Bellona report

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From polar to nuclear?

"Nuclearification" of the Russian offshore oil and gas industry

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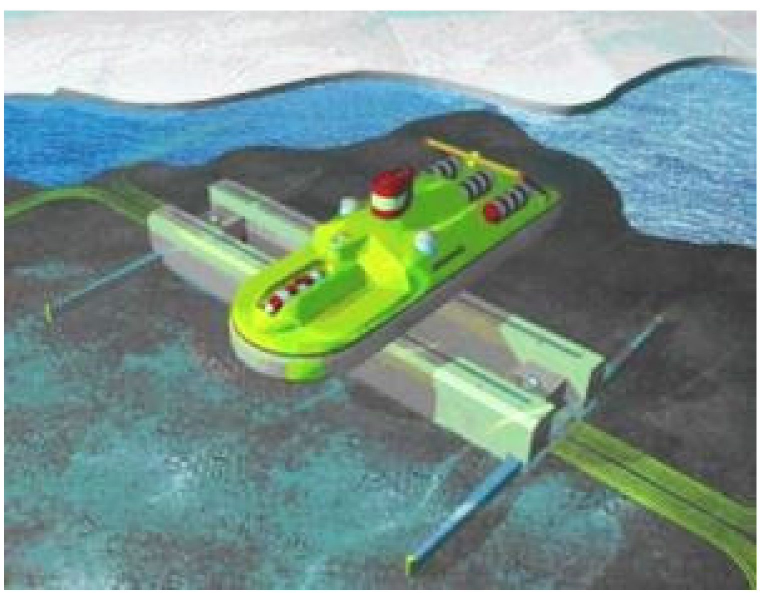

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Executive summary

Russia is planning extensive development of offshore oil and gas reserves in the Arctic. Due to severe climate conditions and the energy demands inherent in this exploration, proposals have emerged to use nuclear-powered underwater drill ships and floating nuclear power plants for the upcoming projects.

The Russian Navy, Russian nuclear industry and submarine design centres which were deprived of lavish state sponsorship after the collapse of the Soviet Union are desperately seeking ways to survive.

One of the ideas which surfaced in the 1990s was to use nuclear submarines as underwater ships to transport cargo along the Northern Sea Route in the Arctic. However, this idea was quickly discarded as it was not proven to be economically viable and was associated with great risks.

The 1980s and 1990s brought the discovery of new oil and gas fields on the shelf of the Barents and Kara Seas. The exploration of these deposits, however, has faced significant limitations due to the severe climate of the Arctic. Because of these factors, the prospect of designing and building an underwater drilling site looks like a reasonable idea. Designers of nuclear-powered submarines believe the technologies they have developed thus far may be applied to offshore oil and gas exploration. They suggest building nuclear-powered underwater drill ships, as well as using nuclear icebreakers and floating nuclear power plants for Russia's oil and gas venture in the Arctic.

Bellona believes that offshore exploration of oil and gas under the harsh Arctic conditions is a risky operation in itself. What the submarine designers suggest is to increase these risks by using nuclear energy with little regard for the environmental consequences, or the terrorist risks involved. In an emergency situation rescue and recovery will be complicated, if not simply impossible. Furthermore, Bellona questions the project economical justification.

Bellona fears any oil and gas exploration in the Arctic, because this vulnerable and unknown area of the planet cannot withstand such an industrial load. Bellona's concern is magnified even more by the notion of utilising nuclear technology for oil and gas exploration and deems this application of nuclear energy particularly irresponsible and reproachable.

Chapter 1

1. An idea is born

In the early 1990s, political circumstances forced the Russian government to take urgent steps to remove from combat duty and decommission a large number of Soviet-made nuclear-weapon-carrying submarines that Russia had inherited after the break-up of the Soviet Union. For the most part, the submarines taken out of service during this period were fully mission-capable second-and third-generation submarines that were still very seaworthy and showed good seagoing qualities. None of the state agencies involved in the decommissioning effort – the nuclear science institutes that developed nuclear reactors for submarines, the military engineering firms that put together reactor designs, the shipyards that built the submarines, or the Navy that operated them – either wanted or were physically capable of fulfilling the task of instantly destroying the fleet of approximately 200 submarines that were removed from service.

At the time, an idea surfaced at a workshop conference arranged by Minatom[1] to cut the missile shafts and torpedo tubes out of the decommissioned submarines and use these subs to transport commercial cargoes under sea ice between destinations along the Northern Sea Route. The freight in question was ores extracted at deposit fields above the Arctic Circle as well as regular deliveries of essential sustenance supplies to industrial cities in the Far North, primarily Norilsk. However, the idea did not spark much enthusiasm among experts not affiliated with Minatom, for the following two reasons:

- The economic feasibility of the project remained a hazy concept; and
- No assessment of anticipated risks was offered.

Because neither the atomic community nor the military could provide any clear information to address these two issues, the only means used to approach the problem was to ask questions based on the logic of common sense.

First of all, if the idea was so good to begin with, why had it not been put into use during the Soviet times, when the majority of all financial, material, and human resources of the country was consistently directed toward fulfilling the purposes of the defense industry? (The fact that all Soviet atomic projects were military-oriented was hardly any cause for doubt?) Why was it that instead of designing a commercial submarine fleet, the USSR chose to adopt the concept of surface ice-breaking vessels? How did it happen that the idea of building nuclear-powered seagoing cargo carriers – dry cargo ships or tankers – never even came up during the era of "atomic euphoria," when the notion of using atomic energy in any and every branch of the country's economy was regarded as a staple of the very near future?

Second of all, even though open access to certain data on accidents associated with submarine operation was not available at the time, it was still a matter of general understanding that the nuclear-powered subsea fleet was extremely accident-prone. These were both contingency situations that were related to navigation and operational errors when steering a subsea battleship in question, and radiation emergencies caused by the unreliability of the components that comprised the nuclear power installation and steam-generating system on board. It was no secret to the higher officials at either Minatom or the Navy as to how costly cleanup operations were after an accident on a submarine.

Finally, situating the cargo correctly and securing it firmly into place are two of the greatest factors affecting the survivability of a submarine. It makes for a challenging task to ensure that bulk cargoes – let alone liquids – have been placed safely on board before the submarine debarks on its course.

In short, as was amply summarized in a critical review published at the time, the entire concept of utilizing subsea vessels to transport commercial cargo only began to make economic sense if submarines were used to transport gold bars. Since the country was hard-pressed to find enough gold to maintain the atomic subsea fleet for commercial shipping purposes, the idea of remodeling naval submarines into dry cargo ships died a natural death.

[1] A Russian acronym standing for what was then the Ministry of Atomic Energy and has for some time now been the Federal Service for Atomic Energy. The common vernacular for the latter is Rosatom.

Chapter 2

2. Stages of submarine technology conversion

2.1. Stage one: a quickie conversion

One country's slapdash attempt at adopting nuclear-powered military subsurface ships for peaceful purposes.

And so it was that the idea of using nuclear-powered submarines as merchant vessels vanished in the haze, while the bulk of the decommissioned submarines were cut up for metal scrap. However, various Minatom structures, specialized design firms and shipyards still had men and women on payroll who had dedicated their lives to developing, designing, and building submarines. They still wanted to do what they knew best, despite the fact that the strategic necessity that had fed their area of expertise no longer existed and the flow of state budget funds had dried up. What was desperately needed now was a source of investment. Because the main source of investment capital for most things in Russia is usually found in the oil and gas industry, this is the sector to which submarine designers and developers turned for financial backing.

In the late 1980s, the management of the design and engineering bureau Malakhit (Malachite), which had been preoccupied with developing subsurface battleships for the purposes of the raging Nuclear Arms Race for decades, extended an offer to Rosneft, the state-run oil giant that was running oil product deliveries at that time along the Northern Sea Route with destinations at the cities and villages of the Soviet Far North. Malakhit's offer was to build a nuclear-powered subsurface tanker fleet to make use of the atomic community's vast knowledge resource. Malakhit developed three novel submarine designs – a tanker, a dry cargo ship, and a container carrier. Yet, the project's sheer costs proved too heavy a burden even for the state budget, let along an individual company. This idea found no support in business circles. Still, the search for the perfect investor continued.

In the early 1990s, when privatization of state property, the pivotal phase in the country's reform strategy, was in full swing, the newly-arrived owners of the Far Northern metallurgy combine Norilsk Nickel were actively looking into ways of cutting shipping costs connected with the deliveries of living staples needed for its enterprises and the surrounding residential areas. Again, submarine designers and builders finding themselves in a predicament after the loss of state commissons, saw this as an opportunity to revive their hope for conversion-associated orders.

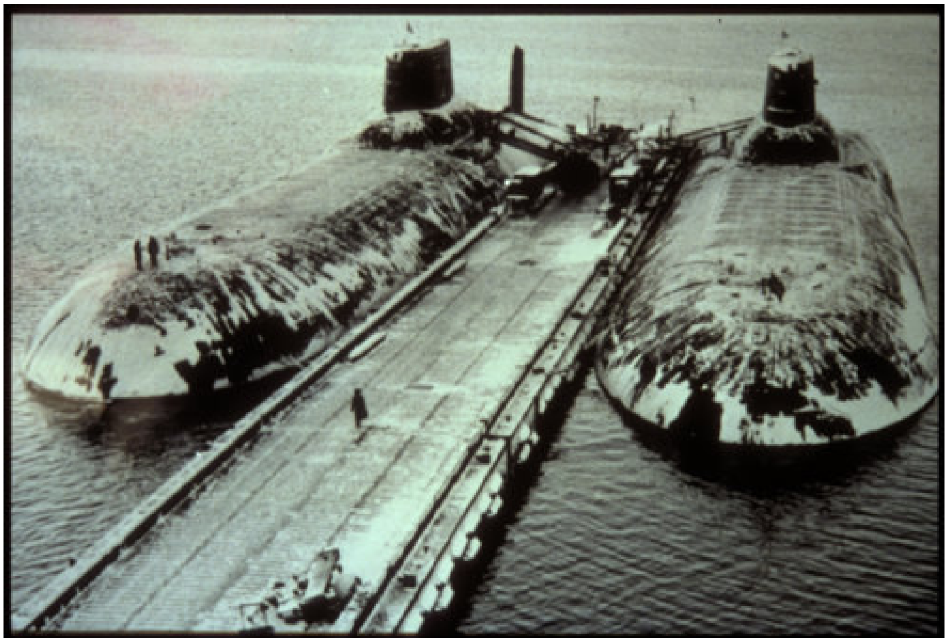
As the case was, a construction order for a series of Project 941 strategic ballistic missile submarines (Akula Class, according to the Soviet designation, or Typhoon, under NATO classification), which was under way at the time, had ground to a halt due to lose of state financing. Six vessels had been completed and delivered to the Navy, while the seventh, still nothing more than a hull, was idling on the slipway at the shipyard Sevmash, in the northern city of Severodvinsk. A pretty sizable amount of money had already been spent on its construction. The estimated building cost of one strategic ballistic missile submarine is around USD 800M, communications and weapons systems not included. The builders' anxiety to find anyone at all to buy a vessel that had suddenly lost its value for the state was quite understandable.

