entire energy complex of a floating nuclear power plant can be divided into two blocs: the main one, which comprises the nuclear power generation system, and the auxiliary one, which is non-nuclear. The nuclear bloc includes the two KLT-40C reactors with a thermal capacity of 150 megawatts each and the two steam turbine plants with turbogenerators each having a power capacity of 35 megawatts. Altogether, the FNPP's thermal capacity totals 300 megawatts and its combined power capacity is 70 megawatts. Each of the reactor pair and the two steam turbine plants are located on either board of the vessel and operate autonomously.[xii]

Simplified, the reactor's thermal circuit functions as follows (see Picture 2). Steam produced by the reactor's steam generators runs through the steam turbine, which spins the power generator. The power generator produces electric power, which is then supplied to the consumer. Passing through the stages of the turbine, exhaust steam is collected to heat feedwater in a special heat exchanger (feedwater heater), as well as to heat water in the heat exchangers of the district heating system. Once it has gone through the turbine, waste steam is condensed in the main condenser using outside water (seawater). A condensate pump then sends the resulting condensed steam into the deaerator, where gasses dissolved in the steam – primarily, oxygen – are removed from it. An extraction pump then pushes the feedwater into the reactor's steam-generating boiler and the cycle is repeated.



Picture 2. The thermal circuit diagram of the floating generating unit's nuclear bloc.

[xii] Please see Appendix 1 for a detailed description of the reactors' thermal circuits and its auxiliary systems.

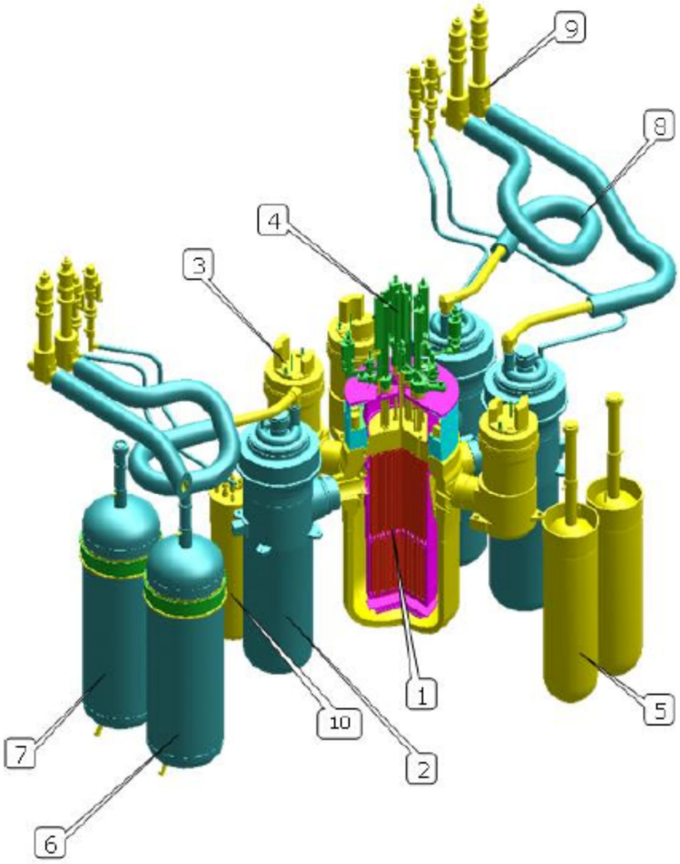
The auxiliary energy bloc comprises four backup diesel-driven generators, each with a capacity of 800 kilowatts, as well as four emergency standby diesel-driven generators with a capacity of 200 kilowatts each. The floating unit's design also provides for a backup boiler station with a steam output capacity of 16 tonnes per hour [1].

1.2.1. Reactor plant and auxiliary systems

The KLT-40C reactor is a modular pressurised-water reactor plant that serves as a steam-generating station (see Picture 3). The main components of the reactor system are: the reactor proper, steam generators, reactor coolant pumps, heat exchangers, pressurisers, valves and pipelines used for a variety of purposes, including valves and pipelines that form the reactor system's main circuits.

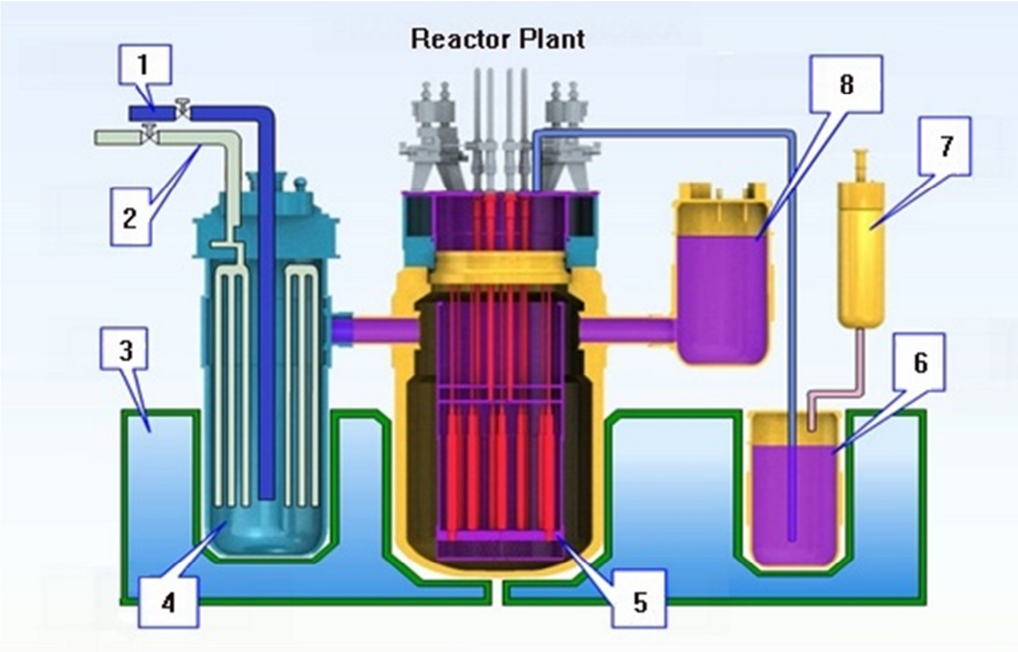
The main reactor circuits are the primary and secondary, as well as third and fourth loops. Each of the two reactors is enclosed in a steel hermetic containment vessel made as a durable-impermeable – that is, both capable of enduring an impact of external force and providing leak-proof tightness – structure of the floating unit's hull and designed to withstand the maximum pressure that may build up inside as a result of an emergency or an accident.

The KLT-40C reactors' main characteristics are listed in Table 2.[xiii]



Picture 3a. View of KLT-40C Reactor Plant [1]: 1. Reactor. 2. Steam generator. 3. Main circulation pump. 4. Control rod drive mechanisms. 5. Emergency core cooling system accumulator. 6. Pressuriser (1st Vessel). 7. Pressuriser (2nd Vessel). 8. Steam lines. 9. Localising valves. 10. Heat exchanger of purification and cooldown system.

[xiii] Please see Appendix 1 for a detailed description of the reactor design and the primary coolant circuit, as well as the list and main characteristics of support systems and auxiliary circuits ensuring normal functioning of the reactor system.



Picture 3b. View of KLT-40C Reactor Plant [1]: 1. Feedwater. 2. Steam (pressure at 3.7 megapascals, temperature at 290 degrees Celsius). 3. Metal-water shielding tank. 4. Steam generator (4 pieces, steam-generating capacity at 240 tonnes per hour). 5. Reactor (150 megawatts in thermal capacity, rated temperature at 350 degrees Celsius). 6. Pressuriser (4 pieces). 7. Gas cylinder (18 pieces). 8. Main circulation pumps (4 pieces).

Table 2.

Main characteristics of the KLT-40C reactor

Parameter	Value
• Reactor type	VVRD[xiv]
• Design concept	Small modular
• Reactor vessel assigned service period, years	35 to 40
• Reactor vessel assigned life limit, hours (h)	280,000
• Reactor weight without water, kilograms (kg)	70,000
• Reactor weight with water, kilograms (kg)	77,700
• Uranium-235 fuel enrichment, percent (%)	18.5
• Thermal capacity, megawatts (MW)	150
• Natural circulation level, percent of nominal load (% N_{NOM})	3 to 5
• Core coolant flow rate, tonnes per hour (t/h)	2,600
• Primary circuit pressure at nominal load, kilograms per sq. centimetre (kg/cm^2)	128
• Design-basis pressure, kilograms per sq. centimetre (kg/cm^2)	162
• Coolant temperature at core inlet, degrees Celsius (°C)	280
• Coolant temperature at core outlet, degrees Celsius (°C)	317
• Design-basis temperature, degrees Celsius (°C)	350

[xiv] For, literally, “water-water pressurised reactor,” a type that would correspond to the Western series of PWRs, or pressurised water reactors – light-water reactors where water is used both as a coolant and neutron moderator. – Translator.

• Steam-generating capacity, tonnes per hour (t/h)	240
• Maximum electric power output, megawatts (MW)	2x38.5
• Maximum heating output, gigacalories per hour (Gcal/h)	146
• Maximum electric output at maximum heating output, megawatts (MW)	2x19.4
Feedwater parameters at steam generator inlet	
• Pressure, kilograms per square centimetre (kg/cm^2)	61
• Temperature, degrees Celsius (°C)	170
Superheated steam parameters	
• Pressure, kilograms per square centimetre (kg/cm^2)	38
• Temperature, degrees Celsius (°C)	290

Reactor core

The floating generating unit comes with a modification on the KLT-40 reactor core design, a cassette-type reactor core where fuel assemblies, according to OKBM Afrikantov, are delivered to the customer as "part of the reactor with the plugged reactor core."[xv] The designers say the new concept of the core has provided a solution for the potential risk of proliferation of nuclear materials and technologies, a concern emerging necessarily with the very idea of a floating nuclear power plant. It is stated that the level of uranium enrichment for the fuel to be used in the core will not exceed 20 percent, which will both allow Rosatom to comply with non-proliferation enforcement standards set forth by the International Atomic Energy Agency (IAEA) for highly enriched nuclear materials (highly enriched uranium has a greater than 20 percent concentration of uranium-235) and improve the project's investment appeal for future customers. However, fuel used in the FNPPs that are planned for deployment in Russia will apparently be enriched to levels higher than 20 percent: It has been announced that one of the goals of creating floating nuclear power plants is to test-prove and perfect the technologies and core concepts in development for further use, in particular, on nuclear-powered submarines and surface ships of various purposes [13].

The main parameters serving to qualify the working efficiency of fuel rods used in the core of a floating power unit's reactors are [10]:

- Accrual of fission fragments in the fuel composition;
- Rate of heat release at averaged operational load;
- Rate of heat release at nominal load;
- Fast neutron fluence;
- Fuel life at load;
- Fuel life of fuel rods with zirconium claddings under coolant surface boiling modes.

The reactors' cassette cores are compact and not subject to repairs – that is, no possibility is provided to remove and replace individual fuel assemblies in case of accidental or wear-induced failures. A fuel cassette serves as a structural element that contains a bundle of fuel rods, spacer grids, a shroud tube, end switches – the top nozzle and the bottom nozzle – and fasteners. The cassette-type design of the core is expected to improve the capacity and operational life – i.e. the energy reserve – of the reactors. Enhancing the reactors' energy-producing capability allowed by using a cassette-type arrangement of the core is done by way of increasing the number of fuel rods and expanding the core in size. Neither the remaining equipment of the reactor nor its structural arrangement change as a result.

[xv] From a booklet on the KLT-40C plant available at http://www.okbm.nnov.ru/english/lomonosov. – Translator.

The cassette-type design also solves the problem of the service life of the shielding assembly (neutron reflector). There is the high likelihood that the fuel used in the fuel cassettes will be dispersion fuel rods based on a “UO2 (uranium dioxide) + aluminium alloy” compound – intermetallic fuel with a higher uranium content. Using this fuel ensures conditions for limiting the enrichment degree in the fuel. The claddings for these fuel rods are made of a zirconium alloy of the new Russian grade dubbed E-635. Studies have shown this zircalloy brand to have good corrosion- and irradiation-resistant properties. The reactor core designer, OKBM Afrikantov, says future reactor cores will have a significantly longer campaign period – the period of time during which a reactor produces energy from one fuel load – or up to ten years, but in the FNPP project under consideration in this report, the stated reactor core campaign period is three years. The main characteristics of the cassette-type reactor core of the KLT-40C reactor are listed in Table 3 [13].

The chief distinguishing feature of the operating environment designed for fuel rods in a floating nuclear unit’s reactor core, compared to reactor cores of nuclear-powered icebreakers, is the higher average operational capacity of the reactor.

This leads to the following modifications in the main operational parameters of fuel rods used in a floating power unit’s reactor:

- Higher heat flux at averaged operational load;
- Longer life period of fuel rods under coolant surface boiling conditions;
- Higher rate of accumulation of fission fragments in the fuel composition;
- Higher rate of fast neutron flux.

Table 3.

Main characteristics of the KLT-40C cassette-type reactor core.

Parameter	Value
Rated power, megawatts (MW)	150
Number of fuel assemblies	121
Circumscribed diameter, millimetres (mm)	1,219
Height, millimetres (mm)	1,300
Energy capacity, megawatt-hours (MWh)	$3.3*10^6$
Campaign duration, efficient days	22,000
Fuel rod diameter, millimetres (mm)	6.2
Rod pitch in fuel assemblies, millimetres (mm)	8.35
Area of heat transfer surface, square metres (m^2)	312.5
Number of fuel rods in the core	12,342
Uranium density in fuel kernel, grams per cubic centimetre (g/cm^3)	4.5
Average fission product build-up in fuel kernel, grams per cubic centimetre (g/cm^3)	0.42
Maximum fission product build-up in fuel kernel, grams per cubic centimetre (g/cm^3)	0.65
Specific power density in the core, megawatts per cubic metre (MW/m^3)	110
Average heat flux from fuel rod surface, megawatts per square metre (MW/m^2)	0.47
Specific linear heat generation rate, watts per centimetre (w/cm)	90.7

1.2.2. Steam turbine plant

The floating power unit will have two steam turbines of the type TK-35/38-3.4c. These are heating turbines designed to produce heat and drive the generators that serve as electric power sources. The rate of fresh steam consumption in the turbine is 220 tonnes per hour at a temperature of 285 degrees Celsius. The turbines have three steam extraction lines. The first and the third are non-regulated bleed-off lines whose purpose is to heat feedwater. The second line is an automatic extraction line that provides steam to heat the feedwater and the water of the intermediate circuit [1].

