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Different scenarios of the oil fields development in the Pechora Sea

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ABSTRACT

The Arctic region is thought to play a key role in the world’s oil and gas field development and hydrocarbon resources production. Estimates indicate that approximately 25% of the world’s unexplored hydrocarbon reserves lay beneath the depths of the Arctic regions.

Starting with a description of the most urgent oil and gas prospects in the eastern part of the Barents Sea the project will discuss investigations for arctic offshore structures, types of offshore structures, transportation system for arctic conditions, the challenges for development of potential hydrocarbon fields in the Barents Sea Area. Main accent in the presented project will be placed on the case study which has been done with regard to the oil field development. Also economical calculations will support technical decisions concerning complex schemes of arrangement.

As well, risky scenarios during platform transportation to the place of installation and during process of offloading will be analyzed to the environmental safety.

Based on a review of possible technical solutions and economical evaluations for oil field development in the Arctic sea, conclusions will be finally given.

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ABBREVIATIONS

FPSO - floating production storage and offloading vessel;

IRGBOET - ice-resistant gravity based offloading external terminal;

IRGBP - ice-resistant gravity based platform;

IRUC- ice-resistant unit of the conductor;

ITS – integrated template structure;

ktonnes – thousand tonnes;

mmCM – million cubic meters.

mmtonnes – million tonnes;

SPS – subsea production system;

TLP - tension-leg platform;

1. INTRODUCTION

The Arctic offshore zone is a promising region for oil and gas production. The most urgent prospects are the fields development in the eastern part of the Barents Sea (Pechora Sea). A number of such promising oil deposits as Varandey-more, Medynskoe-more, Prirazlomnoye, Dolginskoye, Poliarnoye, Alekseevskoye, Vostochno-Gulyaevskoye, Severo- Gulyaevskoye were discovered in the early 80s by geophysical prospecting.

The oil fields in the Pechora Sea are located at a distance of 50-100 km from the shore which is practically devoid of constructional and transportation infrastructure. The distance between the sites, nearest ports and junctions with the acting pipelines amounts to 300-400 km. The constructional and manufacturing capacities with developed infrastructure, adequate for manufacturing stationary marine structures are located in the Kola Peninsula and in the Archangelsk region. They are distanced by more than 1000 km from the future oil fields in the Pechora Sea. Produced hydrocarbon fuel could be transported either by tankers of ice-breaking class or by pipelines with the development of the relevant infrastructure. [138]

In all cases the offshore structures in the Pechora Sea shall be capable of providing the functions of well drilling and oil recovery, preliminary treatment as well as human life safety and operation continuity functions. In case of oil transportation by tankers, storage of large amounts of oil prior to arrival, mooring and loading of tankers should be maintained either by the offshore structures themselves or by special stationary structures. For cases of pipeline transmission the stationary structures shall be equipped with powerful pumping facilities for uninterrupted pumping of oil to the shore bases. [12]

Due to specific geography and oil treatment technology the top side of the offshore structures should maintain boring and subsequent operation of no less than 20 wells from one platform. The service life of one structure shall be no less than 30 years. [12]

2. STATE OF ART

This Master Thesis focuses on the analyses of the integrated development of Prirazlomnoye, Varandey-more, Medynskoe-more and Dolginskoye oil fields. The main aim of the complex oil fields development of the Pechora Sea is to improve the efficiency of the development.

This research paper describes the experience of the application of different structures in the Arctic Seas. There are presented conditions of possible applications, advantages and disadvantages of different structures. Possible schemes of the Pechora Sea oil fields arrangement considered in the chapter 3.7. The mathematical calculations which numerically describe the rates of production were made for each field and for the whole group of fields (chapter 4). Also there is economic justification of presented variants of arrangement.

In the end of project was made a conclusion of the most optimal scheme of the oil fields development of the Pechora Sea.

3. ANALYSIS

3.1. General information about the oil fields

The **Prirazlomnoye oil field** is located south of Novaya Zemlya in the northern Russia on the Pechora sea shelf, at a distance of 60 km from the shore. The field was discovered in 1989. [24] The development license was won by Rossneft in 1993 and transferred to Sevmorneftegaz in 2002. Nowadays the license to explore and produce hydrocarbons in the Prirazlomnoye field is owned by Gazprom neft shelf (former Sevmorneftegaz), a wholly owned subsidiary of Gazprom.[23]