By then, both the Navy and every other entity involved in the operation and maintenance of Typhoon subs had realized how erroneous the decision was to build such oversized subsurface ships to begin with. Both the ships' dimensions and draft did not allow them to leave the waters of the Arctic region. The strategy behind the Typhoons was to have them sail around on patrol duty under the Arctic Ocean in anticipation of World War III and, when it became obvious that the nuclear war had broken out, annihilate half the planet with their rockets. However, rather than fish for the Soviet subs under the Arctic ice, the enemy the USSR was preparing against opted to further develop its missile detection, retargeting and flight destruction systems, rendering these very large and very expensive submarines essentially worthless.

In addition, the Navy's submarine maintenance bases also proved unsuitable for the Typhoon vessels for the very same reasons, while special bases and wharves which were needed to receive the subs for loading, unloading, and maintenance operations had never been built. The idea of employing Project 941 submarines as a kind of subsea cargo-hauling trucks was doomed from the start. Yet, there was one particular feature about their design that developers of the nuclear-powered fleet hitched onto in their desperate quest to replace the lost military customers with civilian ones.

In contrast to all previous submarine designs, where missile launchers were built inside the inner hull, the rockets intended for the Typhoons were so big that they had to be placed *outside* the inner hull –

namely, in the interhull space near the bow, at the midship superstructure. This engineering peculiarity gave rise to the idea to redesign the vessels' bows and replace their missile launchers with cargo holds with a carrying capacity of up to 10,000 tons. This was the proposal that Norilsk Nickel owners received from the management of the design bureau Rubin (Ruby).



Figur 1 Two Typhoon class nuclear powered submarines.

Judging from the fact that the idea of a merchant nuclear-powered subsurface fleet was hardly ever discussed outside these one-on-one talks, the metallurgical giant's top executives quickly grasped just how unrealistic the offer was. The main troubling issues with this plan were:

- Exorbitant operational costs (previously this had never entered into any serious consideration since the vessels were initially built for battle purposes);
- Concerns with respect to nuclear and radiation safety (on account of the absence of any clear data on susceptibility to accidents for both the Typhoon project vessels and submarines of analogous designs);
- The impossibility of conducting any economic feasibility assessment, a step which is imperative for any commercial project, due to the classified nature of the majority of needed information (since analogous military-purpose vessels were still in active operation in the Northern Fleet);
- Absence of duly-equipped onshore facilities for loading and unloading operations, as well as technical maintenance of the ships;
- Navigational restrictions caused by water depths and other limitations along the key Murmansk-Dikson-Dudinka section of the waterway of the Northern Sea Route (Covering the entire route under water would be impossible because of insufficient depths both at sea and along the Yenisei River, the variations in water density – the difference between seawater, for which the subs were designed, and river or desalinated water in the area of "peaceful" navigation – as well as the sheer size of a Typhoon vessel).

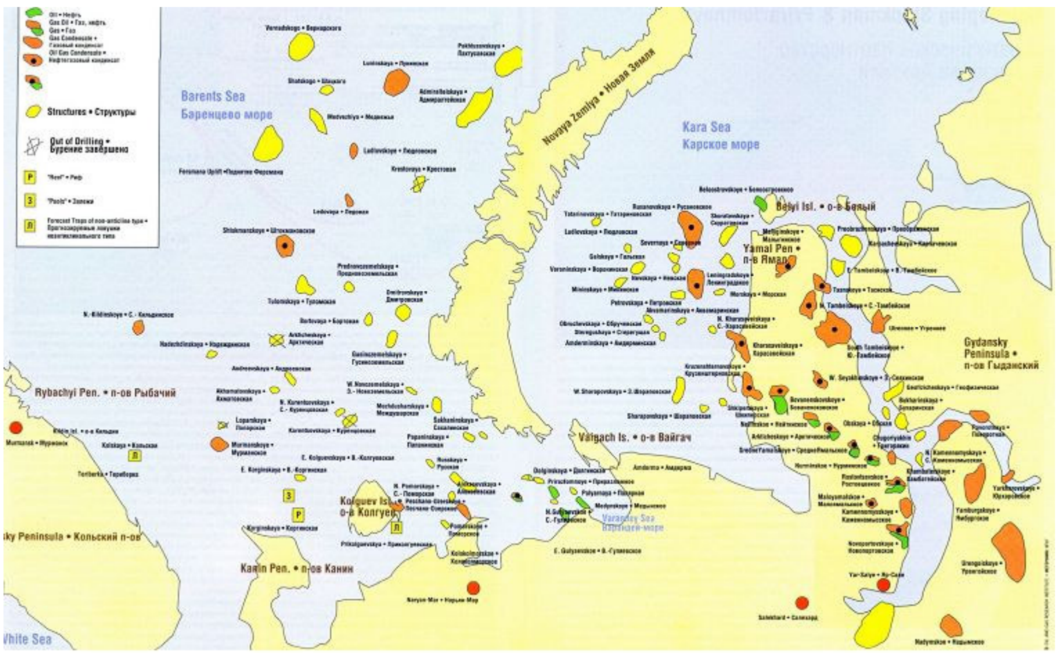
Alas, the first attempts at converting the country's subsurface nuclear fleet to serve the purposes of peaceful application failed miserably. However, because enormous material, financial, and manpower resources have already been flushed into finding engineering and technological solutions for the sake of advancement of the country's military and industrial complex, the obsession with retrieving at least some commercial payoff from these efforts continues even today.

2.2. Stage two: a more thoughtful approach

Putting military technologies to work for the benefit of the Arctic oil and gas extraction industry.

The 1980s and 1990s brought the discovery of new oil and gas fields on the shelf of the Barents and Kara Seas. However, the exploration of these deposits has faced significant limitations due to the severe climate of the Arctic. The costs of hydrocarbon production in this region exceed by more than four times the costs of extracting oil and gas from under seas located in more southern latitudes. It is logical, therefore, that more significant investment funds are required to provide for novel production technologies in order to efficiently develop these fields. In this respect, ideas offered by nuclear submarine designers may be seen as competitive, placed in the context of alternative oil and gas extraction methods.

The problem that these designers propose to solve is of the obvious kind: The major part of proven natural gas deposits in Russia is found above the Polar Circle, in areas covered with permafrost and known for very harsh climatic conditions. Onshore, any operations associated with drilling or transporting the extracted gas can only be performed during the winter. In the summer, when the upper crust of the permafrost melts, it is effectively a stop-work order. It is not that the oil and gas companies are so eager to follow environmental requirements; the simple reason is that in the summer, all machinery and equipment start to drown in the northern marshes and helicopters become the only sensible means of transport. The costs of using helicopters on a daily basis, however, are prohibitive even for a business as privileged as the oil and gas sector.



Figur 2 Oil and gas fields and structures in the Barents and Kara Seas.

As a result, each cubic meter of Arctic natural gas is delivered to the end consumer at a price four times as high as gas extracted in more southern regions. By comparison, drilling one 3,500-meter-deep exploratory well in the south costs around USD 2.5M, while the costs of the same operation in the polar latitudes amount to nearly USD 10M. Over the course of the past few years, there has been a steadily increasing interest in developing natural gas fields located under the shelf of the Arctic Seas, which only drives extraction costs up and makes for a compelling argument to start looking for novel technological solutions to support production there.

Global experience in developing subsea oil and gas deposits is quite substantial. Still, it is hardly applicable in the context of the prospective gas production in the Kara and Barents Seas. The problem is that most of the practical knowledge available in the industry has been gathered extracting gas in warmer regions, where the climate is propitious, the seas are not covered with ice, and hurricanes, though they do occur regularly and can be quite destructive, are nonetheless the kind of a contingency that the well operator can prepare for in advance thanks to weather forecasts.

This, too, is acquired wisdom that world oil and gas giants have paid dearly for. They did not bear the costs of grave accidents or even, at times, the loss of entire drilling platforms only to repeat such hapless experiences in the Arctic. The price of one drilling platform is around USD 2B, in 2000 values. Losing one platform can considerably affect both the owner's financial stability and corporate standing.

Because of these factors, the prospect of designing and building an underwater drilling site looks like a reasonable idea provided that one assumes that hydrocarbon fuel prices are likely to continue to rise exponentially, and consumers will be expected to cover all the extraction and transportation costs. Designers of nuclear-powered submarines believe the technologies they have been developed so far may be of invaluable service to the oil and gas industry. The first to offer their knowledge to assist the needs of this branch of the economy was a department within the Nizhny Novgorod-based design and engineering firm Lazurit (Lazulite), which like its fellow design bureaus has been left to survive with no state commissions and has previously dealt with offshore oil and gas development projects. A group of Lazurit designers has been working on a subsea drilling site project under the management of the department's chief engineer Stanislav Lavkovsky.

Chapter 3

3. The region's climate and weather conditions

An assessment of operational conditions for the prospective development of offshore oil and gas deposits of the Barents and Kara Seas.

The main factors that are set to complicate the exploration of oil and gas fields under the Barents and Kara Seas are the adverse climate conditions of the region, the significant depths at which these hydrocarbon reserves lie, and the considerable depths of the very seas that cover the shelf. The most difficult of obstacles, however, is the continuously drifting solid ice floes that can stretch for a thousand square kilometers and are two meters thick. No machine ever devised by the human mind can withstand such an onslaught of natural forces.