The regulating range of thermal energy flow to the heaters of the intermediate circuit is within 0 to 100 percent provided that power load at the generator terminals does not fall below 30 percent of nominal load. This limitation has to do with cooling the turbine's last stages. An electric load range of between 30 and 100 percent of rated load provides for independent regulation of heat and electric power delivery.

The turbine's heat flow system provides for additional delivery of thermal energy through peak intermediate water heaters by using live steam extracted upstream of the turbine. With this, electric power capacity decreases. Peak heaters are necessary during winter periods as they cover peak heating loads. Heat is carried from the turbine via the intermediate circuit by water under pressure, which serves as an additional barrier against radioactivity carryover to district heating consumers. The steam generator plant's main equipment – the turbine, the horizontal double-circuit surface condenser, and the electric power generator with its auxiliary systems – is designed as a unitised set [20].[xvi]

Table 4.

Main characteristics of the TK-35/38-3.4c steam turbine plant

Parameter	**Value**
Electric power at generator terminals, megawatts (MW)	2x35
Thermal power output to the district heating system, gigacalories per hour (Gcal/h)	2x25
Maximum electric power capacity without heat output, megawatts (MW)	2x38.5
Nominal temperature of water heated in condenser, degrees Celsius (^{o}C)	13.4
Mode of thermal energy transfer from floating power unit	Intermediate circuit
Parameters of superheated steam upstream of turbogenerator set: – Pressure, megapascals (MPa) – Temperature, degrees Celsius (^{o}C)	 3.43 285
Cooling water temperature, degrees Celsius (^{o}C)	10
Cooling water flow rate, cubic metres per hour (m^3/h)	5,400
Steam pressure in turbine condenser (heating mode), kilopascals (kPa)	5
Intermediate circuit water pressure, megapascals (MPa)	~1.6
Intermediate water flow rate, cubic metres per hour (m^3/h)	420
Intermediate circuit water nominal temperature at inlet/outlet, degrees Celsius (^{o}C)	130/70

[xvi] Please see Appendix 2 for the main characteristics of the steam turbine plant's steam lines, as well as the basic information about the condensate-feedwater system and the main condenser cooldown system.

1.2.3. Backup energy supply sources

In order to provide power supply during towage, as well as when the nuclear energy installations on board are under transition or emergency conditions, the FNPP is equipped with emergency generators powered with fuel based on organic sources.

Power for the automatic starter system is provided by a double set of 24-volt starter storage batteries. The emergency diesel-powered generators start up automatically within around 10 seconds. The backup generators' capacity is sufficient to start up or shut down one reactor plant and steam-generating station (with the other reactor plant in shutdown). During voyage (towage), power for internal electricity needs is provided by the backup generators at a voltage output of 400 volts.

1.2.4. Management of spent nuclear fuel and radioactive waste

As per the design, which determines the expected operational parameters of the floating power unit, three reactor refuelling operations are envisioned to ensure its functioning between yard overhauls (10 to 12 years). Two of these are done during the entire operating period, the third coincides with major yard repair. Consequently, the floating power unit's fuel handling complex will have four reactor cores in storage at any time, including fresh fuel before refuelling and spent fuel after refuelling. The project provides for installation, in a safety enclosure, of crane equipment – or a refuelling machine – in order to carry out the sequence of works involved in refuelling the onboard reactors, as well as the operations involved in storage of spent nuclear fuel and its transfer to an onshore facility during the pre-overhaul period. Additionally, "wet" storage facilities are provided for in the project, complete with systems serving to remove residual heat from the spent fuel assemblies. Various solid radioactive waste is also generated in the course of the floating power unit's operation and during core replacement, which includes the spent fuel assemblies removed from the reactor plant, instruments and equipment parts, special-purpose tools used by personnel, cleaning cloth, protective cover material – such as film used to shield surfaces for the duration of specific works – special protective clothing, glassware used by the radiochemical lab, the spent charges of the ion exchange filters of the first and third cooling circuits, and other solid waste that falls under the category of solid radioactive waste.

For these reasons, the spent nuclear fuel and solid radioactive waste storage facility on board the FNPP will perform the following functions:

- accepting for storage, storage, and removal of spent fuel assemblies and solid radioactive waste for transfer onshore;
- maintaining spent fuel assemblies' temperature within the acceptable range based on the actual levels of residual heat release;
- localising release of radionuclides within the confines of the spent nuclear fuel and solid radioactive waste storage facility;
- maintaining quality characteristics of the cooling water that comes in contact with spent nuclear fuel within the ranges that ensure minimal corrosion rate of spent fuel rods;
- maintaining design-basis operational parameters;
- decreasing levels of radioactivity emitted by radiation sources in storage in the spent nuclear fuel and solid radioactive waste storage facility to conform with levels established for the immediate premises of the storage facility and the adjacent premises.

The FNPP project stipulates that storage of solid and liquid radioactive waste will be carried out without involving the use of special-purpose nuclear service vessels or floating maintenance refuelling bases during the entire 12 years of between-overhaul operation.

During dock repairs following the 10- or 12-year between-overhaul operating period, the spent nuclear fuel accumulated over this period will be transferred at the shiprepairing yard from the floating power unit's fuel handling complex into transport containers, subsequently to be shipped off for reprocessing.

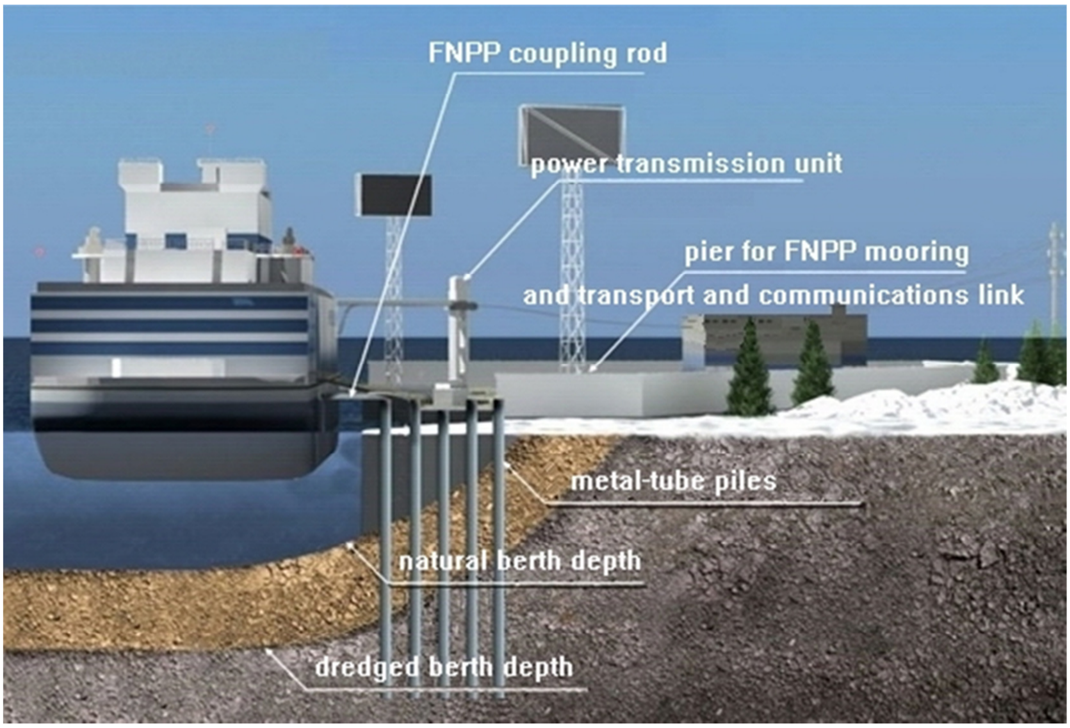
2. Offshore and onshore infrastructure

The project stipulates that the site of the FNPP's expected operation be chosen in a natural water area with sufficient size and depth for its deployment and sufficient additional space allowing for unhindered manoeuvring of service vessels.

Picture 4 shows a simplified arrangement diagram of the FNPP's site of deployment and related infrastructure. A variety of hydroengineering installations are needed in place of deployment to ensure the floating power unit's berthing and unberthing, normal operation, and transport and technological communications lines with the shore. These installations include [2]:

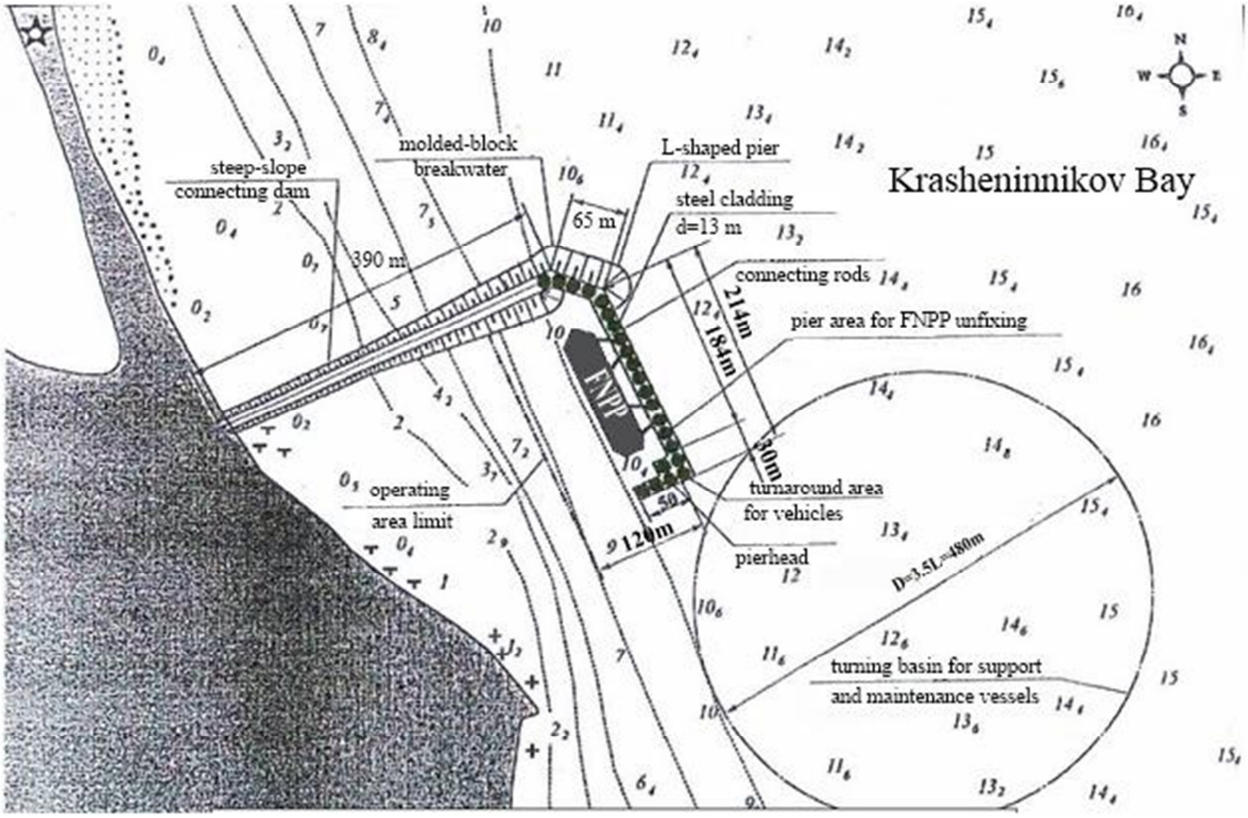
- coastal defence structures (seawalls, breakwaters);
- waterfront structures (berthing facilities) for FNPP deployment;
- water area designated for FNPP operation;
- dredging, bank protection;
- navigation marks.

The water area chosen for FNPP berthing must be wide enough to accommodate service and maintenance vessels as well as to be able to have two floating power units stationed at the berth at once so as one of them can be unplugged from the land-based power grid and its power-feeding capacity replaced by the other as the other is being connected to the grid.



Picture 4. Cross-section view of waterfront facilities recommended by the project for FNPP operation in chosen water area [1].

On the shore side, facilities have to be built to arrange distribution and delivery of energy produced by the FNPP to consumers, as well as utility networks, transport communications routes, and buildings housing administrative and maintenance services. Furthermore, utilities will have to be provided for that will stretch beyond the site of FNPP operation. A heat substation will need to be built to transfer heat from the intermediate circuit of the floating power unit into the onshore district heating network and which will accommodate the pumps of the FNPP's intermediate circuit, hot water circulator pumps, and water-water heaters to heat the district heating system's water. Additionally, the complex of coastal infrastructure will also need to have pollution control facilities for treatment of waste water and storm runoff discharged by the onshore facilities servicing the FNPP and the floating power unit itself (for such cases when the FNPP's own effluent treatment facility is out of operation and the waste water is transferred onshore for disposal). A service road suitable for vehicle traffic must also be in place to allow for transport communication and connect the FNPP with the existing system of local roads and expressways.



Picture 5. Layout diagram showing the FNPP stationed in its place of operation in Krasheninnikov Bay in Kamchatka [1].

3. Safety risks

A floating nuclear combined heat-and-power plant is a complex work of engineering that represents a combination of three sophisticated systems – the nuclear power plant proper and offshore and onshore facilities. Accordingly, an evaluation of such a project's safety factors will have to be done both separately as a nuclear power station and a sea vessel and as an integral site, with all the conditions, operating modes, and stages and phases of its construction and functioning taken together as factors of significance.

3.1. Ensuring the floating power unit's safety and survivability as a marine vessel

A floating nuclear generating unit is a special-purpose flat-bottomed non-self-propelled berth-connected vessel, and its design suggests a practically unlimited operation in all the seas and oceans of the globe, including the Arctic Ocean. It must thus be assessed for safety as such, taking into account all the international requirements set forth for marine vessels.