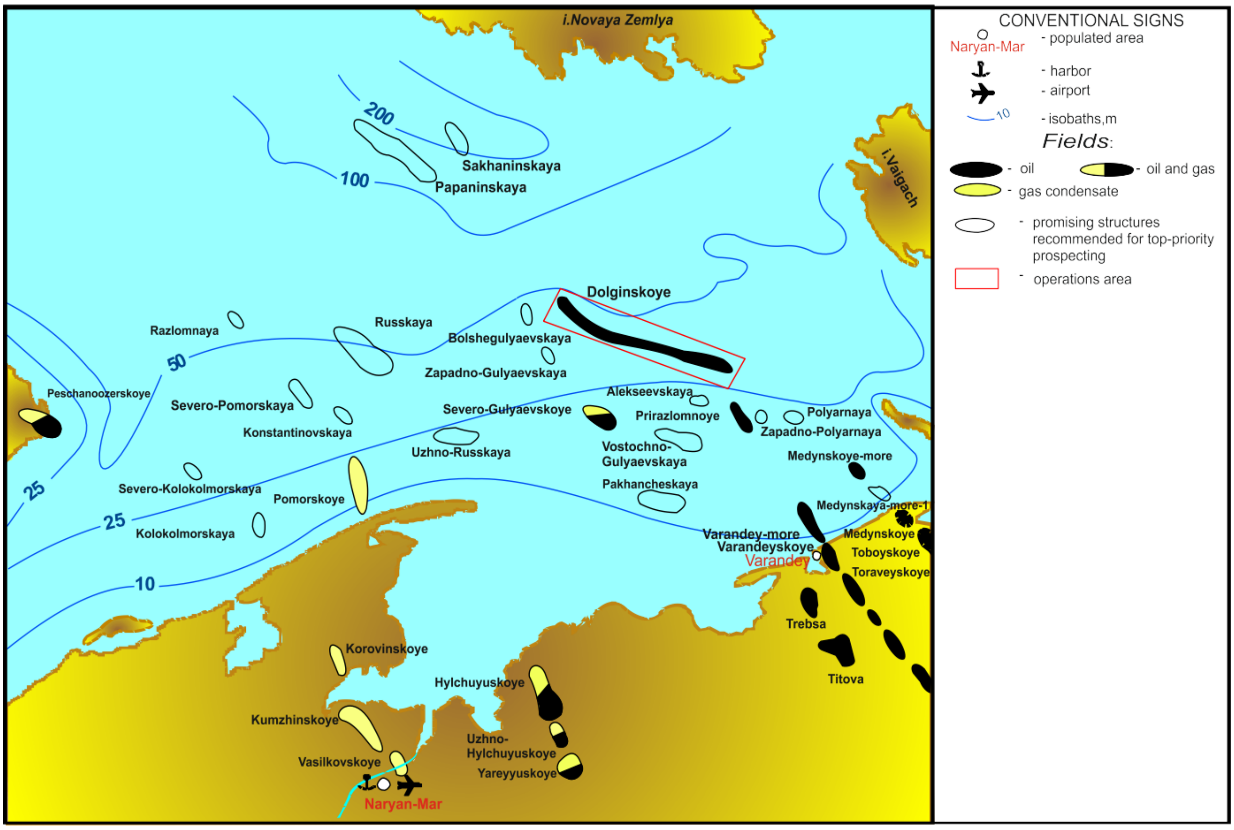


Figure 1. Location of the Pechora Sea oil fields

The Prirazlomnoye oil field is a huge and complicated field by following reasons:

- Recoverable oil reserves – 70 million tons of oil.
- Water depth – 17 to 19 meters.
- The depth of oil formation – 2350-2550 m.
- Density of oil – 910-955 kg/m3 (heavy).
- Overall stock of wells – 35, producers – 19, water injectors –16.

It is essential to mention that this industrially underdeveloped area of the Pechora Sea is characterized by extremely low temperatures and strong ice loads. It is ice-free for 110 days a year and the cold period lasts 230 days. Ice thickness is up to 1.7m. The annual average temperature is -4°C and the temperature minimum is -50°C. Wind strengths reach up to 40m/s and wave heights up to 12m.

The field development concept is based on the single stationary Prirazlomnaya platform. The oil platform is constructed by Sevmash shipyard in Severodvinsk. The Prirazlomnaya platform is equipped with the topsides of the former Conoco's Hutton field TLP platform which was the first production Tension Leg Platform ever built. Produced oil will be transported by double acting shuttle oil tankers Mikhail Ulyanov and Kirill Lavrov built in Admiralty Shipyard and operated by Sovcomflot, to Floating Storage and Offloading vessel Belokamenka, located in Kola Bay near Murmansk.[24]

The **Medynskoe-more oil field** is located near land in the Pechora Sea about 410 km north of Naryan-Mar. The oilfield was discovered in 1997.[20]

The Murmansk-based oil company Arktivshelfneftegaz has drilled four well at the field and completed all exploration works in 2006.[26]