These are the projected climatic and meteorological conditions that have implications for the operation of an underwater drilling complex in the region of the Kara Sea:

- Sea depth: 70 to 400 meters;
- Wave height: 5 meters;
- Wind velocity: 25 meters per second;
- Undercurrent speed: 0.8 meters per second;
- Water temperature: from - 2º C in the winter to + 11º C in the summer;
- Air temperature: from - 50º C in the winter to + 25º C in the summer;
- Ice thickness: 2 meters;
- Ice concentration: 10 tenths;
- Duration of total freezing period: 10 months.

Nowhere in the world has drilling of an offshore oil or gas exploratory or production well yet been attempted in such a hostile environment as is found on the shelf of the Barents and Kara Seas. One area that could provide a slightly commensurate meteorological picture is the offshore deposit fields of the Northern Sea, but production in that region is spared the principal challenge: the enduring freeze-over of sea surface, with ice cover going several decimeters deep. This is what primarily restricts drilling options in the Kara Sea and comprises the essential feasibility factor when evaluating potential technological solutions.

The Rusanovskoye and Leningradskoye gas condensate deposits in the Kara Sea are comparable, climate-wise, to the Shtokman natural gas field located in the central part of the Barents Sea. At the Shtokman field, sea depths exceed 350 meters, with the closest point to the shoreline of the Kola Peninsula approximately 600 kilometers away. The main difference between this location and the Rusanovskoye and Leningradskoye fields, however, is that the former is free from near-permanent ice coverage: Here, one of the Gulf Stream currents does have its warming effect. The region around the Shtokman field is characterized with prominent ice conditions, represented by icebergs and modestly-sized ice sheets. Still, this does not prevent production, although it makes the task of operating a drilling rig that much trickier.

Chapter 4

4. A nuclear-powered subsea drilling site: the concept

4.1. Background information

Taking the climate and meteorological conditions of the Barents and Kara Seas into account, it would make perfect sense that commercial production at the natural gas fields in these areas can only be possible using underwater drilling rigs that would be submerged, or installed on the seabed. Operating these platforms, as well as the whole fleet of support vessels, would call for a complex of unique technological facilities that could function in a self-contained mode for prolonged periods of time while being immersed at considerable depths. In turn, ensuring the reliable operation of these facilities would require enormous amounts of energy. This last argument gave a fresh momentum to the debate over applying nuclear power sources for the purposes of the oil and gas industry.

Academician Yevgeny Velikhov is said to be actively championing this idea, steering potential investors toward appreciating its appeal. What Velikhov is also known for is his staunch advocacy of thermonuclear technologies as a branch of atomic energy science, a field he has been developing for the past forty years as he has moved through the ranks at the Russian Scientific Research Centre "Igor Kurchatov Institute" (formerly, the Kurchatov Institute of Atomic Energy), finally taking the helm as the institute's president. His work has not seen much success in terms of practical application, though over the years, it has absorbed tremendous financial and material resources. The scientist himself believes that taking advantage of thermonuclear fusion as an energy source will not become common practice before 2100. Meanwhile, military nuclear technologies may as well be put to use for peaceful purposes associated with the extraction of natural gas on the shelf of the polar seas of the Russian regions of the Arctic.

In a nutshell, the gist of the idea – which started to morph into a proposal backed by appropriate designs and project documentation in 2003 – can be outlined as follows. A subsea drilling complex consists of a bearing plate and an underwater drilling vessel. The bearing plate is fixed permanently on the seabed and provides support for the drillship during the drilling stage. After the drilling, appropriate facilities are mounted on the bearing plate to start commercial production of natural gas and its delivery onshore for further transportation to the end consumer. The subsea drillship – or Akvabur (Aquadrill), a moniker it has received in the project documentation current at this time – will have on board facilities that will allow for the drilling of a cluster of eight wells as deep as 3,500 meters each, at water depths ranging between 70 and 400 meters. It will be equipped with a drilling rig and enough operating supplies to complete the drilling of one well. To continue drilling, fresh supplies of drilling expendables will be regularly delivered to the ship in containers. At the early stages of project development, power cables are featured as the means of providing energy from the shore in order to run both the bearing plate and the drillship. According to the most recent project documentation, however, the designers have apparently opted for using nuclear power installations as the main energy supply systems to provide power for all floating facilities, both surface and subsurface vessels included.

Bearing plates are expected to be assembled and tested at the plant where they are manufactured, after which they will be surface-towed to the gas field. Once on site, the bearing plate will be installed on the seafloor, connected to transport pipelines, and plugged into the external power grid. The underwater drillship will be moving across the bearing plate's surface as if on rails from one wellhead to another as it performs the drilling. The drilling mud from all eight design-projected wells is planned to be removed for storage in containers placed at the bottom of the bearing plate. The designers have not determined the operational lifespan of a bearing plate. It appears that the plan is to use one bearing plate until the reserves of all the eight wells in the cluster explored from its surface have been exhausted, after which it will be abandoned on the seafloor.

The drillship concept was initially developed as a non-powered vessel that would be surface-towed from the manufacturing plant – presumably, the Severodvinsk-based Sevmash – to its place of stationing. Its positioning over the bearing plate and ensuing immersion and "landing" onto the plate were seen as a complicated multi-stage operation encumbered with a multitude of technical minutia that remained unclear and were supposed to be clarified and adjusted later as the design project was under way. In effect, the very mode of developing the drillship was not unlike that which had been used when creating military-purpose submarines, when the objective was being amended at the same time as solutions needed to achieve it were being researched well into the process of designing and building.

Such a strategy goes against what is understood to be the common approach to implementing a typical business plan, when all project details associated with the prospective production and its case-specific peculiarities, potential risks, and anticipated rise in costs are assessed well ahead of time, at the stage of preparing the investment proposal. Taking into consideration the very scope of investment that is needed to go through with the business plan in question – already at the early stages of designing works, the estimate hovered at USD 9.5B – the verdict was clear: With that degree of elaboration, securing even takeoff investment funds would be a hard nut to crack.

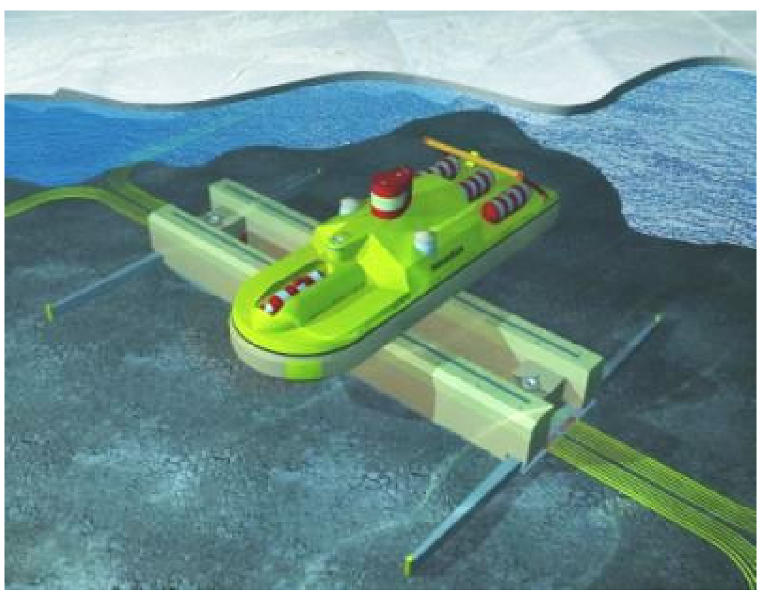
According to the designers' idea, the service life of one drill ship is 30 years. The vessel works in a non-stop mode on top of a bearing plate for four years, after which it is scheduled for a year's worth of maintenance works at the manufacturer's site. That means that one Aquabur vessel's working lifespan will include six operational cycles and five one-year repair periods, which is considerably longer than the experience operating combat submarines suggests. None of the underwater battleships that have ever been in operation with the Navy has undergone so many planned repair cycles, which is why it is absolutely impossible to determine how feasible the proposed mode of operation is.

General characteristics of an underwater drillship:

- Length: 99 meters;
- Width: 31 meters;
- Height: 33 meters;
- Draft: 9 meters;
- Deadweight: 22,850 tons;
- Crew: 60 men.

General characteristics of a seafloor-based bearing plate:

- Length: 123 meters;
- Width: 30 meters;
- Height: 15 meters;
- Draft: 7 meters;
- Deadweight: 8,900 tons;
- Crew: undetermined.



Figur 3 Underwater nuclear powered drillship.

4.2. The scope of work

As the scope of challenges faced by oil and gas production companies on the Arctic shelf has gained a sharper outline, and because anticipated investment costs have continued to rise, the brainpower behind the concept of an underwater drilling site has engaged in further transforming and expanding the complex of technical and technological solutions involved in the proposed idea.

Earlier, this report touched on the publications that provided an overview of the projected range of works and resources needed to start developing the Rusanovskoye and Leningradskoye fields in the Kara Sea. Below are more detailed data made available by the main project developer, the Nizhny Novgorod-based design firm Lazurit, with respect to the necessary facilities and maintenance support that would be required for the operations at the Leningradskoye field. The estimated reserves at this deposit amount to 1,000 billion cubic meters of gas; the estimated timeframe before deposit depletion, at the projected production rate, is less than 12 years.

The Lazurit designers believe that to produce an annual output of 86.6 billion cubic meters of natural gas throughout a period of five years, 96 wells will have to be drilled, each with an average depth of 2,500 meters.

To achieve that, the following sites and facilities first have to be in place:

- Three underwater drillships;
- Twelve seafloor-based bearing plates;
- Three manifolds;
- Three subsurface support vessels;
- Two icebreakers;
- Two subsurface repair and maintenance vessels;
- One floating nuclear power plant;
- One subsea nuclear power plant;
- Ninety-six 2,500-meter-deep wells;
- Underwater pipelines;
- Underwater power communication lines;
- Onshore infrastructure (sites to receive delivery of natural gas produced offshore and prepare it for further transportation).

What remains are a few assessments of the following factors, treated in detail further in this report:

- Anticipated risks that project developers are likely to encounter while implementing the project;
- Estimated investment costs needed to complete the project;
- Technological and industrial production capacities available in the country that may need to be recruited to achieve the stated goals.