The qualities that have a considerable bearing on a vessel's safety, including a floating power unit, are its seaworthiness and those aspects of its design that ensure its stability and unsinkability. With Project 20870, the design of the floating generating unit has failed to meet the rigorous nautical standards – an inadequacy rooted in the very initial concept. The flat bottom, low resistance to wind, and zero steering capabilities due to an absence of steering gear and engines – all these factors automatically qualify the floating power unit as a potentially dangerous (highly dangerous) floating facility that must always be accompanied (safeguarded) by special towing vessels and means even when the FNPP remains at berth.

Floating nuclear power plants are planned for use in both Arctic and subtropical seas, and when designing its seagoing qualities and those characteristics that ensure its unsinkability and endurance, the peculiarities of voyage taken in the Arctic or subtropical waters must be factored in – though it is something that, as practice shows, is quite difficult to implement.

For instance, going in the Arctic seas requires measures to protect the hull against the low temperatures and the impact of ice, while in the warm waters of the southern latitudes, the hull is mostly susceptible to the harmful effects of the algae and the aggressive warm saltwater environment, which triggers and intensifies greatly corrosion processes in both the hull and outboard fittings.

According to technical specifications, the floating power unit is to remain afloat even if two adjacent compartments are flooded [1]. These are not the best possible measures that could have been provided by the design to ensure the nuclear vessel's unsinkability. For instance, designs developed for large military-purpose surface ships allow for inundation of four or more watertight compartments without impairing the vessels' floatability [8]. The floating nuclear generating unit only has seven compartments divided by watertight bulkheads and a large number of internal decks covering the compartments on top, as well as a multitude of bulkhead penetration glands and other fittings, owing to a great concentration of various systems, equipment, and machinery on board. If water permeates the hull, these factors would precipitate an unsymmetrical flooding of the compartments, which in the end will impact negatively the vessel's survivability.

Towage

The project stipulates that the floating power unit will mostly be used as a berth-connected vessel, moored in its place of operation. However, while towed to its place of permanent deployment, it will have to cross great expanses of sea – and possibly, ocean – waters, if Rosatom's plans to sell floating nuclear power plants to customers in Africa, Asia, and South America are to pan out.

Towing by sea is a special case in maritime practice, one associated with complex manoeuvring and requiring special technical, navigational, and organisational measures. Towing a non-self-propelled nuclear vessel that a floating nuclear power plant is would be an exceptional case, one that has had no precedent in the global shipping history to date. Certain experience has been accumulated in towing floating derricks, barges, and other similar floating facilities, but the world is yet to see a case of a nuclear berth-connected vessel transported over a long distance via sea towage. The complexity of such an operation would be compounded by the fact that for nuclear vessels, calling into a port – or even entering a state's territorial waters – is contingent on special permissions and involves a lot of red tape. It was for that reason exactly – limited access to a great number of international ports – that, for instance, the nuclear-powered cargo ship Sevmorput[xvii] proved to be such a challenge for efficient operation.

If during towage an emergency situation develops on board a floating power unit – which is to carry nuclear materials in its reactors and storage facility – and the emergency compels the vessel to request permission to enter a foreign state's port or territorial waters to seek harbour, this may lead to serious problems.

Furthermore, the operation of a floating power unit requires continued security measures both during towage and in place of deployment. Security will be needed not only for the power plant itself and the areas on shore near which it will be stationed, but also for the waters it will be crossing or operating in, including at subsea level. According to the International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code), made mandatory by the International Maritime Organisation (IMO)[xviii] in 1998, the ship-owner must develop, employ, and maintain a safety management system for such ships. Most likely, this task will fall on Atomflot,[xix] a Rosatom structure in charge of operating Russia's nuclear fleet. But it remains unclear just how such measures might be implemented with regard to floating nuclear generating units, which are expected in the future to be operated in other countries and possibly on other continents. What is evident is that installing such a safety management system will entail significant overhead expenses, efforts, and resources. [3].

Towing a non-self-propelled flat-bottomed vessel in storm or ice conditions requires special preparation and ability to make the right decisions. In adverse conditions, using only an ordinary towline will prove inadequate. At least three or four tow vessels or rescue ships will likely have to be used to tug the floating power unit under such conditions, two of which will need to be secured to the vessel along the sides, each on either board, for alongside towing. And if the first FNPP is transported to Kamchatka via the Northern Sea Route, icebreakers will be needed to lead the towing party – and towing such a vessel by an icebreaker is a costly and complex operation, one that will require special tugging equipment and special training for the personnel [3].

The project design guarantees that the floating nuclear power plant will withstand such extreme conditions as wind speeds of up to 25 metres per second, an earthquake with a magnitude of 7 to 8, the impact of a small Yak-40-type aircraft, the impact of lightning, or an explosion destroying an external power supply source on shore or on board a vessel secured to one of the sides of the FNPP, among other possible contingencies [1]. Project documentation says the design of the floating power unit provides for a stable operation of the equipment, machinery, and systems under a G-force of no less than 3g applied in any direction, under conditions of surge, sway or heave. Only experience will show to which extent this will prove reliable in practice, but as a marine vessel, the first floating power unit reveals certain deficiencies and risks linked to its design and expected operation.

[xvii] For more information on this vessel, please see the relevant entry in the Russian Maritime Register of Shipping (http://www.rs-head.spb.ru/app/fleet.php?index=840293&type=book1&language=eng) or Bellona's article on the Russian commercial nuclear fleet at (http://www.bellona.org/english_import_area/international/russia/civilian_nuclear_vessels/icebreakers/30107). – Translator.

[xviii] For more information, please see http://www.imo.org/Pages/home.aspx. – Translator.

[xix] The State Nuclear Corporation Rosatom's description of this entity (at http://www.rosatom.ru/wps/wcm/connect/rosatom/rosatomsite.eng/about/enterprises/#6) says Atomflot "provides icebreaker convoys to escort ships on routes of the Northern Sea Route, arranges high-latitude expeditions and sea shipments of containerized cargoes. It integrates the nuclear-propelled fleet with its onshore infrastructure, providing for operation and technological support of nuclear-powered icebreakers and service vessels." Atomflot's website (http://www.rosatomflot.ru/) is available in Russian only. For more information on this enterprise, please see Bellona's coverage, such as here: http://www.bellona.org/articles/articles_2008/atomflot_newmanagement. – Translator.

The main of these risks are:

- inferior nautical characteristics rooted in the floating power unit's design (flat bottom, no self-propulsion, poor steering capabilities, low wind resistance);
- increased explosion and fire hazards as a result of excessive levels of energy concentration on board the vessel;
- risks associated with:
  - loss of floatability or stability caused by emergency situations or errors on the part of the crew;
  - partial inundation of compartments as a result of impaired watertightness or hull strength or damage sustained by outboard fittings;
  - towage in storm or ice conditions;
  - presence of hazardous cargoes on board (nuclear materials, fuel, and lubricants);
  - presence on board of pressurised gasses of various applications (nitrogen, Freon, oxygen) and highly flammable materials;
  - another vessel colliding with or listing onto the floating power unit;
  - vulnerability to the impact of a typhoon or tsunami, at a significant risk of the floating unit getting thrown ashore;
  - seizure by pirates or terrorists;
  - impact of an aircraft, which will necessarily lead to the sinking of the floating power unit.

Despite the optimistic projections of the FNPP's designers, one must admit that the above risks exist and to downplay or ignore them is to undermine the need to be prepared for and prevent potential dangers.

3.2. Nuclear and radiation dangers

Nuclear safety denotes collectively such characteristics of a reactor plant, condition of equipment and components in use, and personnel qualifications that rule out, to a certain degree of likelihood, the possibility of development of a nuclear accident [10].

There are no absolutely safe nuclear energy installations in the world – no such reactors exist where the probability of development of a nuclear accident is infinitesimally small, much less equalling zero. The KLT-40C reactor, planned for use on board the floating power unit, is no exception.

A **nuclear accident** should be understood as the emergence and development of an uncontrollable chain fission reaction or failure of heat removal from the core accompanied with overexposure to radiation suffered by personnel and/or damage sustained by the nuclear reactor that results in its unsuitability for further operation. A reactor's safety is dictated predominantly by its behaviour after it becomes supercritical and goes into runaway mode absent of any forced limitations imposed on its power load. As pointed out above, KLT-40C designers assert that a whole range of special protective measures have been provided for the FNPP's reactors to ensure their reliable operation and safety.

Still, the overall operation scenario outlined in the floating power unit's design documentation and all accompanying documents is an improbably optimistic one. In real life, one is better served by judging a reactor's safety by taking possible failures and the ultimate reaction speeds of safety devices as the basic premise – that is, using the *pessimistic* scenario as a starting point and assuming the worst. And what plays an important role here is the nuclear reactor's self-protection properties – a feature that determines that level of power at which the reactor is able to return to a subcritical state [5]. In the context of the KLT-40C reactors, the only certainty available to us is that there will not be a nuclear explosion – in the sense of a nuclear bomb explosion, as an example. This will not happen because, before enough energy is amassed to produce a nuclear explosion, the reactor will bring itself back into a subcritical state all on its own, as water, serving as moderator, is pushed out of the core, fuel rods melt down, and other processes occur that disrupt the critical geometry of the reactor core. Still, under certain circumstances, an enormous amount of energy may be discharged into the reactor, which will be enough to cause the components of the core to vaporise quickly, resulting in a primary circuit break and a depressurisation accident, accompanied by a release of fission products [10]. Such an accident is classified as a thermal explosion of a nuclear reactor, which is a type of a nuclear accident. Accidents of this kind occurring in marine nuclear propulsion systems have been described in Bellona's brochure "Russia's Floating Nuclear Power Plants: A Threat to the Arctic, World Ocean, and Nuclear Non-Proliferation" and other works. These accidents are less frequent than emergency situations involving reactor plants – i.e. events characterised by breach of limits or conditions of safe operation of the equipment that have not developed into accidents.

Taking the particular specifications and properties of the KLT-40C reactor into account, the following potential dangers and risks may be identified that may lead to the development of a nuclear accident or emergency situation (situation of nuclear hazard) on board the FNPP during its operation [10]:

- *power excursion on prompt neutrons in case of spontaneous retraction of shim rods.* In this case, everything will depend on how quick and reliable the response of the chain reaction self-shutdown mechanism will be – in other words, on the fast actuation of the reactor's inherent safety features, which rely on the natural reactivity feedback implying negative temperature or power coefficient of reactivity;
- *failure of immediate suppression of chain reaction during accident situations.* Such risks, as a rule, have to do with malfunctions occurring in the control and protection systems or the system responsible for emergency feed of liquid absorber into the core;
- *failure to compensate for the maximum reactivity inventory (maximum reactivity margin) at any moment of the campaign under either normal operating mode or emergency conditions, which allows for the risk of the reactor achieving recriticality after shutdown.* Such risks occur when the reactor is shut down and the xenon poisoning effect is in motion, as well as during the subsequent period of "out-poisoning," or xenon removal. As xenon decays and its concentration decreases in the core, this may release a significant margin of reactivity. In order to maintain the reactor in a subcritical state, there must be the option of inserting such absorbers into the core whose physical weight would be greater than the total reactivity released. This option is available in normal conditions. During an emergency, however, circumstances and conditions may change;
- *development of such reactor operating modes where the degree of fuel rod depressurisation will be higher than the acceptable limits established for the fuel prior to the expiration of the engineered reactor core energy resource.* These risks emerge, as a rule, during operational violations or disruptions as well as because of design defects in the fuel rods or other core components;
- *failure to ensure reliable removal of heat from the core under either normal or emergency conditions during operation at load and after reactor shutdown via forced or natural circulation.* Most nuclear accidents that have involved naval nuclear propulsion systems were related to failures of core heat removal systems;
- *onset and development of chain reaction during nuclear-hazardous works, such as, for instance, core refuelling.* Nuclear accidents that occurred while such works were in progress have taken

place before, in particular, in Severodvinsk, in Russia's Far North,[xx] and Chazhma Bay, near Vladivostok in the Russian Far East[xxi].

Radiation danger

Radiation danger arises from a threat of impact of ionising radiation on human health and the environment. Such a threat ensues as a result of development of a radiation accident or emergency situation involving radiation hazard. Radiation danger occurs also as a result of nuclear accidents, because a nuclear accident leads to the destruction of radiation safety barriers or their impaired ability to contain fission products from being released into the surrounding atmosphere. The primary source of ionising radiation on board a floating power unit with a KLT-40C reactor will be nuclear fuel – and not just the fuel inside the reactors, but, to a greater degree, the fuel that has already been burned in the reactors and is due to be moved to the storage facility. The specific activity of spent nuclear fuel newly removed from a reactor core reaches between 10^5 and 10^6 curies per kilogram. Twelve months following unloading, activity levels will decrease to approximately 10^3 to 10^4 curies per kilogram, but will still remain very high [10]. The dose rate of gamma radiation at a distance of one metre from such a spent fuel assembly totals no less than between 1,000 and 1,500 roentgen per hour [10].

Some 60 heavy nuclides are produced in the reactor core, of which transuranium isotopes – plutonium, americium, and curium – carry the most radioactivity. When a reactor is in operation, radioactive inert gasses (isotopes of xenon and krypton) and the highly volatile isotopes of iodine most contribute to the make-up of a particular radiation environment. Radioactivity levels of the coolant in the primary circuit are predicated on the activation of oxygen nuclei and may in certain cases reach 10^{-1} curies per kilogram. Coolant water activity levels increase with presence of corrosion products in the water as they come under the impact of powerful neutron fluxes and become irradiated. Nuclear reactions in materials irradiated by primary radiation result in secondary radiation – i.e., artificial radiation (induced activity, activation). All matter or substances that are impacted by radiation become radioactive. Irradiation affects the structural components of the reactor installation, the protective biological shield, the moderator, and the fuel. Seawater around the nuclear vessel, too, becomes partially radioactive. The highest radioactivity levels in seawater are achieved when the vessel with an operating nuclear reactor on board lies at anchor, since in this case the radioactive water does not get mixed with and diluted in surrounding water the way it does when churned in the moving vessel's stern wake [10].