License holder has reported the upgraded field estimates for Medynskoe-more to the Russian State Commission on Natural Resources in 2010. The field is now believed to contain a total of 516.6 million tons of oil category C1 and C2, of which 139.9 million are considered extractable. That is 75 percent more than the previous estimates. After the resource upgrade, the Medynskoe-more is almost twice as big as the Prirazlomnoye oilfield. [25]

The Medynskoe-more oil field has the following characteristics:

- Recoverable oil reserves – 139.9 million tons of oil;
- Water depth – 10 to 19 meters;
- The depth of oil formation – 1200-1600 m; 1700-2300 m;
- Density of oil – 910-930 kg/m3 (heavy);
- Overall stock of wells – 42, producers – 27, water injectors –15;
- Harsh environment and ice conditions. [18]

The **Varandey-more oil field** is located in the south part of the Pechora Sea. As a result of drilling exploration wells Varandey Sea #1 and Varandey Sea #2 Varandey-more oil field was discovered in 1995. Oil reserves increase in C1 category amounted to 1.8 million tons.[23]

The Varandey-more oil field has the following characteristics:

- Recoverable oil reserves – 41.8 million tons of oil;
- Water depth – 14 to 18 meters;
- The depth of oil formation – 1780-1820 m;
- Density of oil – 910-915 kg/m3 (heavy) ;
- Overall stock of wells – 23, producers – 13, water injectors –10;
- Harsh environment and ice conditions. [18]

The **Dolginskoye oil field** is located in the central part of the Pechora Sea in120 km south of Novaya Zemlya and 110 km to the north of the continent [24]. As a result of drilling exploration wells North-Dolginskaya № 1 and South-Dolginskaya № 1 this large oil field was discovered at the Pechora shelf in 1999. Recoverable reserves are estimated at over 200 million tons. [23]

The Dolginskoe oilfield is a unique and complicated field by following reasons:

- Recoverable oil reserves – 235.8 million tons of oil;
- Water depth – 45 to 55 meters;
- The depth of oil formation – 3100-3300 m;

- Density of oil – 900-920 kg/m3 (heavy) ;
- Overall stock of wells – 90, producers – 68, water injectors –22;
- Arctic environment and harsh ice conditions. [18]

3.2. Investigations for all arctic offshore structures

Site investigations shall be performed for all arctic offshore structures. The purpose of the investigation is to provide relevant bathymetric, geophysical and geotechnical data necessary for description of site conditions and for the determination of characteristic material properties.

Site investigations shall take the following into consideration:

– the type of structure and foundation actions;
– the size of structure;
– the nature of the sea floor;
– the types of seabed materials;
– the near-field and far-field conditions;
– data available from previous investigations in the area;
– available performance data from existing structures in the area; and
– liquefaction susceptibility. [2]

The far-field investigations shall determine the impact of the following on the design of the structure:

–bathymetry;
–surficial geology;
–bedrock geology;
–the risk of seismic events;
– slope stability and the potential for mass movements;
– the presence of ice gouges;
– the present sedimentary environment and erosional processes. [2]

The near-field investigations shall address the local issues related to:

– detailed sea floor bathymetry;
– detailed soil/ rock seabed stratigraphy;
– foundation stability and displacement;
– local slope stability;
– sediment movements adjacent to the structure;
– the presence and influence of ice gouges, boulders, permafrost and gas hydrates, and shallow faults. [2]

The near-field conditions shall be evaluated to provide detailed quantitative and qualitative data on relevant bathymetric and geomorphological features, geological processes, and geotechnical parameters that can affect the design of the structure. The lateral and vertical extent of the near-field investigation shall be consistent with the size, zones of influence, and placement tolerances of the intended structure and with the complexity of the site conditions.

The near-field investigation shall include as a minimum:

–a bathymetry survey;
–a geophysical survey, including ice gouge delineation where applicable;
–a geotechnical investigation [2]

3.3. Types of offshore structures

It is known that there are three main solutions for offshore fields by using:

- Fixed structures:
  - Gravity based platforms;
  - Man-made islands.
- Floating structures
  - FPSO;
  - Semi Sub platforms;
  - TLP platforms;
  - SPAR platforms.
- Subsea arrangements (tied back to host facilities)[8]

However for the conditions of the Pechora Sea it is possible to use for the drilling and production purposes the following structures:

- Fixed structures:
  - Man-made islands (example: Northstar Islands in Beaufort Sea);
  - Gravity based platforms (examples: Piltun-A,B, Lun-A, “Orlan” in Sakhalin projects; Prirazlomnaya in Pechora sea)
- Floating structures (example: “Sanmar” SDC used in Beaufort Sea).[8]

Main advantages and disadvantages of the structures are presented in the Table 1.