Russia possesses no practical knowledge for the realization of a non-military-related program of this scale. The task at hand will be to evaluate the different aspects of this project based on what research, technological, and industrial experience has in fact been accumulated so far.

4.3. The subsea drilling site's power supply

As was stated earlier in this report, the initial development documentation for the subsea drilling site project implied that both the bearing plate and the drillship would receive electric power via cable lines run across the seafloor from an energy source located onshore. The project papers did not specify what kind of a power source would be used, but certain details allowed for the assumption that a natural-gas-based thermal power plant was what designers had in mind. Further documentation, as well as data most recently made public, stated unequivocally that the proposed energy supply system would be based on power provided by two nuclear power plants. These two are a 300-megawatt floating nuclear power plant of the type PAES-300 and a 105-megawatt subsurface nuclear power plant, of an unspecified type.

It is worth noting that the estimates made available to us that detail the costs and scope of investment necessary to complete the subsea drilling site project do not list that item designated as “power supply to surface and subsurface facilities built as part of the project.” This means that additional financial resources will be required, which, when included into the final cost analysis, are capable of significantly shrinking the project's appeal for potential investors. This is why the project papers that have appeared in print lack even very approximate estimations of costs involved in the creation of this whole nuclear power *ménage*. An assessment of anticipated expenses can be drawn based on the perceived costs commonly cited with respect to building such sites.

For instance, one similar project is currently at its initial stage of implementation on the Kamchatka Peninsula. A small-sized, 77-megawatt floating nuclear power plant of the type KLT-40S is being built for the closed administrative territorial entity[2] of the town of Vilyuchinsk. The project's total estimate is RUR 10.2B, in 2007 values.

It takes a few simple computations to determine that one megawatt's worth of the plant's design capacity will cost around RUR 132M – or USD5.3M, at the rouble-per-dollar rate valid for 2007. If one uses the same USD 5.3-million-per-one-megawatt measurement unit as a basis to calculate the costs involved in the construction and launch of the PAES-300 at the prospective site of operation of the subsea drilling complex, this PAES-300 will lighten the project's pockets by USD 1.6B. The real figure, however, is likely to be even higher than that as this preliminary estimate does not make allowances for such price components as, for instance, the interest rate associated with credits attracted for the project, the preparatory dredging works and other waterway enhancements needed before the PAES-300 is installed at its place of stationing, or the expenses incurred by the certification and insurance coverage required for the operation of a commercial nuclear power plant.

As for the planned subsurface nuclear power plant, the costs of producing one megawatt's worth of electric power output there will be even more imposing, both on account of more intricate technological solutions involved in the construction of a subsea site and because of the assumingly more stringent safety requirements that a non-military underwater nuclear-powered piece of machinery must comply with (on that note, one is yet to see any codified safety regulations applicable to such a site). It can be safely asserted, then, that each megawatt's worth of design capacity at this plant will likely set the project back by no less than RUR 250M, or USD 10M in 2007 values. The price tag of the 105-megawatt subsurface nuclear power plant will, accordingly, feature a figure exceeding USD 1B.

In sum total, outfitting a subsea drilling site with a nuclear-based source of energy supply is capable of expanding the project's budget by around USD 3B. One has to bear in mind, furthermore, that implied here are only the costs of building the nuclear power plants per se. In addition, the project will need investment to cover providing the floating and subsurface power plants with necessary maintenance infrastructure and nuclear fuel supplies, as well as storage facilities to accommodate the spent nuclear fuel generated at the plants, to name just a few expense items.

It should be noted that so far, Russian experience has not included a single example of successfully completing the construction, and proceeding to the operation, of a commercial floating nuclear power plant, let alone a subsurface one. A fog of confusion still enshrouds the project of the first floating nuclear-powered thermal plant that is supposed to be anchored, upon completion, at the coast of Severodvinsk to provide energy supply for the city. The plant's hull was initially under construction at Sevmash, but in the summer of 2008, a decision was made to move the unfinished new building to St. Petersburg to see the assembly works to the end.

Certain optimistic observers believe that this means the project is entering into a concluding stage: The future floating plant is just about finished enough for workers to install the nuclear reactor and move on to testing. Yet, experts close to the ongoing situation are known to have held a difficult discussion at a Minatom conference in the spring of 2008 with regard to which type of reactor should be chosen for the plant. Some propose one of the currently available military submarine reactor designs. Others argue that an entirely new reactor type is called for, one that could comply with the requirements set for the construction of commercial-scale energy producing systems (only then will it be possible to see the project through all the necessary stages of certification). The problem, however, is that the atomic community is yet to come up with ready-made reactor designs suitable for the purpose, and creating one from scratch is not only a costly affair, but likely one that might prove beyond the reach of the manpower Rosatom currently has at its disposal.

Another issue that drew the scrutiny of the conference participants and became a fascinating topic for discussion was the potential impact that the operation of the floating nuclear-powered thermal plant may have on the safety of the surrounding environment and shoreline infrastructure. According to project information, this ground-breaking energy plant is slated to be anchored in Nikolskoye Ustiye, a bay not far from Severodvinsk. But the chosen location has revealed a number of liabilities capable of complicating significantly the implementation of the project. Among these concerns are the following:

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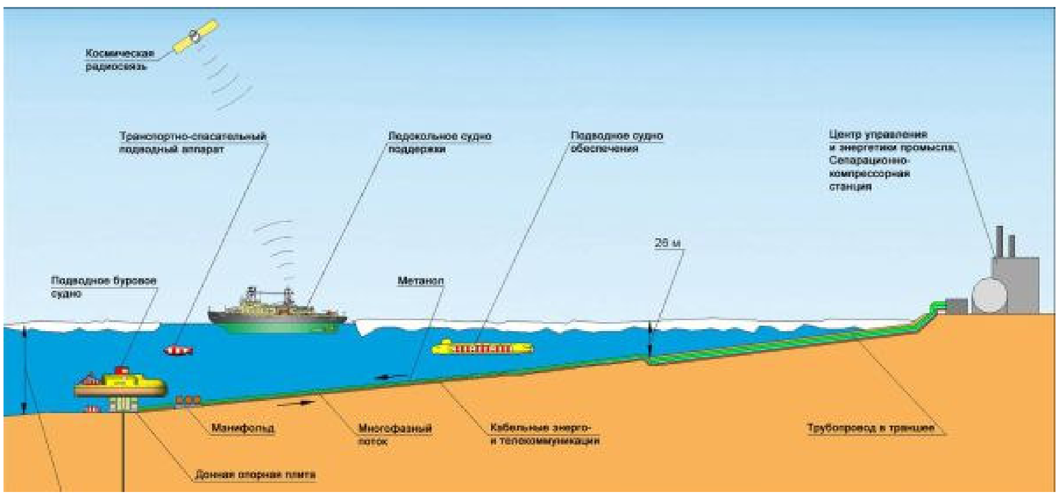
[2] Closed administrative territorial entities (or ZATOs, in Russian), part of the USSR's atomic-drive legacy, are a kind of "reservation" created for the country's scientific community by the Soviet top nuclear authority in the mid-20th century to conduct research and experiments deemed highly sensitive or classified. There are 42 such cities spread across Russia with a combined population of over two million; most of these locations are known by combinations of a name and a digit, such as, for example, Krasnoyarsk-66.

- Traces of both modern-age and prehistoric tectonic processes have been found in the area;
- In order that the floating plant is safely anchored, dredging works first have to be performed to increase water depth by 12 meters; this may accelerate the slumping of the upper layers of the seabed in an area housing 108 waterside sites and facilities, which will either be destroyed or will start sliding into the sea along with the displaced shoreline ground;
- Absolutely no attention has been given to what consequences may follow from the appearance of marine growth on the surface of the plant's hull as a result of water temperature around the site possibly rising as high as + 40˚C;
- Simulations of the operation of the plant's coolant circuit, for which water from the bay is expected to be used, reveal that the reactor's cooling system may be at risk of failure;
- In the contingency of adverse weather conditions, the type of mooring proposed for the plant may lead to hull damage, which could result in the plant's sinking.

All of the above are sufficient grounds to deem the floating nuclear-powered thermal plant project underdeveloped – both in terms of choosing the appropriate reactor type and in terms of finding solutions for the various mooring-related issues. It is furthermore obvious that the implementation of this project will reduce nuclear and radiation safety in the region slated for the prospective extraction of natural gas on the Russian Arctic shelf.



Figur 4 Schematic representation of oil and gas exploration using subsea nuclear facilities.

Chapter 5

5. Risk assessment and an analysis of potential damages

In order that the project of creation and application of a subsea drilling complex be realized, both as an investment and later, a fully functional commercial endeavor, a risk evaluation had to be performed with respect to such contingencies that may be anticipated for the surface and subsurface facilities involved, as well as the staff operating them. An assessment like that is an absolute must if one hopes to attract investment funds from trade-related or financial entities, whose business is based on the concept of turning a profit. The first such evaluation study was completed in 2006. Its conclusions can hardly be called either positive or negative: Rather, the result was acquiring a kind of introductory experience with trying to assess the risks of operating a subsea system that would comprise both mobile, or floating, and stationary, or seafloor-mounted, facilities with power feed provided by nuclear energy sources.

The underlying problem at this stage of project development was that no study pertaining to that kind of risk had previously been attempted as any designs for subsurface sites or vessels that the USSR had ever developed were related to military pursuits and backed by state financing. That meant such projects had to be seen to completion no matter what costs were involved. The outcome of this policy was a high accident rate and secrecy labels slapped on any information that could help in determining potential risks.

The following examination of risks associated with the operation of a nuclear-powered subsea drilling site has been drawn up based on relevant open-access data on accidents that have taken place on Soviet and Russian nuclear- and diesel-powered submarines, as well as causes and concurrent factors observed in these statistics.

5.1. A review of potential risks

Experience gained in the operation of military-purpose submersible craft, or submarines, either those driven by a diesel-electric engine or powered by nuclear energy reactors, shows that accidents on board tend to unfold within the same range of scenarios, irrespective of the type of propulsion system in place. In most cases, an accident is the result of a malfunction in the electrical equipment, defects in the vessel ordinance systems or power-supply systems, and incorrect actions or flawed judgments on the part of the crew.