Radiation dangers posed by a floating nuclear generating unit are increased multifold by the presence and use on board of the reactor fuel reloading complex. The very process of refuelling is a technological operation fraught with nuclear hazards. Nuclear-hazardous situations and even nuclear accidents have been known to occur on more than one occasion during reactor refuelling. One specific hazard associated with all operations involved in refuelling the core of the KLT-40C reactor will be the threat of radiation exposure for all personnel. The radiation hazard is caused by the procedure itself, which implies opening up the hermetically sealed recesses of the reactor compartment and removing the biological shield, then unloading the extremely radioactive spent fuel assemblies and other highly radioactive elements from the core. The radiation environment during this procedure is characterised by high levels of gamma radiation emitted by the core and the structural components of the reactor, as well as by contamination of the air and surfaces by beta, alpha, and gamma radiation. During refuelling,

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[xx] For more information, please see Bellona's topical coverage of Russian Northern Fleet accidents and incidents here: http://www.bellona.org/subjects/1140451820.2. – Translator.
[xxi] For more information, please see Bellona's story here http://bellona.org/english_import_area/international/russia/envirorights/info_access/30672 and coverage of Russian Pacific Fleet accidents and incidents at http://www.bellona.org/subjects/1140452631.27. – Translator.

charges of the ion exchange filters are replaced as well, and levels of radiation they emit may reach 25 curies per litre [6]. Also during refuelling, the equipment of the primary circuit is flushed – or decontaminated. Around 200 tonnes of high-purity water is needed to flush the primary circuit, and another 500 tonnes is used after decontamination [6]. The water becomes radioactive in the process and is thus itself subject to decontamination and special storage as liquid radioactive waste. The water that has been used to flush the coolant circuit is the main source of contamination by radiation carried by gasses and aerosols.

Project designers believe the floating nuclear power plant's nuclear and radiation safety is enhanced by the fact that all nuclear and radioactive materials generated during the reactors' operation and maintenance, as well as spent nuclear fuel assemblies, do not leave the reactor compartment during the entire operating period between yard repairs; they are only unloaded from the vessel once in twelve years, an operation performed on specially equipped premises of the shipyard where the FNPP was built. This, however, is an unconvincing argument, since the very concentration of so much nuclear and radioactive material in one small and isolated place is not a desirable solution. Should a contingency occur involving one or another system or part of equipment or hazardous materials on board, it will necessarily create a risk for the equipment in the immediate vicinity of where the emergency is happening. In case of a serious emergency, such as a fire, the consequences of a situation where vast amounts of nuclear and radioactive materials are aggregated within the confines of a limited space, crammed as it is with energy systems and equipment, may prove grave and unpredictable.

In ordinary practice, where operation of nuclear fleet is concerned, nuclear reactor refuelling and all concomitant operations are performed at shipyards; fuel and radioactive materials are either stored in onshore facilities or on board special-purpose technical support vessels, also called floating nuclear maintenance facilities. Radiation safety is assured with the help of radiation safety service personnel of the shipyard or the technical support vessel involved. But in the case of floating nuclear power plants, all responsibility for ensuring nuclear and radiation safety on board will lie with the small, 70-strong crew consisting of specialists of varying qualifications.

Seismic risks

In terms of extreme impacts caused by natural forces and taking all possible factors into consideration – the range of shock wave across the affected area, the release of energy in a specific period of time, the existing ability to forecast the location, time, and intensity of the event – earthquakes pose the biggest threat. And the Kamchatka Peninsula is an area of an exceptionally high seismic risk.

That the advances of modern seismology and its instruments still leave something to be desired presents an additional problem. Forecasting seismic activity for particular regions – or even correctly assessing the intensity of temblors in a given location – is still beyond scientists' grasp at this time. This sometimes leads to serious errors of judgement, miscalculations – and tragic consequences as a result. The most illustrative examples that reveal this helplessness of human achievement in the face of nature were the 6.9-magnitude earthquake in Armenia's Spitak Region in December 1988; the 7.6 surface wave magnitude Neftegorsk earthquake on the Sakhalin Island in Russia in May 1995; the disastrous ocean earthquake of December 2004 with an epicentre off the west coast of Sumatra, Indonesia, which triggered a series of devastating tsunamis (misestimations of seismic risks in the area where it occurred, in the northeast of the Indian Ocean – the quake was initially assessed as moment magnitude 8.8, later revised to 9.0 – have been officially confirmed by leading American specialists in geophysics, oceanology, and study of tsunamis); and the July 2007 Chuetsu offshore earthquake, in Niigata Prefecture on the Japanese island of Honshu. The latter, though its intensity had been misforecast, was a powerful magnitude 6.6 earthquake which caused major devastation on the island and also damage and radiation safety incidents at the world's largest nuclear power plant Kashiwazaki-Kariwa, where a fire in an electrical transformer, a leak of radioactive gasses and a leak of water from a spent fuel pool were registered.[xxii]

As per the IAEA's recommendations, nuclear power plants are to be capable of withstanding earthquakes of VIII ("Damaging") intensity grade on the Medvedev-Sponheuer-Karnik (MSK-64) scale, where XII ("Very Catastrophic") is the highest intensity rating[xxiii]. According to various studies, the area where the first floating nuclear power plant is to be towed for deployment, is not expected to experience seismic events of intensity exceeding X grade as per the MSK-64 scale. But it is common knowledge that earthquakes cause tsunamis. Tsunami waves threaten Kamchatka coastlines both when they are generated in remote ocean locations and – as it happens in 76 percent of cases – when they approach as a result of a tsunamigenic event occurring in the vicinity, in the tsunami-risk area located some 100 to 150 kilometres off the coast in the western part of the Kuril–Kamchatka Trench.

For Avacha Bay on the southeastern coast of Kamchatka – the enclosed bay that harbours the city of Petropavlovsk-Kamchatsky and the restricted-access town of Vilyuchinsk – the observed locations where tsunami waves originate are across the open part of the bay, on its ocean side, and it is where the most wave-generating risks occur. For a long time, no regular record was kept of tsunami events in Kamchatka. It was only after an especially devastating tsunami of November 2, 1952 that any systematic record of tsunamis and their points of origin was started.

The focus of the earthquake that sent a powerful wave toward the coastline on that day was in the southern part of the Kamchatka shore. These were the main characteristics of that earthquake:

- magnitude: 8.5;
- depth of focus: 3.5 kilometres;
- area of focus: 500 by 170 kilometres.

The waves that reached midway into the entrance to Avacha Bay were four to five metres high. In Krasheninnikov Bay, in the south of Avacha Bay, the waves, according to visual observations, were between 2.5 and 3 metres high. The waves' period was presumably ten to fifteen minutes.

[xxii] As this report was being translated from Russian into English, a 9.0 magnitude undersea megathrust earthquake – the largest Japanese earthquake since records began – followed by devastating tsunami waves of up to 23.6 metres high, struck the eastern coast of Japan. This unprecedented disaster, which occurred on March 11, 2011 and is now known as the 2011 Tohoku earthquake and tsunami, set in motion a catastrophic – and still ongoing, as of early April 2011 – nuclear and radiation accident at Fukushima Daiichi Nuclear Power Plant, where the tsunami destroyed the station's external power supply, resulting in failure of cooling systems and the ensuing hydrogen explosions, partial meltdowns of reactor cores, and exposure of spent nuclear fuel in the plant's cooling ponds. On March 18, the Japanese authorities upgraded their rating of the Fukushima Daiichi accident to Level 5 on the IAEA's International Nuclear Event Scale (INES), while international experts' assessments ranged between Levels 5 and 7 (a Level 7 event describes accidents of worst severity, of which the 1986 Chernobyl accident had remained the only example). The disaster at Fukushima Daiichi had wide political reverberations as nations across the globe reassessed their stance on nuclear energy. As the translated version of this report was being prepared, severe contamination of the environment was in progress around the plant, some resulting in transboundary effects as well as spreading into food and water supply in the country's capital and other areas, and works were continuing to bring the situation at the plant under control in conditions of extremely high levels of radiation. For more information, please see Bellona's extended coverage here: http://www.bellona.org/subjects/nuclear-metldown-in-japan. – Translator.

[xxiii] The MSK-64 scale (http://en.wikipedia.org/wiki/Medvedev-Sponheuer-Karnik_scale) is a macroseismic intensity scale used in Europe and the former USSR in the 1970s and 1980s to evaluate the severity of ground shaking on the basis of observed effects of an earthquake. It is still used in India, Israel, Russia, and other countries. In the early 1990s, a European standard, called the European Macroseismic Scale, was also developed based partly on the MSK scale. – Translator.

For a floating nuclear power plant, tsunami is an extremely serious threat of impact brought on by a natural disaster. Should the FNPP, with its reactors still in operation, be thrown on shore by the force of a powerful tsunami wave, a nuclear accident with grave consequences will be unavoidable.

Export of floating nuclear power plants and security concerns

Physical security of nuclear sites plays an important role in advancing the goals of nuclear non-proliferation and in countering the threat of terrorism. This is why physical protection of floating nuclear power plants will be one of the critical issues in ensuring the safety of these facilities in the context of export deliveries. If this Russian technology is exported and put to use on an international scale, it must be guaranteed, first and foremost, that this activity would comply with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT),[xxiv] as well as be in accordance with two IAEA documents – the Convention on the Physical Protection of Nuclear Material (CPPNM)[xxv] and Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities.[xxvi]

Several reports have studied the possibilities of using floating nuclear power plants in Asia [16]. These reports point out that Southeast Asia is one of the world's most troubling hot spots in terms of international terrorism – a given, to a large extent, of the particular geography of the region. This is where strategic international trade routes lie, along which between 200 and 600 commercial vessels pass daily, carrying crude oil and other hydrocarbon fues, as well as chemicals, exported and imported by Japan, China, South Korea, and other Asia-Pacific countries. This is also where important sea and air routes cross toward South Asia and the Middle East. In the UN's estimates, up to 80 percent of the six billion tonnes of cargoes traded annually in the world is shipped by sea – and of that percentage, almost 75 percent is moved through one of the five shipping "pinch points" – the narrow waterways of the Panama and Suez Canals, the Strait of Gibraltar and the Strait of Hormuz, as well as the Strait of Malacca in Southeast Asia. The news agency World Net Daily has reported that the international militant Islamist network al-Qaeda has already managed to procure two dozen vessels for the group's terrorist activities. Al-Qaeda, the World Net Daily said, may use its ships to take a cargo of deadly chemicals, or a so-called "dirty bomb" – a radiological weapon capable of dispersing radioactive material across a wide area by means of conventional explosives – or even nuclear weapons to a civilian port in order to carry out a terrorist attack there. These ships are, in essence, the suicide bombers of the terrorist future. Even without taking into account the ever-present piracy risks that the international shipping trade is facing daily, there is the real threat that the most important shipping routes and fairways may prove vulnerable to an attack by al-Qaeda or a like-minded group with close ties with it [12].

Indonesia and Malaysia, as countries that have, among other potential customers, already expressed an interest in Russia's FNPP project, are of most concern in that regard, since a combination of their geography, the booming shipping trade along their coastlines, and other factors forms just such conditions that create a considerable risk of terrorist attacks at sea. This risk is compounded, furthermore, by the alarming statistics of pirate attacks in the region. For a floating nuclear power plant lying at anchor at its place of operation, the threat of falling prey to a pirate or terrorist attack and its crew being captured for ransom, or to use as hostages in a negotiation, is very real – and so is the risk that the nuclear materials or radioactive waste on board may also be hijacked in the process for use in

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[xxiv] For more information, please see the IAEA's page on the NPT (http://www.iaea.org/Publications/Documents/Treaties/npt.htm) or visit the UN's NPT page (http://www.un.org/disarmament/WMD/Nuclear/NPT.shtml). – Translator.

[xxv] For more information, please see the IAEA's page on this convention (http://www.iaea.org/Publications/Documents/Conventions/cppnm.html). – Translator.

[xxvi] To view the document, please follow this link to the IAEA website (http://www-pub.iaea.org/MTCD/publications/PDF/Pub1481_web.pdf). – Translator.

further criminal activities. Analyses have shown that operating a floating nuclear power plant in the waters off the shores of the island states of Indonesia and Malaysia may not just be unsafe for those countries and their closest neighbours, but may also pose a global risk. Should a terrorist attack scenario be carried out successfully and the nuclear vessel captured, with the nuclear materials and/or radioactive waste on board falling into the wrong hands, these materials may then be used to perpetrate criminal acts elsewhere in the world. Additionally, the reports that examine the prospects of operating floating nuclear power plants in the Asia-Pacific region also mention the dangers and risks that arise in case of an outbreak of armed hostilities on the territory of the customer country.

The following must be considered as the main possible scenarios of a terrorist attack involving an FNPP [12]:

1) Theft or other illegal act of procuring fissile material for further enrichment and use in nuclear weapons. A floating nuclear power plant will necessarily have medium-enriched uranium on board. Depending on the technological skills and capabilities at the terrorists' disposal, and given the FNPPs' vulnerabilities, the possibility that the plant may be hijacked with the specific purpose of obtaining this uranium presents a real threat. Floating nuclear power plants are also susceptible to the risk of falling into the hands of extremist forces seizing power in the customer country via, say, a government coup.

2) Use of radioactive materials hijacked from the floating nuclear power plant in order to produce a radiological dispersion device (so-called "dirty bomb").

3) An attack on the reactors or other nuclear facilities with the aim of causing radioactive fallout and contamination of the area. Aggressors in this case may choose to carry out an attack from the air or from the sea, or by underwater means, both at the FNPP's place of operation and during towage, targeting the vessel's life support systems in order to cause a reactor core meltdown – a melting of the nuclear fuel in the reactor core, with an accompanying release of radioactive material outside the containment. Up to 1 million curies of radioactivity – an amount corresponding to one tonne of irradiated nuclear fuel – may be discharged into the surrounding atmosphere as a result of such an attack. Depending on the prevailing currents at sea, the spread of contamination in this case may be quite substantial, with consequences of both local and regional scale. The tragedy of September 11, 2001 showed that no surface (land-based) site can be rendered completely immune to an air attack, be it a bombing or missile strike or purposeful crashing of a jetliner. Should a falling passenger or cargo aircraft be directed by terrorists to crash onto a floating nuclear power plant – which, unlike, a "stationary" nuclear power plant, lacks a solid foundation and is by definition less protected against such a forceful impact, and which also has a higher concentration of operational premises and communication and service systems than a conventional plant – the damage and destruction caused by such an attack would be far more devastating in scope. Even if the reactor itself successfully sustains the impact of a crashing airplane, the risk is still formidable for the spent nuclear fuel in storage on board the FNPP, as destruction brought on the vessel's SNF storage facility may entail consequences commensurate with those of a reactor explosion. Risks of an attack carried out with the use of subsurface craft must not be discounted, either.