Table 1. Pros & Cons of different types of structures

Pros	***Cons***
1. Artificial (man-made) Islands	
• Resistance to icebergs; • Year-round production; • Dry well trees; • Large open area.	- Not available for large water depth; - Absence of building materials; - Sea spraying; - Ice ride up; - Maintenance.
2. FPSO	
• Disconnectable turret; • Storage capacity; • Ice vanning; • Decommissioning.	- Dependence on ice management; - Large mooring forces; - Sea spraying; - Oil spill prevention.
3. Gravity based structure with vertical walls	
• Year round production; • Dry well trees; • Large operation area; • Drilling from GBS; • Storage capacity; • Low wave and current loads.	- Limited to water depth; - Large ice loads→crushing; - Icebergs→large design load; - Decommissioning.
4. Gravity based structure with slope walls	
• Year round production; • Dry well trees; • Large operation area; • Drilling from GBS; • Storage capacity; • Reduction of ice loads.	- Limited to water depth; - Larger waves and current loads; - Icebergs→large design load; - Decommissioning.

3.4. World experience of using different types of structures for arctic conditions

Experience in the use of offshore structures for oil and gas fields in the freezing waters is limited.

In the early 70's on the Arctic shelf of Canada in the Beaufort Sea were built about 30 man-made islands at the depths of the sea nearly 20 m, which is mainly constructed of local materials (sand, gravel, crushed stone). These artificial islands were designed to exploration drilling and have been calculated on a limited lifespan 2 ... 3 years. [2]

The main factors influencing to the possibility of using man-made islands in the Beaufort Sea were the presence of sand and gravel quarries in immediate vicinity of the construction areas as well as favorable to the construction and operation natural conditions- small depth of the sea, a moderate excitement, lack of seismic hazard and a relatively long period of navigation.

Operating experience of the man-made islands in the Canadian Arctic has shown that the main disadvantage of all types of ground islands is the complexity of protecting slopes from wave and ice erosion. All facilities used for this (dumping stone, sand bags, metal mesh, etc.) were ineffective, and so far this problem is almost not solved. In addition, wave beating was observed at the production site so that revealed a need to increase the wave deflector height.

Taking into account the above mentioned, combined artificial island structures, consisting of soil cores contoured by reinforced concrete or steel structure (caisson), were much more effective. Such contouring construction ensured sustainability to the impact of wave, sand, ice and also it greatly reduced the labor intensity and duration of marine construction. The example of such structure was built in 1981 in the Tarsyut field in the Beaufort Sea, an artificial island which consists of an underwater berm, soil, core, sand, 4-contouring concrete caissons (Figure 2).

Significant disadvantage of man-made islands is a low rate of building in the sea which does not provide them with construction in one navigation period. Therefore it makes possible the occurrence of the collapse of unfinished structures with ice. [2]

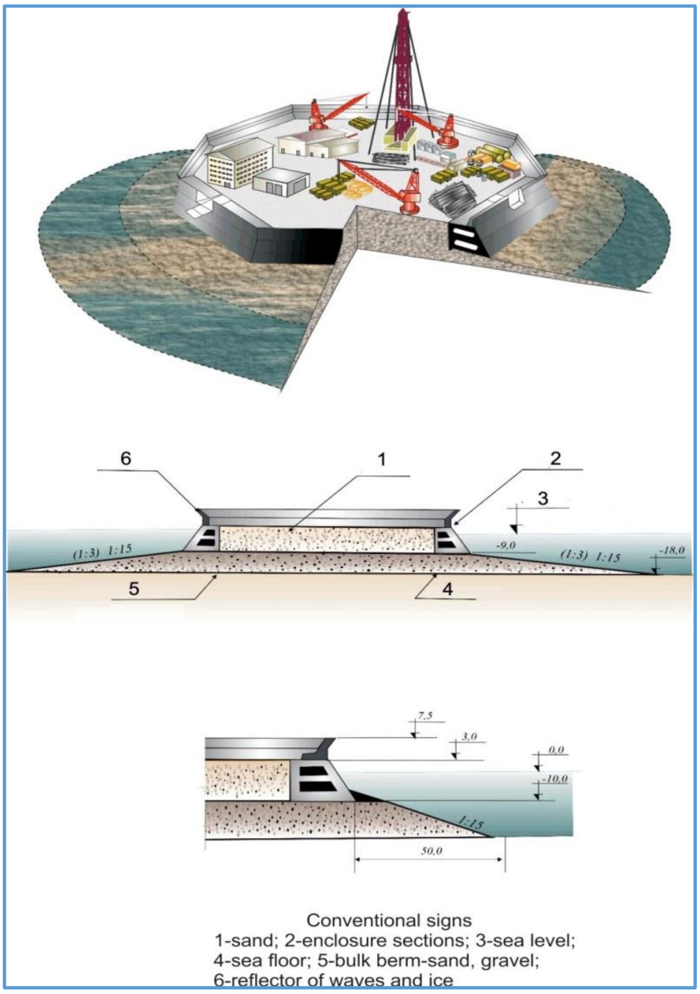


Figure 2. Man-made island of the Tarsyut field at the Beaufort Sea [2]