Most serious accidents that have occurred on Soviet and Russian nuclear and diesel-driven submarines have been in connection with design and environment factors, which all have a specific bearing on a submarine's operation. The highly intricate equipment, the extremely cramped and "energy-packed" inner quarters, hundreds of kilometers of pipelines and thousands of kilometers of cable, explosives and toxic substances on board – all of this is bundled within a confined space surrounded by water.

An underwater floating facility such as a subsea drillship is an extraordinarily elaborate piece of machinery made to function in conditions very dissimilar to those generally deemed "conventional," or simply put, above water. As a result, the following environment-specific emergency situations are prone to develop and have to be taken into consideration when examining potential operation-related risks:

- Failure or breakdown of the nuclear power-generating system followed by a spread of radioactive substances within the hull or beyond both during planned drilling works and while undergoing scheduled repairs at the manufacturing site;
- Sinking as a result of outside water inundating the hull;
- Fire outbreak prompted by having a massive load of combustible materials on board along with kilometers of electric cables, all crammed within the confined space of a subsurface vessel characterized by unique atmospheric conditions considered unstable because of the specific gas composition and pressure;
- Explosion caused by a leak and combustion of high-pressurized gases in the conditions of the confined space of the submersible;
- Suffocation or poisoning suffered by the crew as a result of a localized fire;
- Suffocation or poisoning suffered by the crew as a result of toxic gases or toxic fumes penetrating the ventilation system;
- Failure of control systems (designed to maintain control over a large number of maintenance-free facilities or unattended quarters that are only subject to occasional visual supervision), which is a frequent cause of fires, mechanical damage, and subsequent sinking of the submersible;

- Threat of toxic drilling sludge and toxic and flammable wellhead gases leaking into the drillship's living quarters;
- Threat of mechanical damage to the structures of the subsea drilling site as a result of vibration associated with the operation of the drilling equipment and the shale shaker; and
- Threat of cement powder penetrating into the drillship's living quarters, cementation and breakdown of the drilling rig and the site's auxiliary systems.

Erroneous actions undertaken by the crew in emergency circumstances comprise a serious aggravating factor when preventing or handling an accident. Among the most likely scenarios that could be set into motion by human mistakes are the following:

- Navigation-related incidents caused by steering errors on the part of the crew of the drilling vessel or those of surface or subsurface ships in the vicinity (vessel-to-vessel collisions, shock produced by hitting the ice or the sea bottom, submersion below allowable depths, or sinking as a result of outside water inundating the inner spaces of the submersible);
- The crew's failure to follow safety regulations;
- Performing works that can result in the generation of sparks in the conditions of fire hazard;
- Unsanctioned use of open flame and smoking on board;
- Consumption of alcohol by crew members and various erratic consequences of behavior under inebriation.

Expert evaluations of factors that commonly result in accidents or disasters on board military subsurface vessels show that in 75% of cases, the causes contributing to the development, or escalation, of emergency situations are rooted in the erroneous response on the part of the crew, who tend to lose control over the intricate equipment during contingency events. Faced with emergency circumstances, specially trained and well-prepared crew members quite often start to deviate from instructions, or do exactly the opposite of what they have been taught to do. The very necessity of following procedure and numerous guidelines and safety rules unerringly in the context of the confined space of a submarine takes the toll on the men's psychological preparedness and interpersonal compatibility, which is crucial during emergencies.

A case of underwater spouting of natural gas from the well, or an out-of-control gas kick (fast egress of gas out of the well) as a result of an accident, incorrect response actions on the part of the crew, or unpredicted activity inside the well may all lead to a radical disruption in the operational conditions in the area of the subsea drilling site's stationing. That, in turn, may propel the drillship into out-of-control motion or lead to its sinking. According to project documentation, in such an event, the vessel must be undocked immediately from the bearing plate and brought to the surface. However, no known practical experience has ever been acquired with this kind of evacuation procedures, which defies realistic assessments of how feasible such an emergency surfacing might be. Furthermore, the experience that is at all comparable – that of operating a surfacing rescue chamber of a military submarine – has proven well below expectations. One of the stark examples is the performance of the rescue chamber of the *Komsomolets*, which only saved one crew member.

The climatic and weather conditions in the area of the prospective operation of the subsea drilling site are characteristically harsh, which limits the application of well-developed technologies and procedure used in the organization of drilling works elsewhere. The natural hazards that may threaten drilling operations in the Kara Sea – the exact effects of which are yet to be adequately examined – include the following:

- Severity of the natural environment (low temperatures, prolonged ice conditions, strong winds and currents);
- Random behavior, i.e. movement, of sea ice;
- Changeable patterns of sea currents;
- Unforeseen tectonic processes or subaqueous slumping in the area of the drilling site's operation, which may be triggered by the bearing plate subsiding into the hollow formed as a result of extraction works performed on the deposit;
- Unforeseen cryogenic, or permafrost-associated, processes in the vicinity of the drilling site's operation due to the generally predicted shrinking of the permafrost and areas with prolonged ice coverage (where the thawing may further be accelerated by gas production) and the associated rise in alluvial runoff (displacement of the solid fraction) from the shore, an

increase in sediment concentration in the sea water, as well as changes in the subsea structural relief and formation of new shoals;

- Unpredictable changes in the local natural environment caused by the ongoing global climate change, which may manifest as drastic fluctuations in weather patterns in the area of the drilling site's operation.

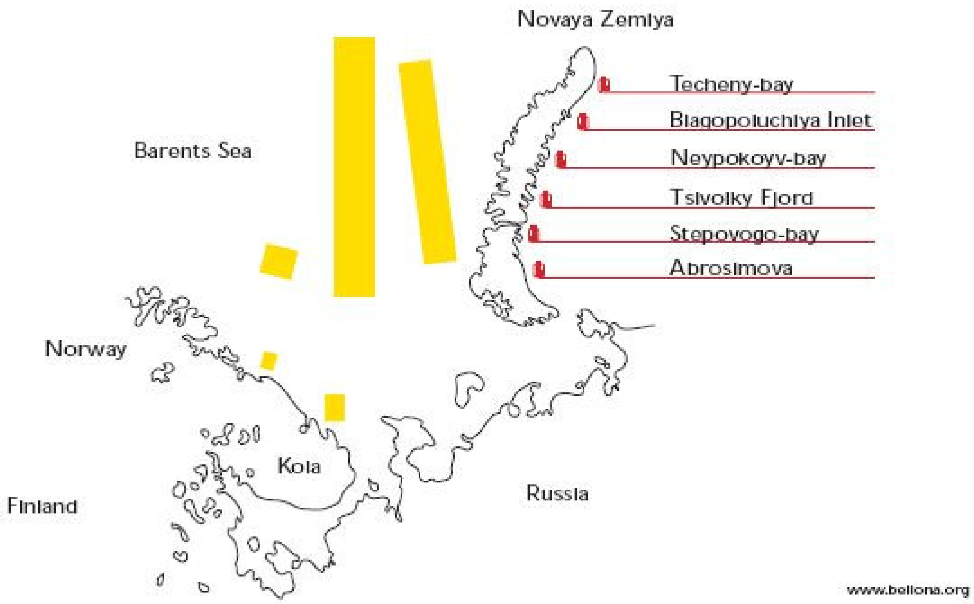
The seismic conditions in the project area are another concern that requires additional research and assessment. Because extraction rates at the deposits are supposed to rise fast as the fields are further developed, the production complex may be faced with the manifestations of what is called "induced" – or technogenic – seismicity, which could lead to dramatic changes in the operational environment of the drilling site. It would also be sensible to anticipate the risk that the bearing plate may subside as the seafloor might give way due to the formation of hollows where the natural gas extraction operations will be performed.

Climate changes observed in recent years on the global scale – the shrinking of prolonged ice coverage and disappearance of both alpine glaciers and polar ice caps – are very likely to be exacerbating in the near future. This will result in changes in ice conditions in the seas of the Arctic region, as well as disruptions in permafrost-related processes on the shore. Gas production in the Kara Sea will only contribute to further destruction of the region's permafrost. The inevitable outcome of that will be the increase of alluvium, or solid particles such as sand, clay, or silt, moved by coastline streams into sea water. This will lead to changes in the seafloor relief and an increased muddiness of sea water as sediment concentration will rise.

Risk assessment should also take into account the hazards inherited from the operations of the Soviet nuclear-powered naval fleet in the region of the Barents Sea. The Soviet Navy acquired the practice of dumping large amounts of radioactive waste of varying degrees of radioactivity area around the Novaya Zemlya archipelago. This radioactive waste includes containers with spent nuclear fuel (SNF), reactor sections cut out of nuclear icebreakers and submarines, and entire nuclear submarines which are dumped at locations whose precise coordinates remain unknown.

As for waste lying on the bottom of the Kara Sea along the coast of the archipelago, some of the information is in fact available, such as the number of submarine nuclear reactor compartments cut out and dumped into the sea with or without the spent nuclear fuel still in them. However, the total number of containers with radioactive waste and spent nuclear fuel that has been disposed of at sea is yet to be established. Any evaluations of the actual scale of the risks associated with the potential escape of these radioactive substances into the surrounding environment will have to be only very approximate estimates. The available data on radioactive waste and spent nuclear fuel dumping in the Kara Sea by geographical location are as follows:

- Tsivolka Bay: three reactors cut out of the nuclear icebreaker *Lenin* (the SNF was unloaded prior to dumping), a tugboat with a container holding 125 damaged spent nuclear fuel assemblies from the *Lenin* and 4,750 containers with solid radioactive waste (the exact degree of radioactivity remains unknown; according to calculations performed by Igor Kurchatov Institute experts, radioactivity levels reach around 460,000 curies; however, independent estimates put that value at over 1 million curies);
- Stepovoi Bay: K-27 submarine (two liquid metal fuel reactors, with SNF still in the reactors, combined radioactivity emitted is likely to be no less than 2 million curies) and 1,850 containers with solid radioactive waste (radioactivity levels unknown);
- Abrosimov Bay: eight reactors (SNF still remaining in four of them, with combined radioactivity levels of these four reaching no less than 4 million curies) and 550 containers with solid radioactive waste (radioactivity levels unknown);
- Bay of Currents: two reactors from K-140 submarine (one reactor still containing SNF, which was only used for a short period of time);
- Novaya Zemlya Trough: 1,450 containers with solid radioactive waste (170,000 curies);
- Olga Bay: 850 containers with solid radioactive waste (radioactivity levels unknown);
- Blagopoluchiye Bay: 850 containers with solid radioactive waste (radioactivity levels unknown);
- Neupokoyev Bay: unknown number of containers with solid radioactive waste (3,400 curies).