The above-mentioned studies warn, accordingly, of the very high likelihood that such terrorist threat scenarios may be implemented. Based on these considerations, the system of physical security measures installed for a floating nuclear power plant must be sufficiently effective to thwart any external physical impact incurred in the course of an intrusion, ensure that the floating generating unit's hull is duly defended against such an attack, and provide for timely detection of a security breach attempted with the use of watercraft or divers entering the protected surface and subsurface perimeter of the floating nuclear power plant.

In Russia, security for storage facilities where nuclear waste is in storage is commonly provided by military units of the Ministry of Internal Affairs of the Russian Federation; the Ministry of Defence of the Russian Federation also renders support with forces dispatched to guard or convoy nuclear materials in transit, where necessary. In the given circumstances, it is very likely that the floating nuclear power plant will have to remain under constant protective surveillance of the Russian Navy.

One should not forget, either, that the onshore territory that is part of the FNPP complex, must, too, be protected against unauthorised access or infiltration. By varying estimates, maintaining due physical security of the entire FNPP complex will take between 10 and 50 percent of the FNPP's overall costs [16]. The responsibility for providing necessary security measures may possibly be shared by Russia and the customer country. In that case, the parties to an FNPP export contract will have to settle a multitude of legal issues, as well as determine the path of future actions in the contingency that hostilities break out in the region of the FNPP's deployment that require military intervention. Taking the anticipated physical security costs into account, the price of energy produced by the FNPP may grow significantly for the customer – thus possibly compelling the buyer to opt for a safer and more reliable, land-based source of energy, nuclear or otherwise.

4. FNPP economics

A large land-based NPP is a unique project with a considerable number of contractors and a large volume of construction and assembly works, which as a whole results in implementation time frames and expenses that are difficult to predict.

It is proposed to make floating nuclear power plants (or floating nuclear cogeneration plants, or low-capacity nuclear power plants), which began to be developed actively in Russia in the 1990s, as standardised as possible, and thus promote them on the world market. It is thought that because of the lower scale of the project, the client has better control over expenses. In practice, however, the cost of the first FNPP project, now nearing completion at Baltiisky Zavod in St. Petersburg, grew from the $150 million declared by the former Ministry of Atomic Energy in 2001 to the $550 million (RUR 16.5 billion) announced by Rosatom head Kiriyenko in 2010, i.e. by more than 3.5 times. The situation is such that the atomic industry today intentionally underestimates the cost of building a floating nuclear power plant, because in projects that were developed in the 1990s, a cost of between $192 million and $254 million was initially established.

As said above, a tender held in 2006 resulted in a contract signed between Rosatom and the Severodvinsk-based Sevmash on the construction of the first such movable plant to be deployed in the town of Vilyuchinsk. The deputy head of Rosatom at the time, Sergei Obozov, said then the project cost RUR 9.1 billion, or EUR 226.8 million. But according to the feasibility study of the project done in 2007, the total cost, including capital expenses, cost of project preparation works, research and development, planning and surveying and design works, was to reach already RUR 10.540 billion in 2007 prices.

When in 2010, the first reactor unit was floated, Kiriyenko finally revealed the cost of the unit to be RUR 16.5 billion, of which RUR 14.1 billion was the cost of the unit proper, and RUR 2 billion was the cost of coastal and offshore structures; the entire project was thus estimated at $550 million. Project preparation works were financed from the federal budget, and on the whole it is difficult to judge to what extent these RUR 80 million – the cost of these works as specified in the feasibility study of the project – is an adequate estimate, since this included work done by several organisations that was spread out over a period of time.

It is likewise not very clear to what degree the project includes financing of the social infrastructure. According to V.M. Kuznetsov et. al [11], these expenses should add another 10 percent to the total costs.

The idea to develop the sector of small-scale nuclear energy installations has received the status of a so-called socially significant project. It is financed under a federal target programme and, accordingly, has extremely low requirements for economic indicators. For example, the required discount rate was set at 4.5 percent per annum. This rate is extremely low, but simple calculations show that applying rates that are even slightly closer to commercial rates – for example, 6 percent – would make the whole project unprofitable.

As in the case of ordinary nuclear power plants, capital expenses are enormously significant for the profitability of a project, but here, the uncertainties stemming from the project's subsequent operation play an even more important role.

The volume of turnover, as expressed through the installed capacity utilisation factor (ICUF), depends mainly on two factors – demand for energy in the region and the uninterrupted operation of the plant itself. The project is based on two estimates of electricity sales volumes to consumers of the closed administrative territorial entity of Vilyuchinsk and the Central Power Distribution System of the Kamchatka grid – 455 million kilowatt-hours and 410 million kilowatt-hours per year starting from 2015, which means 74 percent and 67 percent, respectively. These estimates seem to be excessively optimistic. The total installed capacity of power plants feeding electricity to the Kamchatka grid's Central Distribution System is 477 megawatts, but output levels stand at just 1.37 billion kilowatt-hours. Given the current demand, it can be assumed that the floating nuclear power plant should provide for exactly a third of the region's needs.

For a closed energy system that does not have the possibility of selling surplus energy outside the region during periods of low energy consumption, lower ICUF values are realistic – not more than 50 percent. A considerable stake is made on auxiliary projects that should enable a general increase of power demand in the region.

Besides demand restrictions, there are technological ones as well, as the plant must regularly undergo routine maintenance and then overhaul maintenance in dry dock every 10 to 12 years, which makes it impossible to attain ICUF values of more than 82 percent.

The installed capacity utilisation factor has enormous importance for the prime cost per unit of production, as the majority of operating expenses do not depend on the sales volumes. Current operating expenses can be divided into expenses connected with the fuel cycle, salaries, and various deductions as per existing standards and regulations to provide for future obligations.

A number of expenses require adjustment, as several of them, according to some experts, have been deliberately underestimated. These include expenses incurred by the nuclear fuel cycle, decommissioning expenses and the associated annual deductions, and insurance deductions. In particular:

1. Deductions tied to replacement costs for key assets (first and foremost, depreciation) are significantly higher because of the greater final cost of the project.
2. Deductions (in semi-variable expenses) which are calculated based on the sales volume may be lower because of the overestimated ICUF, but as the electricity tariff may well be higher than the one that the project bases its calculations on (expenses must be covered somehow in any case), it is difficult to judge whether they need to be adjusted up or down.
3. Higher expenses on nuclear fuel should be expected. Firstly, the practice of free use of weapons-grade uranium from military conversion programmes will inevitably come to an end at some point, and all fresh fuel will have to be purchased at market prices. Without

attempting to forecast global prices for uranium ore, we can nevertheless say that no phase-out of world nuclear energy is yet taking place and the demand for uranium is not dropping, while the supply is limited by the capacities of existing mines. And development of new fields translates into a higher level of prices. Secondly, charging rates for treatment (transport, storage, and processing) of spent nuclear fuel and radioactive waste are clearly underestimated and do not cover the real expenses of specialised organisations engaged in these activities. Storage and transport of spent nuclear fuel and radioactive waste in remote regions are particularly expensive. The difference is covered by state subsidies, commercial foreign orders, and redistribution of resources within the industry – meaning, ultimately, again by state financing. It is clear that a more realistic estimate of the actual expenses associated with the nuclear cycle is one and a half times higher than the one planned in the project.

4. It is suggested that expenses for decommissioning the plant are to be funded via annual deductions accumulated on a special account. The project estimates these costs at RUR 28.5 million per year, which translates into RUR 1.0277 billion over 36 years. According to V.M. Kuznetsov et al. [11], however, the decommissioning costs should be estimated at around $150 million, i.e. around RUR 4.5 billion. Of course, if an annual interest rate of 4.5 percent is factored in, the accruements can be expected to result, over the 36 years, in an amount of RUR 2.57 billion, but the final sum will still be around RUR 2 billion short of the more realistic target.
5. There is practically no correlation between the size of a nuclear power plant or the volume of production output and the majority of risks and the scope of potential damage, which should mean a greater percentage of insurance payments in the structure of expenses for a low-capacity NPP compared with an ordinary one. If one takes into account the fact that at present, only some of the risks are insured against that are linked with nuclear energy, and in case of an accident, the state will bear the better part of the liability, the actual expenses for insurance premiums will almost certainly have to be estimated as one and a half times as high.

Uncalculated expenses

1. One specific problem of a floating NPP is that every 10 years (or 12 years, according to the project) it must be put in dry dock for repairs. This involves considerable direct expenses (lease of the dock, towing to the dock, and the actual repair works) and indirect expenses (the need, for the grid, to compensate for the resulting loss of electricity supply with more expensive power supplies and to maintain reserve capacities, which also requires maintaining sufficient fuel supplies). The entire procedure takes about a year and the project provides for other capacities substituting for the absent nuclear power plant according to a flexible schedule. The idea is that the entire fleet of floating NPPs will consist of several (eight, on the whole) plants. Of course, it is possible that by the time that the term of overhaul repair for the first plant comes around, a second plant will be built which will replace the first, but so far this second plant does not exist, and we must assume that during overhaul maintenance, the region will have to put up with a year-long loss of capacity.

Even if we assume that the direct expenses are covered by deductions for these purposes (which is disputed by V.M. Kuznetsov et al. [11]), then the indirect expenses still cannot be accounted for and calculated as part of the prime cost of production.

To make a rough estimate of the expenses the grid will incur owing to the peculiarities of the FNPP's operation, we can multiply the volume of production at the capacities to be removed from the grid, divided over the period of the plant operation, by the difference in the prime costs with the replacing capacities. We should also add here the expenses the grid will have to bear to maintain these replacement capacities for the period that they stand idle in cold reserve. Most likely, one of the existing thermal power plants (TPPs) will be used as a reserve facility. As of 1997, the prime cost of producing one kilowatt-hour of electricity at Kamchatka TPP-1 was RUR 2.87. According to project documentation, the prime cost of electricity produced at a gas thermal power plant is RUR 3.6. The weighted average cost of power capacity paid for by consumers in Kamchatka as of 2010 was RUR 557,333 per megawatt per month, but these figures clearly exceed the real expenses for maintaining the cold reserve in working condition. For a modest estimate, we will take one tenth of the declared cost.

2. Payments to the owner of invested funds are not provided for in the project at all. It is assumed that the state receives profit through increasing tax payments and a reduction in expenses it usually bears delivering goods to the remote and barely accessible territories in the Russian North. Nevertheless, from an economic standpoint, funds invested at the low rate of 4.5 percent should be paid back. If one assumes that a loan at a 4.5 percent interest rate was taken out to implement the project, then the interest on the loan should accordingly be included in the prime cost.

Thus, the structure of operating expenses and the prime cost, if the needed adjustments are done in the calculations and factored in accordingly, will look as follows:

Table 5.

Constant and semi-variable expenses

Articles of expense	**Value, in million roubles per year**	**Adjusted value**
Salaries	84,480	
Unified social tax	21,965	
Ongoing maintenance of fixed assets	33,604	
Rent payments for land	4	
Fire prevention services	300	
Health rehabilitation services for personnel	590	
Mess expenses for the crew	3,390	
Other expenses for ensuring normal work conditions and industrial safety measures	4,510	
Primary and additional training for the personnel	118	
Expenses of service facilities	1,500	
Unforeseen expenses	10,987	
Environmental pollution tax	2,700	
Service water	2,119	
Communications services	1,200	
Charges for the use of water area	15,178	
Physical protection	2,022	
Deductions for overhaul maintenance	145,584	
Decommissioning	28,547	49,977
Wear and tear	273,840	462,000
Nuclear fuel supply	209,026.4	313,539.6
Personnel insurance	3,078	
Deductions to the FNPP reserve fund[xxvii]	34,889.2	
Property and liability insurance	18,470.75	27,706
Interest on loan		742,000

[xxvii] An account set aside for expenses arising with the operation of the FNPP's nuclear reactors – such as for future decommissioning costs etc.

TOTAL	**887,795**	**1,981,681**

These expenses do not include the indirect costs incurred to the Kamchatka grid, which come to RUR 105 million annually.

Thus, taking into account the adjusted total costs and keeping the cost share allocated to each product, we can now estimate the production cost of electricity and heat as follows:

Table 6.

Calculation of prime cost

Net generation of:		
– Electric power, in million kilowatt-hours per year	455	307
– Thermal energy, in thousand gigacalories per year	270	219
Prime cost of production of:		
– Electric power, in roubles per kilowatt-hour	1.54	4.9
– Thermal power, in roubles per gigacalorie	730	2,169

Taking into account the indirect expenses, the prime cost of heat and electrical energy will be RUR 2,284 per gigacalorie and RUR 5.1 per kilowatt-hour, respectively.

5. Legal framework

The "Declaration of Intent to build an LCNPP on the basis of a floating power-generation unit with reactor plants of the type KLT-40C for operation in the closed administrative territorial entity of the town of Vilyuchinsk, Kamchatka Region" lists around 200 regulatory legal documents and regulatory technical documents, on the basis of which the design, construction, and operation of the FNPP is to be carried out.