Another example of using man-made islands is Northstar Island in the Beaufort Sea (Figure 3) which has following characteristics:

• Construction: The Island is protected from sea ice by:

- a concrete armour,
- a steel sheet pile wall,
- underwater bench and berm system

• Location: 6 nm NW of Prudhoe Bay in 13 m water depth;

• Area: 2×104 m^2

• Oil is processed on the island and transported by an undersea pipeline (2.5-3.5 m buried) to a connection with the Trans-Alaskan Pipeline;

• Northstar is not connected to shore: An ice road is used in the winter. Helicopter or hovercraft is used in the non-winter season;

• Production was started in 2001.

Figure 3. Northstar Islandat the Beaufort Sea (summer and winter view) (bp.com)

In the 60's in the Cook Inlet in Alaska 18 ice-resistant steel stationary platforms have been built and put into operations at the depth of the sea 20 ... 25 m. All platforms except one have the same type of design consisting of 3 or 4 pillars connected to each other under the water level and coverage of ice (Figure 4). Thus, formed support block was attached to the bottom of the sea by using steel piles pocketed on the perimeter inside the pillars. The steel deck with drilling and operational equipment was installed to the support block. Drilling wells were organized through scored in the bottom of the sea piles. One of the 18 platforms had a single supporting column and it was also attached to the seabed with steel piles (Figure 5). [2]

This type of the platforms was chosen for Cook Inlet according to several environmental and climatic conditions which are necessary to point out:

- unfavorable conditions for the geotechnical construction;
- significant fluctuations of sea level (up to 10meters)caused by tides;
- sufficiently long period of navigation (4 ... 5 months);
- not severe ice conditions (one-year ice, the thickness of smooth ice field up to 1.5m).

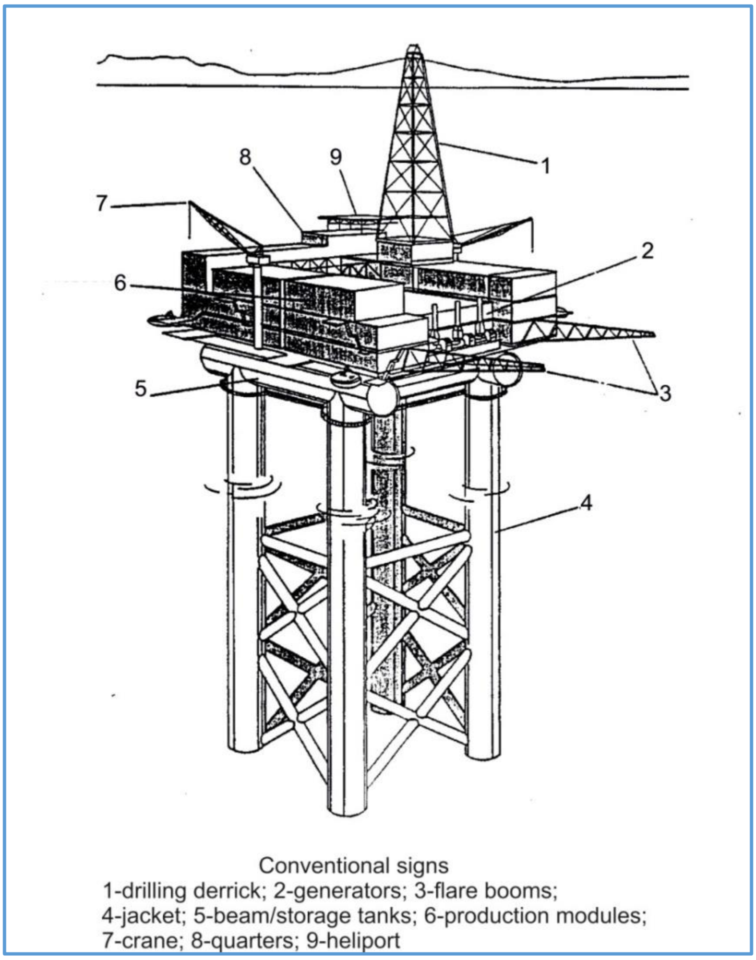


Figure 4. Four pillars ice-resistant steel stationary platforms (the Cook Inlet, Alaska) [2]