Figur 5 Overview over dumped radioactive waste in the Barents and Kara Seas.

Also dumped in the Kara Sea near Novaya Zemlya were the following three special vessels that had been used to provide technical maintenance to Soviet merchant and military nuclear-powered ships; these three had been heavily contaminated by years of operation and have radioactive waste on board:

- In 1964, Tsivolka Bay: the *Nikolai Bauman*, dumped with a load of solid radioactive waste;
- In 1968, Olga Bay: a tugboat, designation SB-5, dumped with a load of solid radioactive waste;
- In 1976: *a special-purpose technical maintenance vessel*, designation PSSN-28, dumped with a load of both liquid and solid radioactive waste.

Of all waste disposed in the Kara Sea near Novaya Zemlya, the worst threat in terms of potential radioactive contamination of the surrounding environment is posed by the six submarine reactors, with SNF still remaining in their cores, and the fuel assembly from the nuclear icebreaker *Lenin*, which were all dumped in bays characterized with shallow water conditions.

Another important consideration is that energy-related sites commonly require enhanced security to prevent the threat of terrorism, a factor that has been the subject of increased awareness in recent years. In that respect, a subsea drilling complex should be viewed as a site dangerously exposed to potential terrorist attacks for the following reasons:

- It is a floating facility;
- It serves to cover energy needs of a large number of consumers;
- It has great material value;
- It is vulnerable to the impact of both external and internal factors.

Therefore, special attention must be paid to providing the subsea drilling complex with security measures in its place of stationing, at the prospective drilling sites, and at locations where the complex is to undergo technical maintenance and repairs. Additionally, consideration must be given to the risk of terrorists acquiring access on board the complex while posing as part of the crew.

5.2. Emergency scenarious and their potential consequences

Evaluations of likely emergency scenarios show that none of the practical knowledge or experience gained from accidents that have already taken place on board the Soviet military nuclear fleet is ever taken into consideration, or used as a valuable lesson when attempting to prevent, or take control of ongoing emergencies. This is explained by the extremely difficult psychological and operational conditions in which the crew of a submarine under distress has to act to handle a contingency event.

The statistical data used in this report present a telling – although, far from comprehensive – picture of accident history across the fifty-odd years of operation of the Soviet subsurface military-purpose fleet. Because a range of characteristics makes an underwater drilling vessel comparable to a submarine, for the purposes of this analysis the information available should be considered applicable to assessing potential emergency scenarios and their consequences on board a drillship.

The total operational experience accumulated by the Soviet Union, and later Russia amounts to 260 submarines. Overall, the combined operational lifespan of this fleet, from a submarine receiving in-service status to its decommissioning, is equivalent to 5,000 "submarine-years."

The calculating method was as follows: All operational lifespans of individual vessels were added up; from the year the submarine becomes operational to when it is taken out of commission, and then divided by the total number of submarines ever operated by the Soviet, and then Russian, Navy. One submarine's service lifetime ranges between three and 30 years. On average, each vessel is in active duty for around 20 years.

As to information on accident history on board Soviet or Russian submarines, this is less of a determinable parameter. Only data on certain accidents, those with the gravest consequences which for a variety of reasons the Navy has been unable to hush up, is available for open access. Because of this, accident data presented below cannot be considered comprehensive. According to information that has appeared in print, records show that 338 emergency situations occurred on board the Soviet Navy's submarine fleet between 1970 and 1990 alone, where there was registered evidence of radioactive substances leaking beyond the nuclear power systems on board, as well as increases in background radiation levels.

All of the accidents placed on official record and described in open-source materials across the years of both experimental and practical operation of Soviet and Russian submarines – 5,000 years per a total of 260 submarines – can be systematized to show the following:

- Accidents involving failure of the nuclear power installation on board / including those resulting in casualties among crew members (54 / 3);
- Fire outbreaks, localized fires, and explosions / including those resulting in suffocation or death of crew members (43 / 16);
- Loss of impermeability (outside water penetrating into the inner hull, including the reactor compartment) as a stand-alone accident / including cases involving sinking of the submarine and casualties among crew members (26 / 4);
- Navigation-related accidents (34 / 0);
- accidents caused by failure to follow technological procedure during planned operations or repair works / including those resulting in casualties among crew members (11 / 1);
- Chemical poisoning suffered by crew members (1 / 0).

In expert estimates, this information amounts to no more than 15% of the actual number of severe accidents that have taken place in the fifty-odd years of submarine operation in the USSR and Russia and where significant harm was inflicted on a submarine's integrity or human health (in effect, the real accident statistics would be 6.5 times as high as the figures above). Furthermore, there are currently no statistics showing operational performance and accident history pertaining to the operation of the Soviet diesel-powered submarine fleet, which numbered far more vessels than were in service in its nuclear-powered counterpart.

Likewise, there are no exact statistics for accident rates on commercial subsurface ships or stationary subsea facilities (the number of such sites or vessels is not too large and is within the limits of statistical error).

The scope of consequences resulting from emergency situations on military subsurface vessels can be quite significant:

- Human losses or impact on human health (injuries or casualties sustained during an accident);
- Loss of property (in kind and in monetary value);
- Harm inflicted on the environment, including on seawater and bottom-dwelling flora and fauna, with destruction of the vulnerable ecosystems of the Arctic seas (in kind and in monetary value);

Of these types of consequences, losses of human life or health impairment as a result of an emergency event on a subsurface vessel are classified as severest and most irretrievable. No open-source materials exist with complete enough statistical data regarding injuries or deaths sustained in emergency situations on board Soviet military submarines. Expert estimates, which are based on information that has appeared in the press, say that over the 50 years of operation of the Soviet nuclear-powered fleet, the total number of fatalities among crew members or repairmen involved in at-sea operations or maintenance works has reached over 700 people. These statistics do not include those who have sustained injuries of various degrees of severity and died soon after discharge from naval service or retirement (not even approximate estimates are available for this type of cases). Judging from data commonly available on average crew strength, as well as that on the number and severity of accidents on record in the Navy, this group of cases would exceed 10,000 people.

After each emergency event a subsurface vessel undergoes a period of renovation works, which may range from one year to 10 years (not counting the time of voyage to the repair site), depending on the severity of the accident as well as technological and financial capacities obtainable for the repairs.

The costs of renovations performed on Soviet military-purpose subsurface vessels were on a scale of between several million roubles in the 1960s and RUR 350M in the late 1980s.

As renovation works get under way, it is not infrequent that the construction of a submarine reveals inherent engineering defects, or errors made at the stage of selection of building materials during construction, which drives up repair costs significantly. In around half of the known cases, the costs of repair works performed on a submarine exceed those that would have to be paid to build a new one.

Under regular operation, a military subsurface vessel does not present too grave a threat to the environment. However, contingency situations carry with them considerable risks of adverse environmental impact if they result in toxic or radioactive substances leaking into the surrounding environment, which could prove extremely harmful to the very vulnerable, age-old ecosystems of the Arctic seas.

No assessments of what scope such environmental detriment could take in the course of experimental, or practical, operation of military-purpose subsurface vessels has ever been published in any source. Because of that, any evaluations of potential environmental damage inflicted by subsurface fleet operation will have to be made with the help of methods used to identify environmental risks associated with the operation of comparable commercial surface vessels.

Chapter 6

6. An assessment of the subsea drilling project's economic feasibility

6.1. Available natural resources and overall exploration costs of the Arctic deposits

Information on the estimated reserves of energy resources available for extraction is the principal factor around which estimations of the commercial potential of exploring a field are built. This is why such information always becomes the bargaining chip in a bull speculation game that interested parties play to boost a field’s commercial appeal and attract potential investors. Following a decision by the government of the Russian Federation and various federal guidelines, data pertaining to the estimated oil and gas reserves in known Russian deposits are closed for public access, so only approximate estimates – which may also fluctuate greatly, depending on the source – are obtainable for an analysis.

Because this review examines predominantly the prospects of the Rusanovskoye field (discovered in 1989) and the Leningradskoye field (discovered in 1991), namely the technological solutions needed for the setup of production facilities and extraction of natural gas and gas condensate from these deposits, the focus here is on the information that has appeared in print with regard to what reserves are perceived to be available for recovery in these fields. One has to bear in mind, meanwhile, that the main source of these data is press releases circulated by the Russian state-owned gas giant Gazprom. Gazprom’s top executives can be expected to always promote higher capitalization values, for which such information is crucial, so there may be grounds to suspect that the data below are overstated. There are hardly other conceivable reasons to haze over the true estimates of established reserves.

Organizations pushing for the use of nuclear technologies in the oil and gas industry in the Arctic estimate the overall reserves of hydrocarbon resources on the shelf of the Kara and Barents Seas at 65 billion tons of fuel equivalent. Of these, hydrocarbon reserves of the Kara Sea are deemed to be totaling 28 billion tons of fuel equivalent, with 80% of these resources believed to be in deposits found in shelf areas with water depths of over 70 meters. At the same time, 70% of the entire shelf area in question is covered with multi-year drifting ice sheets.

Finding reliable data on estimated natural gas reserves is a challenging task. Certain sources peg the total reserves available for production at the region’s most promising gas fields – Shtokman, Rusanovskoye, and Leningradskoye – at between 10 trillion and 11 trillion cubic meters, while other experts believe the Rusanovskoye and Leningradskoye fields alone would account for between 9 trillion and 10 trillion cubic meters of gas. Furthermore, estimates on these two fields are only based on information that has become available from the drilling of two exploratory 2,500-meter-deep wells at each deposit. Though the four wells are considered by experts to be “prolific” ones – with a daily output rate there reaching 600,000 cubic meters of gas, and, by extension, yearly output figures at each well adding up to a potential value of 200,000 million cubic meters, provided all factors ensure a smooth year-round production – they are hardly a solid basis upon which to found sensible prognoses. These same experts point out that in order to arrive at more conclusive evaluations, no less than 40,000 meters’ worth of exploratory wells will have to be drilled at both fields, that is, at least 10 wells each.