However, if one objectively analyses this list of documents, it turns out that practically all the norms and requirements set forth in the documents were established for stationary land-based nuclear energy stations and nuclear vessels of various purposes. Practically no regulatory documents have been developed specifically for floating nuclear power stations, with the exception of regulatory technical documents developed by design and engineering organisations (such as, for example, the design firms Aisberg[xxviii] and OKBM Afrikantov) and other enterprises participating or running the administration of the FNPP project. In some documents in the above-mentioned list (for example, the Sanitary Rules for Designing and Operating Nuclear Power Plants (SP AS-03), it is stressed that *"the present rules [SP AS-03] are mandatory for organisations carrying out activities related to the siting, designing, construction, commissioning, and operation of nuclear power plants with reactors of various types (VVER, RBMK, BN, etc.), with the exception of nuclear vehicle propulsion plants and reactor plants of special purposes."*

In other words, these rules cannot probably be applied to a floating power unit, which is a marine vessel, or nuclear reactors on board of such a vessel (which are based on the concept of a nuclear propulsion system used in nuclear icebreakers). Strictly speaking, a floating power unit falls into the class of nuclear propulsion vessels, or transportable nuclear energy installations. Some documents from the above list provide for no reservations or clarifications on the issue, so it is unclear whether the requirements of these documents are mandatory for FNPPs or not. And if so, do they apply in full, or

[xxviii] Please see Footnote VIII. – Translator.

selectively? If only some of the regulations apply (which is confirmed by practical experience), then who decides which rules do apply and which do not and why these particular decisions are made? On the whole, it remains unclear just how legally valid it is to apply the norms and rules established for sites of a different type to the particular category of floating nuclear power plants.

Furthermore, no international rules or recommendations exist for FNPPs. The IAEA is yet to develop any regulatory documents or guidelines whatsoever for floating nuclear power plants. Therefore, issues remain as to the completeness of the regulatory legal framework to serve as the basis for selecting sites of FNPP deployment and providing physical security and maritime safety, and for the regulation of many other aspects pertaining to the construction and operation of a floating nuclear power plant.

6. Conclusion and general findings

The construction of a floating nuclear power plant and its subsequent operation leave open a multitude of issues, with the result that the advisability of this project is now doubted not just by the general public but by specialists as well, including those who created and set the project in motion. For Rosatom, it is a business project whose eventual success is not at all evident. Rosatom head Kiriyenko has announced publicly that the FNPP project will not have economically viable prospects unless a large series – at least seven units – is built. Construction of the first FNPP, provided that it is delivered and commissioned in 2012, will have by 2012 taken five years (counting from the start of construction in 2007). Manufacturing a large series, or at least seven floating power units, will at least take 20 years (and each unit is designed to remain in operation for a term of 36 years). It is thus unclear who will want, in 20 years' time, to purchase a technology that by then will have become outdated. And if the plans to build the subsequent units are based on a rationale that new and upgraded technologies will be employed in the construction, then this will mean different time frames and different costs.

At present, according to the information provided by the shipbuilder (Baltiisky Zavod), accessory equipment is only available for the one unit under construction. It will hardly be possible to commercialise the project based as it is on old technologies and with the risks that are described in the present report. Therefore, the first unit, the construction of which is already loss-making today, is unlikely to attract investors or potential buyers from abroad. The only party that can be expected to express an interest in this project will be the Russian state and, by extension, if any money comes into the project, it will likely be from the federal budget. Already now the FNPP project is referred to in the context of a new ownership model developed by Rosatom that is rooted in the principle of "we build, we own, we operate." This means that the construction, operation, safety, security, and other expenses will be paid for by Russia, as it is unlikely that a country will be found that will be able to afford itself the luxury of buying a "diamond-encrusted platinum-clad" floating power unit or even the kilowatts that it will produce. All hope lies solely with the Russian state budget and the Russian taxpayers' pockets.

Finally, there still are issues relating to the FNPP's operation, technology, economics, security, and many other aspects that still remain unanswered.

6.1. The hull, ship systems, and seakeeping qualities of the floating power unit

The hull of a floating nuclear power plant is a complex floating structure with a length of 140 metres, a beam of 30 metres, and a total height of around 40 metres. The FNPP's low resistance to wind as well as its zero steering capabilities and flat bottom, will require significant efforts while towing the vessel, especially if towing is performed in the open ocean waters and Arctic conditions.

At anchorage or at berth, especially if the vessel is in an area characterised by high risks of hurricanes, tsunami, or gale winds, the floating power unit's safety will have to be ensured by tow vessels or other watercraft capable of providing it assistance in case the adverse weather conditions force the floating plant to break off the mooring or tilt heavily or capsize.

The large displacement – of 21,500 tonnes – and the draught of 5.5 metres mean that in order to operate safely, the floating nuclear power plant needs water area depths of no less than 10 metres where it is expected to be deployed. Furthermore, the floating power unit is heavily loaded with extremely energy-saturated equipment that poses heightened risks of explosions, fires, electrical malfunctions, and radiation hazard. The FNPP concept has no analogues across the world's broad arsenal of naval and commercial watercraft in terms of such high concentration of potentially hazardous equipment on board, because no nuclear-powered ship in history – including naval vessels – had previously such a combination of diesel-fuelled electric generators, steam turbines, and nuclear facilities, plus storage facilities for spent and fresh nuclear fuel and radioactive materials in addition, all packed into one vessel's hull.

The FNPP hull's design and characteristics, and all the hull equipment installed on the ship that relates to its survivability and floodability, play a major role in ensuring its general safety. Because the plan is to produce floating power units for transport and operation in a variety of regions across the globe, the overall design and ship equipment must conform to all the requirements that shipping registers set forth for marine vessels. This leaves unsolved certain issues that pertain to the structural strength and integrity of the hull and its components, as well as the FNPP's seagoing qualities, adequate as they must be for all possible cases of operation, including variations in ice, wind, and wave conditions, and with no restrictions imposed on the designated operating area.

Because the floating power unit is a non-self-propelled berth-connected vessel, essentially a barge, the class it is assigned by the Russian Maritime Register of Shipping (KE* [2] A2) does not include ice class notations. The project only mentions ice-resistant paint coating to withstand the impact of ice, but the information available does not make it clear if the floating power unit will be certified as an Arctic class (or Arctic category) vessel or whether the ice resistance provided by the hull coating will be sufficient to safely operate the ship during towage along the Northern Sea Route in open ice conditions or during the lengthy berthing period in Kamchatka – let alone the location near Pevek[xxix], above the Arctic Circle, where project initiators aim to deploy the next FNPP in the series.

Even without the challenging ice conditions, towing a non-self-propelled flat-bottom vessel with a displacement of 21,500 tonnes, a length of 140 metres, and a total height of around 40 metres, is a difficult operation and one fraught with many risks. Maritime history abounds with stories of broken or snapped tow cables and the damage such accidents can cause during towage. One example is the towing of the old cruiser Murmansk, a 1955-built vessel with a displacement of 18,000 tonnes and a length of 200 metres, which, while being transported to India for scrapping in 1994, ran into a heavy storm and was torn loose from its tow vessel and thrown onto the Norwegian coast.

6.2. Reactor plant

The floating power unit's reactor plant and its auxiliary systems were designed as far back as the 1970s, with some of the systems and equipment partially upgraded in the later years (hence, the third-generation nuclear marine propulsion systems). It is thus impossible, forty years on, to refer to the FNPP's reactor systems as the most up-to-date cutting-edge technology they are purported to be. The

[xxix] Pevek is a town and Arctic port in the Chukotka Autonomous District, on the northernmost tip of the Russian Far East. It is located on the shore of Chaunskaya Bay, part of the East Siberian Sea. A town of 5,206 residents, as of 2002, it has experienced a pronounced depopulation trend in recent years owing to poor economic conditions (http://en.wikipedia.org/wiki/Pevek). – Translator.

only exception here is the reactor core, which was designed specifically with the peculiarities of the floating power unit's future operation in mind.

The Russian State Nuclear Corporation Rosatom speaks of the KLT-40C reactor plants as installations with a high level of safety. But because the documentation relating to the project is not entirely available for open and unrestricted access, independent experts do not have enough specific information on their hands to carry out a full public environmental impact evaluation of the project and make sure that the reactors to be used on board the FNPP meet all safety standards. The public thus has to place its trust with Rosatom and the isolated documents that are posted on the Internet or published in specialist literature on the subject.

These publications say, in particular, that the reactor plant designed for the FNPP *"…does not have hydrogen suppression systems, nor a pilot-operated relief valve on the primary loop, while the computerised process control system is designed to allow for one system failure every six or seven days. The flow diagram of power output delivery to the grid does not provide for automatic stuck breaker protection or out-of-step protection devices, or pressure regulators. The requirements of the Rules of Removal of Heat from the Reactor Core to the Ultimate Heat Sink have not been satisfied…*" [14]. What is meant here is that during berthage, the water around the site of FNPP deployment will be sufficiently heated as a result of the plant's operation. If the service water supply system on the side of the essential power consumer of Group A[xxx] does not meet the requirements set for the distance between the process water intake point and water discharge point, the main condensers and other heat exchange systems will be unable to ensure efficient heat removal from the site.

The KLT-40C reactor plant is designed as a compact modular-type reactor. The design description stipulates that the reactor, steam generators, and main circulation pumps are connected with short nozzles (without long pipelines) [1]. The concept allows for the use of natural circulation in the primary loop at power load of 3 to 5 percent of nominal load.

For nuclear-powered watercraft – submarines, nuclear cruisers, icebreakers – whose reactors operate at an average load of around 30 percent and for a rather short period of time (up to three months), natural circulation in the reactor's primary coolant loop at a level of 3 to 5 percent of rated load is an additional option to ensure core heat removal during accident situations, i.e. when forced circulation ceases to function [9]. Should an emergency scram occur at an FNPP reactor, if it has been operating for a prolonged period of time at nominal capacity, decay heat, occurring on account of beta and gamma radiation emitted by accumulated fission products, will correspond to roughly 7 percent of nominal load, since residual heat values depend on the capacity level at which the reactor was operating, the length of the operating period, the efficiency of the absorber rods, and other factors. In other words, a level of natural circulation of 3 to 5 percent may prove insufficient for efficient heat removal from the core in case an accident occurs.

It is practically impossible to make absolutely accurate assessments regarding the safety of the FNPP's reactors on the basis of the meagre documentation that is available for open access. In particular, it is impossible to predict the development or consequences of accidents that are regarded as "beyond-design-basis" accidents. For instance, what kind of consequences would ensue from using the

[xxx] Essential power consumers of Group A fall into Category I, defined, as per the Russian Ministry of Energy's Regulations for the Design and Construction of Electrical Installations (PUE, 7th Ed., July 2002), as "power consumers where outage in power delivery may entail a threat to human lives, threat to national security, considerable material damage, disruption of complex technological processes, and disruption in the operation of especially important elements of public services, communication links, or television." Especially distinguished in this category is the group of consumers whose uninterrupted power supply is "essential for accident-free shutdown of operations for purposes of prevention of threats to human lives," including fires and explosions. – Translator.

reactor caisson[xxxi] *flooding* system and *containment flooding* system – the systems that serve to fill the caisson and containment with seawater to avert the threat of core meltdown and prevent damage to the reactor bottom by the molten mass from the core? And if a meltdown does happen? Stationary nuclear power plants have a special kind of "trap" – a "core catcher" – that "traps" inside the molten reactor core (corium) during a severe accident with a meltdown, precluding it from escaping the containment. But there is no such corium capture and localisation system provided for in the FNPP project, and in case that the core melts through the reactor bottom, there will be no core catcher to prevent the overheated blend of fuel and metal from making contact with water – which will give rise to an unpredictable situation of severe nuclear and radiation hazard.

The same is true for other beyond-design-basis accidents. For instance, the fall of a large aircraft with a greater weight than a Yak-40 – or even of the same type – will most likely cause the floating power unit to go under, with all the consequences that follow the sinking of a nuclear vessel. In fact, the likelihood of accidents that are classified as "beyond-design-basis" events is not much smaller than that of development of design-basis accidents, which is why there must be a level of preparedness to prevent or respond to such emergencies just as high as there is for design-basis events.

And finally, there are issues connected with the fuel that project designers plan to use in the floating power unit's reactors. The announced degree of enrichment of uranium-235 is to be 18.5 percent. But once one has at one's disposal uranium enriched to 18.5 percent, it is already easier to enrich the material further to 20 percent or more – easier, in any case, than it is to start from scratch, to enrich natural uranium, which only contains about 0.7 percent of uranium-235. Besides, it is common knowledge that any thermal nuclear power reactor is a "conversion system" – that is, its operation results in the generation in the core of secondary fuel, plutonium-239, and other fissile materials. If two FNPP reactors remain in operation at 80 percent capacity in a course of one year, their cores will by the end of that period have produced some 60 kilograms of plutonium.

These and other factors must be considered before the floating nuclear power plants are offered for wide-scale construction and use around the world.

6.3. Steam turbine plant

With the FNPP in operation at its place of mooring at the shore, the main circulation pump of the steam turbine plant, with the turbine working at full capacity, will discharge hot water heated in the main condenser at a rate of almost 6,000 tonnes per hour, or 144,000 tonnes per 24 hours. If the two main circulation pumps are in operation, the cooling water, heated to 24 degrees Celsius, will be discharged at double that rate, at 12,000 tonnes per hour. If one adds to that the hot "brine" from the floating power unit's desalination plant – 105 tonnes per hour with salt content of about 42.5 grams per kilogram of water – as well as all the discharges from all the cooling circuits (the third and fourth loops, the auxiliary circuit, the condensate coolers, etc.), then the total amount of processed water discharged by the FNPP overboard will reach around 13,000 tonnes per hour, or 60,000 tonnes per 24 hours. This is bound to have its effects on the nuclear power reactors' operation and the condition of the water basin, as well as the biota of Avacha Bay in general and Krasheninnikov Bay in particular – though only practical experience will show just what sort of impacts exactly the natural environment of the area will suffer. But it is clear already now that the combination of low air temperatures at the location of deployment in the bay and the hot processed water discharged by the floating power unit will produce a permanent cloud of fog shrouding the vessel – which will have its detrimental effect both on the health of the personnel servicing the FNPP and the condition of the equipment on board.

[xxxi] A "cradle" holding the reactor in the reactor compartment. – Translator.

The operation of the condensate-feedwater system will be affected by the ice conditions in the bay. The average duration of the ice season in Krasheninnikov Bay is 149 days, from November to May; the longest on record was 199 days. The maximum ice depth – in Yagodnaya Bay – is 144 centimetres. The fastest speed of ice drift has been observed at between 0.3 and 0.6 metres per second. Total ice floe area at the entrance to the bay can reach 200 by 200 metres. Ice floe shifts have on a number of occasions inflicted damage on the floating causeways at the waterfront around the small residential neighbourhood of Rybachy and in Gorbushechiya Bay.