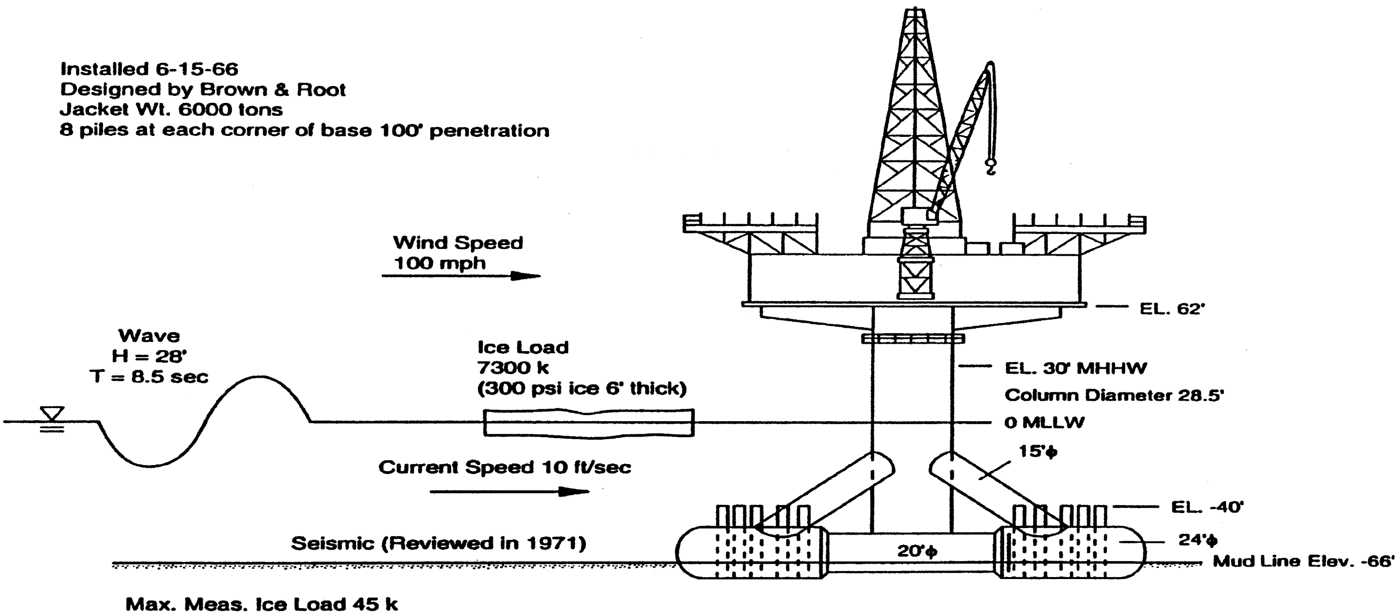


Figure 5. Ice-resistant steel stationary platform with a single supporting column (the Cook Inlet, Alaska) [2]

In the 80's of last century, based on the experience of the construction and operation of ice-resistant structures, the mobile ice-resistant drilling platforms have been built and operated successfully for year-round exploration drilling in the Arctic shelf of Canada in the Beaufort Sea. They are known under the names of Molikpaq (steel platform with a sand core), CIDS (combined reinforced concrete platform with ballast water) and SDC (converted tanker). All of these platforms relate to the gravity structures designed to work in water depths of 15... 30 m.

Later Molikpaq and CIDS were converted under development drilling and were used to work on the Russian shelf near Sakhalin Island.

Mobile platform SDC (named "Sanmar") consists of two rigidly inter connected parts (Figure 6):

- the top is a converted oil tanker retrofitted with reinforced concrete sides;
- the bottom is a large steel pontoon construction with a trapezoidal cross-section(base plate) called "mat" and playing the role of a sandy berm.

The main SDC feature is the design of a base plate which ensures the stability of structures in a relatively unfavorable geotechnical conditions due to the special design and a layout of the fin-skirts height of 2monthebottom area. [2]

Figure 6. Ice-resistant mobile platform SDC "Sanmar" [2]

The great interest is experience of hydrocarbon fields development on the Sakhalin shelf of the Okhotsk Sea. In 1997 in this region on the Piltun and Lun (the “Sakhalin-2”project) oil and gas fields three ice-resistant platforms Piltun-A, Piltun-B and the Lun-A were established one after another. Both fields are located in the15…20 km from the coastal area of Sakhalin Island in water depths of30…50km.

Piltun-A platform represents gravity steel structure consisting of a converted mobile ice-resistant drilling rig «Molikpaq» installed on a steel underwater section having height of 15m(Figure 7).