One fact here draws special scrutiny: Earlier data speak of far more considerable natural gas reserves assumed to be available on the shelf of the Kara Sea as compared to information published more recently. Whereas in 2000, the reserves of the Rusanovskoye field’s shallow horizon alone (at depths of 1,500 meters) were pegged at 1,050 billion cubic meters of gas, and another 2,100 billion cubic meters was believed to be available at depths of 2,500 meters (with a total value amounting to 3,150 billion cubic meters), only a few years later, in 2006 and 2007, overall estimates did not exceed 780 billion cubic meters. The same mystery surrounds prognoses ventured for the potential reserves of the Leningradskoye field: In 2000, gas deposits there were estimated at 1,500 billion cubic meters at depths of 1,500 meters and at 1,550 billion cubic meters at depths of 2,500 meters (with overall potential reserves reaching 3,050 billion cubic meters), while in 2006 to 2007 already, total reserves were assessed to be 1,050 billion cubic meters of gas. In effect, the latest figures were 3.5 times down from earlier forecasts.

This means that at an annual production rate of around 100 billion cubic meters of gas – which is considered a prerequisite value when analyzing prospects for investment return – the reserves of the

Leningradskoye field will run out in less than 10 years; for the Rusanovskoye field, that figure is eight years. At the same time, according to assessments made by the subsea drilling site concept developers, their project's minimal payoff period is 12 years. True, they emphasize that their calculations are based on gas prices current at the time of the assessment. But while making an allowance for the anticipated rise in market prices for natural gas, one also has to keep in mind that price hikes will be accompanied by commensurate increases in costs of materials and services needed for the exploration of a gas field, which will guarantee that the project's budget will swell accordingly. There are grounds to argue that the gas-market-price-versus-exploration-costs ratio will remain unchanged.

Figur 6 Oil platform in the Kola Bay.

Meanwhile, according to existing information, at least 300 production wells will have to be drilled at the Rusanovskoye and Leningradskoye fields, which, at the minimum of USD10M-per-well cost of drilling in the Arctic conditions, will amount to USD 3B. In addition, 35 bearing plates will have to be built and installed on the sea bottom. Given the price tag for the construction and operation of one bearing plate – USD 35M in project developers' estimates – those costs will round up to USD 1.2B. Other expenses will include building five underwater drill ships at a combined price tag of USD 2.35 B, with one drill ship estimated by project developers at USD 470M.

These are the preliminary estimates for the minimum of investment funds that will have to be attracted, according to information found in open sources. Below follows a more detailed assessment based on project calculations of expenses anticipated from the prospective development of field infrastructure and transportation of recovered gas to the end consumer.

The Shtokman natural gas field in the Barents Sea is quite comparable to its counterparts Rusanovskoye and Leningradskoye in terms of climatic conditions prevailing in the area. According to existing estimates, its recoverable reserves total 3,200 billion cubic meters of gas. By the most modest cost assessments, the exploration of the Shtokman field will require USD 50B worth of investment, which will constitute between 10% and 20% of the price of the extracted gas, even though as far back as several years ago, an amount of USD 20B was considered sufficient for the project. Transportation of the gas to the end consumer will account for a similarly sized price component.

6.2. Competitive technologies for the oil and gas reserves development market

Modern-day offshore drilling technologies date back at least several decades. Drilling at sea from stationary, or pile-supported, platforms has been in use for a hundred years, though the application of existing technologies has so far only been possible in areas with comparatively shallow sea depths. Drilling options in deeper basins improve significantly when the operations are performed using a buoyant drilling platform. A fundamental element of a floating drilling platform is the global positioning system, which helps maintain the platform at a particular geographical location in order to keep intact the drilling facilities that connect the platform with the sea-based deposits. An advantage of this method is that it allows for drilling at considerable water depths. The chief drawback is its reliance on the complicated satellite navigation system, as well as managing the platform's vulnerability to strong winds and wave conditions.

If the buoyant platform is permanently fixed in place using extended tension legs, maintaining its position at a particular geographical location is not as challenging. However, this approach is only applicable for sites with relatively insignificant sea depths.

Recent years have seen an increasing demand for submersible platforms, intended for use at drilling sites in the Norwegian regions of the Arctic shelf. Yet, these platforms have not been in operation long enough to yield information sufficient for a substantive discussion of this method's advantages or weaknesses.

The only shipyard in Russia that is capable of building deep-sea submersible drilling platforms with dimensions larger than 100 meters by 100 meters is the Severodvinsk-based Sevmash, the birthplace of many Soviet combat submarines, including the gigantic Typhoons. Since 2005, on order from the Norwegian company Moss Mosvold Platforms AS, Sevmash has been building a series of semi-submersible platforms of the type MOSS CS 50. In September 2007, the Norwegians received the first construction. A second platform is currently under construction. Following the completion of this order, Sevmash management hopes to land a similar order from Gazprom to build a platform for the development of the Shtokman field. Expanding Sevmash's operations has required a range of modernization works at the yard, for which Gazprom has already provided a certain amount of funds. It can be safely said that via this initial investment into the yard's shipbuilding capacities, the Russian gas monopoly has apparently been forging a forthcoming partnership with Sevmash.

Still, it is too early to call Sevmash's experience with building drilling platforms for the oil and gas industry a raging success. The yard has since 1995 been engaged in the construction of the *Prirazlomnaya* platform for oil production at the Prirazlomnoye field, in the area around Pechora Bay (estimated extractable reserves here amount to 83 million tons). The platform's dimensions are 126 meters by 126 meters, it weighs over 70,000 tons, and the costs of its construction exceed USD 850M. Certain components of the new building have both been developed and assembled at Sevmash; other design elements have been "borrowed" from an old, out-of-service drilling platform bought from Norway. *Prirazlomnaya* is intended for year-round drilling operations; it will be equipped with a drilling rig, two cranes, a helicopter pad, and living quarters for 200 workers.

At the moment, *Prirazlomnaya*'s completion and launch timeframes remain anybody's guess. Deadlines have been pushed back repeatedly.

6.3. The economic expediency of the subsea drilling site project

As was mentioned earlier in this review, the actual magnitude of the subsea drilling site project gradually started to dawn on the project developers. In 2006, the designers were considering building one drillship, without the nuclear power installation, and one seafloor-based bearing plate. Electric power supply to feed the drillship and the bearing plate was supposed to be provided via electric cables run across the sea bottom from a power plant based onshore. Then entered academician Yevgeny Velikhov, and the project's scope grew exponentially. Added also was the absolute prerequisite that the project's implementation would be contingent on the application of nuclear power plants as the sole source of energy for all the components of the subsea drilling site, as well as the transportation infrastructure. At that stage, the project's costs were only subject to very approximate estimates.

According to a more recent attempt at assessing the entire scope of investment needed to provide all natural gas production facilities at the Leningradskoye field alone – limited to the pre-production period, but having an annual output of 87 billion cubic meters of gas in mind (in estimates presented to the expert community in the summer of 2008) – the project has swollen to include the necessary construction of 12 bearing plates, three manifolds, three drillships, three subsurface support ships, two icebreakers, two subsurface repair and maintenance vessels, and other seafloor-based and onshore infrastructure. That single project stage was estimated to cost nearly USD 6.3B, or 66.1% of overall investment it is hoped to land. The construction of underwater pipeline and power infrastructure carried an additional price tag of around USD 2.3B, or 24.7% of total investment funds. Elsewhere, drilling and building the necessary facilities to start production at 96 wells was assessed to require around USD 900M, or 9.2% of total expenses. In its entirety, the project adds up to USD 9.5B worth of investment funds.

The team behind the project believes that the cost of 1,000 cubic meters' worth of natural gas output at the Leningradskoye production sites will amount to USD 18, not including transportation expenses, which in these parts are quite commensurate to those associated with production. Judging from the fairly optimistic outlook at how extensive the natural gas reserves actually are at the Leningradskoye field (1,050 billion cubic meters) and what the planned yearly output is supposed to be (87 billion cubic meters), the deposits can be estimated to last 12 years. At the same time, the payoff period for the launch investment package alone is six years. Yet, the investment plan lacks consideration for operational expenditures incurred by the maintenance of the field facilities, or the generation and subsequent disposal or treatment of radioactive waste and spent nuclear fuel from the nuclear power plants, or both the scheduled and various unforeseen repairs that the intricate subsea machinery and floating sites might need. Apparently, the underlying reason is that the project developers estimate the total investment return period at no less than nine years, after which natural gas production operations are supposed to continue for another two to three years, free from the heavy burden of having to retrieve initial costs. This means that a 10% to 15% error made in the estimates of extractable resources will result in the economic unprofitability of the entire project.

Will the potential investors be able to pledge their own, quite sizable funds to a relatively long-term project? Or will they have to attract credits? It is likely that a project of this scope will necessitate credit financing. Meanwhile, where it concerns estimations for the financing it will be necessary to land, the project's cost analysis does not include such an important item of any investment plan as the anticipated credit interest. There is likelihood that attracting credits to support the project will drive up implementation costs by another 12% to 15%. That is, even in early 2008 values, the project's price tag will approach USD 11B.

It is also foreseeable that despite all kinds of global economic crises, natural gas prices will continue to rise for another 10 to 15 years. In proportion to that, costs associated with running various services and purchasing materials needed for the exploration and production of gas fields can also be expected to increase. Consequently, the total costs of the endeavor in question will grow accordingly. An analysis of similar projects currently in the development or implementation stage suggests that the overall expenses that the subsea drilling site project will have incurred will double in the next five years. Over the next 10 years, they will already be 150% as high. There is a very strong probability that such costs will simply propel the project beyond the boundaries of commercial feasibility.

Because the project is obviously well within the sphere of interest of large Russian energy monopolies such as Gazprom and Rosatom, these market players are likely to exert substantial lobbying pressure to attract the necessary state financing to back the project at least at the initial stage of implementation. The only obstacle that may emerge in the path of their efforts will be the expected downward tendency in Russia's budget earnings from oil and natural gas exports, which according to current forecasts may establish itself already in 2009.