The condensate-feedwater system can become a source of radioactive contamination of the water area around the floating nuclear power plant should a leak occur in the steam generator plants or loss of watertightness in the piping system of the main condenser. Technologically, at any rate, such a possibility cannot be ruled out and contamination remains a realistic risk.

6.4. Backup energy supply

The project stipulates that the floating power unit will have enough backup power sources to ensure uninterrupted power supply during emergencies involving the reactor plants, as well as to provide power to cover internal needs if or when the reactors are not in operation. However, the pressing issue remains of the reliability of these power sources, especially during severe and unpredictable contingencies such as natural disasters – storms, earthquakes, tsunamis,[xxxii] fires, etc.

6.5. Management of spent nuclear fuel and radioactive waste

Russia – either as an independent state or as part of the Soviet empire – has had no experience refuelling nuclear marine reactors in such operating conditions as are envisioned in the floating nuclear power plant project. Never have there been such circumstances where a starboard reactor would be refuelled while the portside one would be in continued operation, or vice versa. Unloading spent nuclear fuel from, and loading fresh fuel into, one reactor – counting in the period it takes to remove decay heat, perform all preparatory works, and finally carry out the actual refuelling operation – takes up to three months. Refuelling marine reactors has usually been done at specialised yard facilities and involved the use of special maintenance vessels and specially trained personnel. Crews trained to operate nuclear reactors cannot perform refuelling operations since specific qualifications and skills are required for this job. Therefore, special maintenance teams will be needed to defuel and refuel the FNPP's reactors.

Furthermore, the very presence of a fuel handling complex on board, and, first and foremost, its storage facilities for spent nuclear fuel and fresh fuel, plays a major role in augmenting the nuclear and radiation risks posed by the floating plant.

6.6. Offshore and onshore infrastructure

The coastal part of the operations area – some 1.5 hectares of land – will surely have an impact on the state of the environment in the vicinity of the FNPP. Taking the land-to-building ratio – at 0.3 to 0.5 – into account, the area covered by buildings, utilities, and infrastructure will total between 0.45 and 0.75 hectares, or approximately 0.002 percent of the territory of the closed town of Vilyuchinsk. Animal and plant life in and around the area will also be impacted by the hydraulic

[xxxii] Again, the urgency of paying due attention to such risks has been rendered bitterly crucial by the still ongoing – as of early April, 2011 – nuclear catastrophe at Japan's Fukushima Daiichi Nuclear Power Plant, where external power supply was cut off following a devastating dual natural disaster and backup power supply failed as well, after which the crisis with multiple meltdowns and spent nuclear fuel exposure, complete with massive releases of radiation, ensued. Please see Footnote XXII. – Translator.

engineering structures the FNPP will need for its operation. These will, to one degree or another, affect the natural environment within a water area of around 8 hectares.

The main environmental impact factors that will result from FNPP operation, affecting the aquatic life in the area will be:

- removal of the natural habitat;
- alteration of temperature regimes;
- alteration of sea currents;
- alteration of wave patterns etc.

6.7. Safety

It is an undisputed fact that any nuclear power reactor presents a potential nuclear and radiation danger. In the case of a floating nuclear power plant, added to these hazards are risks and dangers that arise necessarily with operation of a marine vessel. Other potential risks that all have to be considered when analysing such a facility's safety have to do with the fact that the floating power unit will also be a floating storage facility of sorts, with a concentration of spent nuclear fuel and radioactive waste accommodated on board.

The Kamchatka Peninsula, where project initiators plan to operate the floating nuclear cogeneration plant, is one Russian region that is most prone to earthquakes. This further increases the risks associated with this project. Summarising all of the above, we can make a certain conclusion that the Russian State Nuclear Corporation Rosatom, guided as it seems to be by loosely defined objectives, has been promoting this new and potentially dangerous project even as it offers no economic, technological, social, or ecological prospects or significance to speak of.

6.8. Economic considerations

Taking into account all the costs stated above in our analysis of the FNPP's economics, it appears that a low-capacity nuclear power plant that the project envisions is in fact one of the most expensive alternatives there may be to gas-powered plants. According to official data, the projected costs of building one floating nuclear power plant total around RUR 16.5 billion ($550 million). The unit cost of FNPP construction comes to about RUR 240 million ($7.8 million) per one megawatt of installed capacity. At the same time, the unit construction cost of a land-based nuclear power plant that is currently being completed in Finland,[xxxiii] for instance, is $3.3 million per one megawatt.

In 2007, the issue of the FNPP's economic expedience drew this harsh criticism from the economist German Gref, former head of the Russian Ministry of Economy and Trade, during a government meeting convened to examine a three-year programme of investments into the Russian power generation industry: "*The cost of one kilowatt of installed capacity of the floating nuclear power plant is $7,200. […] this will never pay off. It's seven times as high as in heat generation*." Today, experts have been heard pegging this figure at $10,000 per kilowatt – ten times as high as the cost of one kilowatt of installed capacity of a thermal power plant. Given that Rosatom's experts say the FNPP is to pay off within 12 years – and one must add to the capital costs involved the running expenses

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[xxxiii] Finland has ordered a third reactor, an EPR model, for its Olkiluoto Nuclear Power Plant on Olkiluoto Island in the Gulf of Bothnia in Western Finland. Construction has been implemented by France's Areva, but delays caused by violations of construction standards and issues of supervision, as well as those of overspending – the project is said to have run $2.125 billion over budget – have drawn criticism to the project from all sides, including energy experts, environmentalists, and STUK, the Finnish nuclear safety regulator. The new reactor was projected to go online in May 2009, but after several postponements, the deadline was most recently set for 2013. For more information, please see Bellona's coverage, for instance, here: http://bellona.org/articles/articles_2010/finland_repository. – Translator.

incurred by maintaining physical security at the plant and other expenses described above – two pertinent questions clamour to be asked: How high a price will Rosatom's calculations have to result in for one kilowatt of power? And who will buy such expensive electricity?

Furthermore, the total cost of building an FNPP should probably also include the expenses the Russian Ministry of Emergency Situations will bear creating additional means of emergency management and keeping related equipment, infrastructure, and forces ready in case it needs to respond to a nuclear or radiation accident in the area of anticipated FNPP operation. Expert findings must be taken into account as well that state that the costs of physical protection measures provided for an FNPP sold for export and stationed abroad may reach 50 percent of the total construction costs. It seems self-explanatory, therefore, that given all these factors, the FNPP endeavour is patently loss-making, and no investor – apart from the state – will risk investing anything into a hopelessly unprofitable project such as this.

Judging by statements made by top managers of Rosatom and representatives of various organisations that are involved, to one degree or another, with FNPP construction, the first floating power unit is being built today specifically as a *demonstration facility*. Shall we remind our readers that this demonstration facility will cost the Russian state $550 million, by most optimistic estimates.

That Kamchatka has no use for this floating power station is an uncontroversial fact and undisputed by anyone. The letter forwarded by Kamchatka Governor to the Russian Minister of Energy Sergei Shmatko,[xxxiv] which asks for an "additional examination" of the issue of stationing the FNPP near the Kamchatka coastline, is compelling evidence of that. A choice between a floating nuclear power plant, a gas supply project, and development of geothermal sources of energy has been essentially forced on the region.

In September 2010, Russian President Dmitry Medvedev inaugurated the Sobolevo-Petropavlovsk-Kamchatsky gas pipeline, a mainline link stretching for almost 400 kilometres. This pipeline is capable of covering in full the energy demand of the town of Vilyuchinsk, which needs some 40 million cubic metres of gas per year. Additionally, the Russian gas giant Gazprom intends in 2011 to start geological prospecting works on the West Kamchatka shelf. In preliminary estimates, the forecast resources of the shelf total some 1.3 trillion cubic metres of gas – Gazprom counts on around 20 billion cubic metres' worth of annual production – and on the order of 500 million tonnes of oil. The company plans to supply around 1 billion cubic metres of gas to Kamchatka Region and transport the rest to other regions or sell for export. To these ends, Gazprom will start building either a liquefied natural gas plant or, more likely, a gas compression plant, since it is more efficient to ship compressed gas over long distances via sea routes.

There are other commercially and ecologically promising options as well for Kamchatka. Kamchatka is a highly attractive region to develop power generating capacities based on geothermal sources – subterraneous natural reservoirs of hot water or steam that can be used to produce energy and power. There are significant geothermal reserves in Kamchatka with temperatures in excess of 100 degrees Celsius. Already now the two power stations that generate electricity from the geothermal resources of the Mutnovsky field alone, in Southern Kamchatka, produce an annual output of over 120 megawatts. In December 2010, speaking at an interregional conference of Russia's ruling party, United Russia, in the Far Eastern city of Khabarovsk, Prime Minister Vladimir Putin noted the importance of developing alternative energy sources, in particular, the geothermal energy potential of Kamchatka Region. The town of Vilyuchinsk, where the first floating nuclear power plant is slated to be stationed, can be switched completely to energy supplied from local geothermal sources, such as the thermal

[xxxiv] The Russian version of this report contains a copy of this letter as entered into the ministry's correspondence logs. Please see the Afterword section of this report to view the translated version. – Translator.

waters of the nearby Verkhne-Paratunskoye field. With proper development, the capacity of a district heating system that could supply thermal energy to Vilyuchinsk from the geothermal sources in the Verkhne-Paratunskoye field could reach 88 megawatts by 2012. And it would certainly involve far lesser costs than building a floating nuclear power plant – not to mention the definite considerable reduction in risks incurred on the natural environment and population health.

Afterword:
Does Kamchatka even need a floating nuclear cogeneration plant?

The following is a translated copy of an official letter forwarded by Kamchatka Krai Governor Alexei Kuzmitsky[xxxv] to the Russian Minister of Energy Sergei Shmatko.

Russian Federation
KAMCHATKA KRAI
GOVERNMENT

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06 April 2010 No. 08.13.04

On holding a meeting on
the issue of construction of an FNPP
in the ZATO[xxxvi] of the town of Vilyuchinsk
of Kamchatka Krai

Minister of Energy
of the Russian Federation

S. I. SHMATKO[xxxvii]

Dear Sergei Ivanovich,

The government of Kamchatka Krai has received a letter from the State Nuclear Energy Corporation Rosatom, of 13 November 2009, No. 03-8861, with a request to examine and coordinate the project of a decree by the Government of the Russian Federation on building a floating nuclear cogeneration plant (hereinafter, FNPP) with placement of it in the closed administrative territorial entity of the town of Vilyuchinsk in Kamchatka Krai.

Introduction into the central power distribution system (hereinafter, CPDS) of Kamchatka Krai of a new major generating source – an FNPP with an installed capacity of 70 megawatts – will fundamentally change the power production economy in the region and aggravate power load problems of the system's existing power stations (the total installed capacity of these power stations, including Kamchatka TPP-1[xxxviii] and Kamchatka TPP-2, the Mutnovsky Geothermal Power Plants, and the cascade

[xxxv] As the English translation of this report was being prepared, Kuzmitsky was relieved of his post by a presidential decree citing a "voluntary resignation request." – Translator.
[xxxvi] The Russian acronym for "closed administrative territorial entity." Please see Footnote III. – Translator.
[xxxvii] Rules of etiquette established for official documents require in Russian the use of initials standing for a person's first name and patronymic before the last name. In communication, full first name and patronymic are used in polite address. – Translator.
[xxxviii] For "thermal power plant." – Translator.

of the Tolmacheva Hydropower Plants, is 476 megawatts, with a maximum load during winter periods of 255 megawatts).

According to data provided by Atomenergo[xxxix], the estimated prime cost of electricity produced by the FNPP – as calculated in 2009 values – will be RUR 5.6 per kilowatt-hour excluding VAT, while the prime cost of producing electricity in the Central Power Distribution System in 2009 was RUR 3.89 kilowatt-hours excluding VAT. Furthermore, it should be taken into account that connecting the FNPP to the Kamchatka energy grid will require building an additional high-voltage power line, expanding the existing substations, upgrading the protective relay system and automatic equipment of the power system, which in turn will require additional investments.

In the opinion of the Kamchatka Krai government and RAO Energeticheskiye Sistemy Vostoka,[xl] the above shows the need for additional elaboration of the issue of construction of the FNPP.

Taking into account the coordinating role of the Ministry of Energy of the Russian Federation in issues of developing the energy industry in Russia, I would ask you, dear Sergei Ivanovich, to request that a meeting be held in the near future at the Ministry of Energy with the participation of all interested parties in order to assess the impact of FNPP construction on the functioning of the Kamchatka energy system.

Subsequent to this meeting and the adoption of a consolidated position – and taking into account that the construction of the FNPP affects the interests of not only the residents of Vilyuchinsk, but also of those of the City of Petropavlovsk-Kamchatsky and the Yelizovo Municipality (which are home to over 70 percent of the region's population) – the Government of Kamchatka Krai intends to hold public hearings entitled "Construction of a floating nuclear cogeneration plant and its potential impact on the living environment."

Yours faithfully,

Governor of Kamchatka Krai A.A. Kuzmitsky

Executed by
Lina Fyodorovna Litvinova
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[xxxix] In project documentation, the St. Petersburg-based ZAO (for closed joint stock company) Atomenergo is named as the company in charge of designing coastal and hydraulic engineering facilities for the project. For more information, please see the company's website at http://atomenergo.org/ (in Russian). – Translator.