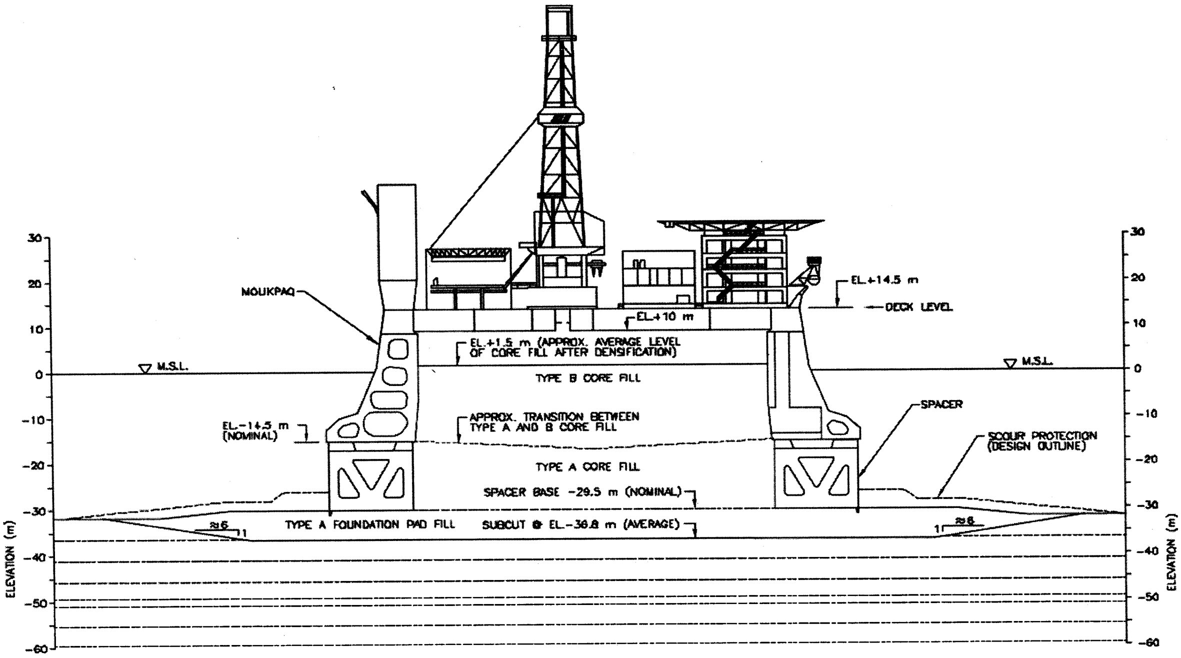


Figure 7. A schematic cross-section of the Molikpaq platform at Piltun-A field (“Sakhalin 2”, Russia) [2]

Drilling and production equipment for oil and gas injection, pumping of oil from floating storage (FSO) were established at the converted Piltun-A platform. Offloading of oil is conducted by using offloading external terminal which is associated with the FSO by means of subsea pipeline.

Piltun-B and Lun-A platforms have the same type of structure (Figure 8). They are gravity-type structures consisting of reinforced concrete jacket and integrated steel deck installed on technological equipment. The supporting blocks include a subsea pontoon and four pillars that hold up the deck. Supporting columns have a cylindrical shape with a diameter of 22…26 m and wall thicknessof0.6…0.75m. They are used to install directions of drilling wells, risers and supporting systems.

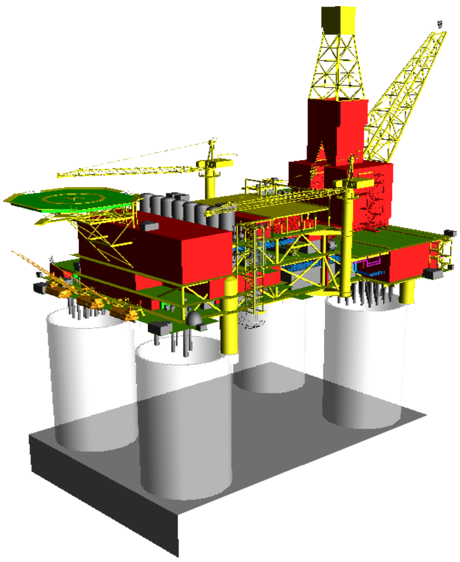


Figure 8. Ice-resistant stationary reinforced concrete Lun-A platform (“Sakhalin 2”, Russia) [2]

Collection and full field of oil, gas and water treatment are organized on the Piltun-B platform. Ordinary installation of the necessary equipment on the Lun-A provides primary gas processing. Full treatment is carried out at onshore processing facility. [2]

In2005on the Chayvo-sea oil field (the project "Sakhalin-1") at the distance of 8…9km from the coast line in-water depth of 14 m "Orlan" platform was installed (Figure 9). This platform was converted into production platform from SIDS platform which since 1984 has been in continual use in the Beaufort Sea and has operated as a mobile drilling rig for year-round exploration drilling.