Chapter 7

7. An evaluation of Russian industrial capacities

One of the chief economic factors behind the dissolution of the Soviet Union was the weak Soviet industries engaged in the production of commercial, or non-military, commodities. Not only has this problem not been solved in the years that have passed since the breakup of the USSR, it has actually become aggravated over time. Even those heavy industry branches that were traditionally considered well-developed such as heavy engineering construction, machine tool building, professional equipment and instrument manufacturing, or high-technology metallurgy have greatly deteriorated or ended in a state of ruin.

This deplorable state of affairs is further exacerbated by a severe lack of qualified manpower in almost all branches of industrial production. At the same time, the Russian population is spiraling into a deep demographic downfall caused by the low birth rates during the Perestroika years, between 1988 and 1996, which overlapped the fading decline in population growth that had started in the period of the Second World War. This means that no improvement in terms of successfully developing the country's work force should be expected in Russia for at least another 10 years.

Despite the various grand plans blazoned out by the Russian government to push to develop nanotechnologies, the atomic industry, the energy industry, aircraft and automotive engineering, and shipbuilding, the current demographic trend and workforce pool suggests a prognosis that envisions a further worsening of the current crisis is likely as the problem of shortage of qualified specialists becomes evermore acute.

All of the troublesome limitations described above suggest that the implementation of the project of a subsea drilling complex will not only be a daring affair in terms of financial or economic obstacles. The infirm Russian industry and the severe lack of a skilled work force will also have to be contended with. The successful realization of a project of such a scope will only become a feasible prospect if the reserves of natural gas in the Russian Arctic deposits prove to be considerable enough, if foreign-based investors are given a leading role in the implementation of the project, and if extensive material and technical resources, as well as technologies and a well-experienced work force, are imported from abroad.

On that note, one last remark is in order: One important aspect of the subsea drilling complex project, namely, the risks associated with using nuclear power sources to provide energy to the site's facilities may render the whole undertaking that much less attractive for major international investors.

Conclusions

Today, the Arctic ecosystem is being subjected to severe technogenic change bringing with it shifts in climate patterns due to global warming, a global spreading of pollutants, radioactive contamination, illegal fishing, introduction of new species, etc. The oil and gas industry is pushing for exploration of oil and gas in the Arctic as access to these resources has become easier with the melting of ice. The tremendous growth of oil and gas exploration in this region may become a death sentence for its environment. The natural world of these northern seas is so sensitive, and so vulnerable, that even the slightest breach in its ecosystem can lead to negative consequences which will be irreversible. Furthermore, these consequences will be difficult to prognosticate as the ecosystems of the northern seas have yet to be fully studied.

It should be obvious that where the Arctic shelf is concerned, the risks brought about by exploring oil and gas reserves there are higher than anywhere else on the planet as a result of advancements in the oil and gas industry under the difficult conditions of the northern environment and climate.

The use of nuclear energy in exploring oil and gas reserves in the Arctic will multiply the risks which already exist or are introduced during the large-scale industrial operations in the area.

The following risks are associated with the use of nuclear energy:

- Contingencies on board any submersible that are prone to escalate severely or lead to full-blown disasters are events of high probability. In a predominant number of cases, emergencies quickly precipitate to accidents and are further exacerbated by having extensive technological equipment packed into the comparatively small, confined space of the submarine;
- The most typical catastrophe-scale accidents that occur on offshore drilling and production platforms are prompted by fires or explosions. For subsea vessels, the most common disastrous scenario is loss of impermeability of the inner hull caused by a fire outbreak or an explosion, external impact, or erroneous actions on the part of the crew. Such accidents on a nuclear drilling rig could lead to contamination of the surrounding marine environment;
- The operation of subsurface vessels in Russia – and a drillship would classify as one – is not subject to any kind of safety regulations or documentation quantifying potential risks;
- While assessing potential external hazards unrelated to the specific operations of a drillship, special attention must be paid to the risks associated with gas spouting or an uncontrollable "gas show" in a well. The geological conditions of the southern parts of the Kara Sea suggest that there is a high likelihood of such a scenario, which could lead to the destruction of the drillship operating in the area and contamination of the environment;
- A comprehensive risk analysis would also give consideration to other potential drilling-related hazards, such as fire outbreaks, explosions, jet fires, and loss of impermeability of the drillship, as well as the radioactive contamination of the area;
- Rescue systems for emergency response are unavailable and will be difficult, or impossible, to create due to the remoteness, darkness, and extreme weather conditions in general;
- The use of nuclear energy will make the infrastructure more susceptible to acts of terrorism.

Bellona further concludes that the project is not economically viable. But this can be overturned by large Russian energy monopolies such as Gazprom, the Russian gas monopoly, and Rosatom, the state corporation which runs nuclear industry in Russia. These companies can exert substantial lobbying pressure to attract the necessary state funding.

Bellona is against any oil and gas exploration in the Arctic. The use of nuclear energy in the exploration process will only aggravate the Arctic ecosystem further.

The burning of fossil fuels is one of the main reasons for ongoing anthropogenic climate change. The world needs to make efforts to develop into a sustainable society using clean, renewable energy sources, rather than to seek new ways of developing the oil and gas sector.

Appendix I

Reference sources

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[3] In the Russian tradition, initials are commonly used for a variety of occasions instead of first names. The full names of these two authors were not available for the purposes of this translation.

Appendix II

Main technical characteristics of Project 941 submarines

(as vessels most comparable with the subsea drillship project under development)

Project	941
Number of vessels built	6
Designation	*Akula*
NATO classification	*Typhoon*
Length, in meters	172.8
Beam, in meters	23.3
Mean draft, in meters	11.5
Displacement, surface / submerged, in tons	28,500 / 49,800
Maximum speed, submerged, in knots / kilometers per hour	27 / 50
Maximum submersion depth, in meters	500
Self-sustaining period, in days	120
Propulsion type (nuclear power and steam generation systems)	two OK-650-41 190-megawatt pressurized-water reactors; two 80,000-horsepower steam turbines (two 100,000-horsepower steam turbines)
Crew	163 men

Source: V. Ilyin, A. Kolesnikov. “Russian nuclear-powered submarines,” *Tekhnika i vooruzheniye vchera, segodnya, zavtra* magazine (Armaments and machinery yesterday, today, tomorrow), May/June 2000.

Appendix III

Estimated natural gas reserves on the shelf of the Kara Sea

Field / sea depth in meters	Depth of occurrence, in meters	Estimated natural gas reserves, in billion cubic meters, in pre-2000 assessments	Estimated gas condensate reserves, in million tons	Estimated natural gas reserves, in billion cubic meters, in assessments published after 2005
Rusanovskoye / 70	1,500 2,500 4,000	1,050 2,100 70	- 80 4	
		3,220	**84**	**780**
Leningradskoye / 100	1,500 2,500	1,500 1,550	- 60	
		3,050	**60**	**1,050**
West Sharapovskoye / 130	1,000 1,500 2,500	680 250 25	- 12 2	
		955	**14**	**-**
Total		**7,225**	**158**	**1,830**

Source: Compiled from various sources.

Appendix IV

Total investment funds necessary to provide field facilities and start natural gas production at the Leningradskoye field on the shelf of the Kara Sea

The following cost analysis covers pre-production investment, with a view to achieve an annual output of 86.6 billion cubic meters of natural gas. Bringing annual production output to the stated figures requires drilling 96 production wells within a period of five years.

Field facilities:

- Three subsea drillships: USD 1.416B;
- Twelve seafloor-based bearing plates: USD 420M;
- Three manifolds (systems of pipelines and locking devices installed at an oil or gas wellhead to ensure safety of production works and prevent oil or gas blowouts or spouting): USD 162M;
- Three subsurface support vessels: USD 600M;
- Two icebreakers: USD 700M;
- Two subsurface repair and maintenance vessels: USD 760M;
- Other facilities (number or nature of purpose unidentified): USD 280M;
- Onshore facilities (number or nature of purpose unidentified): USD 1.781B;
- Project engineering documentation and feasibility study: USD 150M;

Subtotal: USD 6.269B (66.1% of total investment funds)

Underwater infrastructure:

- Pipelines: USD 2.036 B;
- Underwater power supply systems: USD 305M;

Subtotal: USD 2.341B (24.7% of total investment funds)

Drilling costs:

- 96 wells at USD 9.14M per one 2,500-meter-deep well;

Subtotal: USD 877M (9.2% of total investment funds)

Total: USD 9.487B in investment / capital costs expected to be incurred by providing field facilities at the Leningradskoye field prior to the start of extraction operations.

Source: Stanislav Lavkovsky. “Nuclear-powered underwater and under-ice technologies: The sole solution to gas production challenges in the Arctic,” a report presented at the international conference “International Cooperation for the Elimination of the Nuclear Legacy of the Soviet Nuclear-Powered Fleet,” April 17, 2008.

Appendix V

Project participants

- Russian Scientific Research Centre *Igor Kurchatov Institute*, Moscow;
- Joint Stock Company *Afrikantov OKB Mechanical Engineering*, Nizhny Novgorod;
- Joint Stock Company *Lazurit Design and Engineering Bureau*, Nizhny Novgorod;
- Joint Stock Company Research and Manufacturing Association *VNIINEFTEMASH* (formerly, All-Union Scientific Research & Design Engineering Institute of Petroleum Machinery Manufacturing Industry), Moscow;
- *Krylov Shipbuilding Research Institute*, St. Petersburg;
- Gazprom's Limited Liability Company Scientific-Research Institute of Natural Gases and Gas Technologies *VNIIGAZ*, Moscow;
- Federal State Unitary Enterprise *Sevmash* (*Sevmashpredpriyatiye*, Northern Machine-Building Enterprise), Severodvinsk;
- Federal State Unitary Enterprise Far-Eastern Shipyard *Zvezda*, Bolshoi Kamen, Primoriye region;
- Joint Stock Company *Kaluga Turbine Works*, Kaluga;
- Federal State Unitary Enterprise Machine-Building Company *Barrikady*, Volgograd;
- *Nizhny Novgorod State Technical University*, Nizhny Novgorod;

- Chief engineer: Stanislav Lavkovsky;
- Research supervisor: Yevgeny Velikhov.

Source: Stanislav Lavkovsky. "Nuclear-powered underwater and under-ice technologies: The sole solution to gas production challenges in the Arctic," a report presented at the international conference "International Cooperation for the Elimination of the Nuclear Legacy of the Soviet Nuclear-Powered Fleet," April 17, 2008.

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