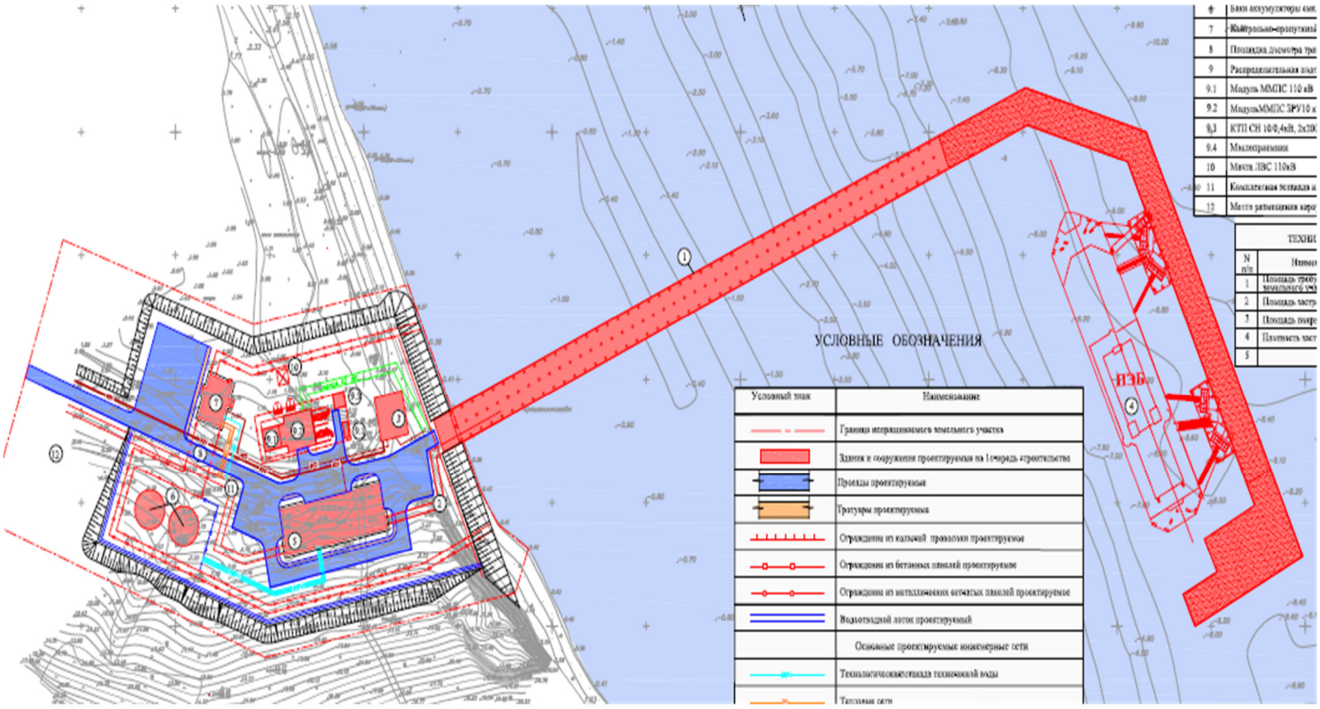
[xl] For Russian Joint Stock Company Eastern Energy Systems, an energy holding operating in the Russian Federal Far Eastern District. More information is available at the company's website at http://www.rao-esv.ru/ (in Russian). – Translator.

Appendices

Appendix I

Appendix III

General construction layout at the site of FNPP deployment in Vilyuchinsk, Kamchatka Krai [1]



Appendix IV

Accidents involving nuclear reactor plants at Russian (Soviet) floating nuclear sites (submarines and icebreakers) [11]

No.	Year	Location	Submarine designation (icebreaker name)/ propulsion system	Accident type
1	1960	Northern Fleet	K-3/VM-A	Reactor accident
2	1961	Northern Fleet	K-19/VM-A	Nuclear accident
3	1961	Northern Fleet	K-19/VM-A	Reactor accident
4	1962	Northern Fleet	K-52/VM-A	Reactor accident
5	1962	Northern Fleet	K-14/VM-A	Reactor accident
6	1962	Northern Fleet	K-3/VM-A	Reactor accident
7	1963	Northern Fleet	K-19/VM-A	Reactor accident
8	1965	Severodvinsk	K-11/VM-A	Nuclear accident
9	1965	Murmansk	Nuclear icebreaker *Lenin*	Reactor accident
10	1965	Northern Fleet	K-33/VM-A	Reactor accident
11	1967	Murmansk	Nuclear icebreaker *Lenin*	Reactor accident
12	1968	Northern Fleet	K-27/VT-1 (RM-1)	Nuclear accident
13	1968	Severodvinsk	K-140/VM-4	Nuclear accident
14	1970	Gorky	K-320/VM-4	Nuclear accident
15	1975	Pacific Fleet	K-23/VM-A	Reactor accident
16	1975	Northern Fleet	K-172/VM-A	Reactor accident
17	1976	Pacific Fleet	K-116/VM-A	Reactor accident
18	1976	Northern Fleet	K-387/VM-4	Reactor accident
19	1979	Northern Fleet	K-90/ VM-A	Reactor accident
20	1980	Pacific Fleet	K-45/VM-A	Reactor accident
21	1980	Severodvinsk	K-222/VM-5m (V-5R)	Nuclear accident
22	1981	Pacific Fleet	K-66/VM-A	Reactor accident
23	1982	Northern Fleet	K-123/OK-550	Nuclear accident
24	1983	Pacific Fleet	K-94/VM-A	Reactor accident
25	1984	Pacific Fleet	K-184/VM-A	Reactor accident
26	1984	Northern Fleet	K-279/VM-4	Reactor accident
27	1984	Northern Fleet	K-508/VM-4	Reactor accident
28	1984	Northern Fleet	K-210/VM-4	Reactor accident
29	1984	Northern Fleet	K-216/VM-4	Reactor accident
30	1984/1986	Northern Fleet	K-462/VM-4	Reactor accident
31	1984	Northern Fleet	K-47/VM-A	Reactor accident
32	1984/1986	Northern Fleet	K-38/VM-4	Reactor accident
33	1984/1986	Northern Fleet	K-37/VM-4	Reactor accident
34	1985	Northern Fleet	K-367/VM-4	Reactor accident
35	1985	Pacific Fleet	K-314/VM-4	Nuclear accident
36	1985	Pacific Fleet	K-431/VM-A	Nuclear accident
37	1985/86	Pacific Fleet	K-175/VM-A	Reactor accident
38	1985	Northern Fleet	K-447/VM-4	Reactor accident
39	1985	Northern Fleet	K-209/VM-4	Reactor accident
40	1986	Northern Fleet	TK-208/OK-650	Reactor accident
41	1986	Northern Fleet	K-371/VM-4	Reactor accident
42	1986	Pacific Fleet	K-175/VM-A	Reactor accident
43	1986	Pacific Fleet	K-59/VM-A	Reactor accident
44	1989	Northern Fleet	K-192/VM-A	Nuclear accident
45	1991	Pacific Fleet	K-94/VM-A	Accident at both reactors

Appendix V

Countries where Russia plans to sell floating nuclear power plants [19]

Appendix VI

The following is a translated copy of a letter addressed by the former Federal Agency of Atomic Energy (now the State Nuclear Corporation Rosatom) to Greenpeace Russia in June 2005.

On construction of the floating nuclear power plant

FEDERAL ATOMIC ENERGY AGENCY

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119017, Moscow
Fax: (095) 9533053
Telex: 611050 “Votum”

June 27, 2005 No. 16/1031

V. N. Pisareva,
Energy Project Coordinator,
International Non-Governmental
Non-Profit Organisation
Stichting Greenpeace Council,
Greenpeace Russia

6 Ul. Novaya Bashilovka, 125040 Moscow

Re: No. of
On construction of the floating nuclear power plant:

Dear Vera Nikolayevna,

In reference to your letter of May 5, 2005, No. 5/213, please be advised that the approved concept of the project of a low-capacity nuclear power plant on the basis of a floating power-generation unit for foreign customers stipulates that the floating power-generation units with nuclear power reactor plants will always remain the property of Russia, hence it is not planned to sell them to countries in Southeast Asia.

Let me also inform you that when selecting sites for the deployment of LNCPPs on the basis of floating nuclear power-generation units, no sites susceptible to the catastrophic impact of tsunamis are chosen for consideraton.

Deputy Department Head V.I. Uryvsky

List of references

Translator's note:

For the reader's convenience, non-English titles of sources cited in this report are stated in their English translations followed by original titles rendered with standard Russian-to-English transliteration rules.

1. Declaration of Intent to build an LCNPP on the basis of a floating power-generation unit with reactor plants of the type KLT-40C for operation in the closed administrative territorial entity of the town of Vilyuchinsk, Kamchatka Region, 1999 (Deklaratsiya o namereniyakh stroitelstva ASMM na baze plavuchego energobloka s reaktornymi ustanovkami tipa KLT-40S v raiyone zakrytogo administrativno-territorialnogo obrazovaniya gorod Vilyuchinsk Kamchatskoi oblasti, 1999). / The IAEA's Status Report No. 73 on the KLT-40S reactor design, Advanced Reactors Information System (ARIS) (http://aris.iaea.org/ARIS/reactors.cgi?requested_doc=report&doc_id=73&type_of_output=html)./ Design Features To Achieve Defence In Depth In Small And Medium Sized Reactors, IAEA Nuclear Energy Series, No. NP-T-2.2; Annex I, Safety Design Features of the KLT-40S (ISBN 978–92–0–104209–5, ISSN 1995–7807; http://www-pub.iaea.org/MTCD/publications/PDF/Pub1399_web.pdf).
2. Low-capacity nuclear cogeneration plant on the basis of a Project 20870 floating power unit with reactor plants KLT-40C in the town of Vilyuchinsk, Kamchatka Region. Investment Feasibility Study, 2004. (Atomnaya teploelektrostantsiya maloi moshchnosti na baze plavuchego energobloka proyekta 20870 s reaktornymi ustanovkami KLT-40S v g. Vilyuchinsk Kamchatskoi oblasti. Obosnovaniye investitsii, 2004).
3. Rules of the Russian Maritime Registry of Shipping. ND No. 2-020101-052 – Rules of Classification and Construction of Marine Vessels, Moscow (2008). (Pravila Rossiiskogo morskogo registra sudokhodstva. ND No. 2-020101-052 – Pravila klassifikatsii i postroiki morskikh sudov. M., 2008)./ Symbols and Abbreviations Used in the Register of Ships. The Russian Maritime Registry of Shipping (http://www.rs-head.spb.ru/en/).
4. V.I. Dmitriyev. Ensuring vessel survivability and prevention of environmental pollution. Moscow, Morkniga, 2010. (Dmitriyev, V.I. Obespecheniye zhivuchesti sudov i predotvrashcheniye zagryazneniya okruzhayushchei sredy. M.: Morkniga, 2010).
5. A.A. Sarkisov, V.N. Puchkov. Principal physics of operation of nuclear steam-generating plants. Moscow, Energoatomizdat, 1989. (Sarkisov A.A., Puchkov V.N. Fizicheskiye osnovy ekspluatatsii yadernykh paroproizvodyashchikh ustanovok. M.: Energoatomizdat, 1989).
6. M.V. Korotkov. Refuelling ship-based nuclear reactors. Moscow, Voyennoye izdatelstvo, 1991. (Korotkov M.V. Perezaryadka korabelnykh yadernykh reaktorov. M.: Voyennoye izdatelstvo, 1991).
7. N.A. Dollezhal et al. Nuclear energy-generating plants. Moscow, Energoatomizdat, 1990. (Dollezhal N.A. et al. Yadernyie energeticheskiye ustanovki. M.: Energoatomizdat, 1990).
8. V.A. Yakimov et al. Handbook of ship survivability. Moscow, Voyennoye izdatelstvo, 1984. (Yakimov V.A. et al. Spravochnik po zhivuchesti korablya. M.: Voyennoye izdatelstvo, 1984).
9. V.A. Kuznetsov. Nuclear marine propulsion reactors. Leningrad, Sudostroyeniye, 1988. (Kuznetsov V.A. Sudovyie yadernyie reaktory. L.: Sudostroyeniye, 1988).

10. V.I. Vladimirov. Physics of nuclear reactors. Moscow, Librokom, 2008. (Vladimirov V.I. Fizika yadernykh reaktorov. M.: Librokom, 2008).
11. V.M. Kuznetsov, A.V. Yablokov, A.K. Nikitin et al. Russia's Floating Nuclear Power Plants: A Threat to the Arctic, World Ocean, and Nuclear Non-Proliferation (http://www.bellona.ru/reports/floatnpp). Moscow, Center for Russian Environmental Policy, 2000. (Kuznetsov V.M., Yablokov A.V., Nikitin A.K. i dr. Plavuchiye AES Rossii: Ugroza Arktike, Mirovomu okeanu i rezhimu nerasprostraneniya. M.: TsEPR, 2000).
12. Floating nuclear power plants in Southeast Asia. Rosatom's newest gamble. Greenpeace, 2006. (Plavuchiye atomnyie stantsii v Yugo-Vostochnoi Azii. Ocherednaya avantyura Rosatoma. Greenpeace, 2006).
13. The reactor of a floating power unit. (Reaktor plavayushchego energobloka (PEB)). http://www.reactors.narod.ru/index.htm.
14. Russia starts construction of floating nuclear power plants (news story), PRoAtom.Ru. (Rossiya pristupila k stroitelstvu plavuchikh atomnykh elektrostantsii, PRoAtom.Ru). http://www.proatom.ru/modules.php?name=News&file=article&sid=2508.
15. A.P. Khudoleyeva. Floating nuclear power plants: An analysis of physical security in export conditions, a thesis. Polarlights.Ru, 2009. (Khudoleyeva A.P. Plavuchiye atomnyie elektrostantsii: Analiz fizicheskoi bezopasnosti v usloviyakh eksporta, tezis. Polyarnoye siyaniye, 2009). http://www.polarlights.ru/ru/thesises/read/mnuItm:thesises/catId:18/thesisId:93/#.
16. Archive of news stories on floating nuclear power plants (in Russian), http://www.atominfo.ru/archive_floatingnuclearplant.htm.
17. G.V. Tomarov et al. Development of Russian geothermal energy technologies. Teploenergetika, 2009. Issue No. 11. (Tomarov G.V. i dr. Razvitiye rossiiskikh geotermalnykh energeticheskikh tekhnologii. Teploenergetika, 2009. No. 11).
18. S.N. Zaviyalov. Floating nuclear cogeneration plants, project status (report). Moscow, 2010. (Zaviyalov S.N. Plavuchiye atomnyie teploelektrostantsii, sostoyaniye proyekta (doklad). M.: 2010).
19. General information about the project of building an energy-producing site on the basis of a floating power unit with reactor plants KLT-40C. (Obshchiye svedeniya o proyekte energokompleksa na baze plavuchego energeticheskogo bloka s reaktornymi ustanovkami KLT-40S). http://www.energetica.ru/rus/m_e/peb_rus/m_e_peb_ru.htm.

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