Figure 9. Ice-resistant gravity based "Orlan" platform ("Sakhalin 1", Russia)[2]

The Prirazlomnaya offshore ice-resistant oil-producing platform is a major development facility in the oil field (Figure 10). The platform ensures well drilling, oil production, storage and offloading. The main features of platform are resistance to strong ice loads, long self-sustainability and year-round operability. 40 slanted wells will be drilled from this platform. The Prirazlomnaya is designed to receive oil from other fields as well. A single platform will enable to involve adjacent fields into efficient development and to reduce infrastructure associated costs. [2]

Figure 10. Prirazlomnaya offshore ice-resistant stationary oil producing platform (shelf-neft.gazprom.ru/)

The proper selection of substructure design of marine ice-resistant platforms and their anchoring is the function of numerous conditions, the main of them are the following:

1. Principal diagram of site development, production and transportation technology:
   - the distance between construction and transportation bases and the shore
   - functions performed by a structure (boring, fuel production and processing, storing, pumping into tankers or ashore or combination of the above operations at one structure);
   - treatment and transportation chart;
   - operation life of the structure.
2. Environmental conditions at the installation site:
   - hydrometeorological and ice conditions;
   - sea depth in the point of installation and over the transportation zone;
   - engineering geological conditions at the installation point, soil strength and deformability of parameters.
3. Platform manufacture:
   - limitations during manufacture and delivery from the shipyard;
   - specific features of ballast filling and mounting the substructure;
   - specific features and limitations of transportation to the mounting site.[1]

3.5. Preliminary conclusions

1. Man-made ground islands are not recommended for using as the operating structures for the arrangement of the oil fields located in the Pechora Sea due to their short life span, lack of local building materials, and also extremely harsh environmental conditions (primarily heavy ice conditions with a short period of navigation).
2. Man-made ground islands contoured by reinforced concrete or steel caisson (such as Tarsyut or Northstar Islands) can be used but their construction also requires the usage of local building materials (sand, gravel, crushed stone).
3. Steel structures for production of ice-resistant platforms used in the Cook Inlet and containing binders' tubular members between the support columns do not meet the heavy ice conditions of the Pechora Sea with winter and spring movements of the ice.
4. Such concrete four-column supporting structures as gravity platforms Piltun-B and Lun-A mounted on Sakhalin shelf at sea depths of 32 and 48 mare not optimal for water depths of 10 …20 m.
5. Such gravity based platforms as CIDS and SDC (Sanmar) can be applied in the Pechora Sea but they also are not optimal. Because of large dimensions and weight they are subjected to significant ice loads and therefore they show increased requirements to the ground base of installation location. As a result, this type of platforms will be costly.
6. Variants of development and arrangement of Prirazlomnoye field by using gravity based ice-resistant platforms are quite acceptable for development of Varandey-more, Medynskoe-more and Dolginskoye oilfields taking into account the existing experience of the construction and operation of this platform type.

3.6. Choosing transportation system for arctic conditions

For offshore fields there are two main alternative delivery systems to the markets of oil and gas: tankers and pipelines. Each of them has its advantages and disadvantages (Table 2). Assessment of the technical parameters showed that at the initial stage of fields' development the most realistic option is a system of tanker transport.

Pipeline transportation of crude oil is economically inexpedient for arctic conditions in view of actual terms of the fields' development beginning. There for the tankers system is regarded (or has been already accepted) in arrangement of arctic oil fields.

The feature of the Pechora shelf is that both existing and planned oil production centers are export oriented. So that oil produced from the fields cannot be delivered for processing to existing refineries in Russia. In general the development project is focused on the direct oil export from marine oil platforms to markets with or without intermediate transshipment.

At first glance, the creation of an intermediate transshipment complex increases the cost of the system because input of extra objects of arrangement in the system leads to an increase in capital expenditures. However the specific conditions of the arctic, primarily ice conditions and shallow water combined with the remoteness of the locations of oil production from the market size, give an advantage for the transportation with transshipment. If we talk about the transshipment transportation the ice-class tankers are operated only on the ice relatively short part of the route where the use of large tankers is impossible because of the shallow depth of the sea.

Table 2.Pros & Cons of two main types of transportation systems

Pros	**Cons**
Oil tankers	
Smaller CAPEX; General more accepted.	Dependence on ice management; Dependence on harsh sea conditions; Oil spill prevention in the ice conditions; Large OPEX due to ice management.
Subsea pipeline	
Independent on weather; Quick and easy transportation; Smaller OPEX.	Iceberg scouring; Oil spill prevention in the ice conditions; Difficult maintenance; Large CAPEX.

From transshipment complex more efficient transportation is carried out by the tankers with a large capacity of 150-200 thousand tons or more. Transshipment complex should be placed in such unconquerable (ice-free) areas as the Kola Peninsula.

In addition, because there are virtually no «free» ice-class tankers (also equipped with turrets to load oil) in the world they must be designed and built while the ordinary tankers can be used on a rental basis which saves capital costs for the vessels of the transport system with transshipment.

3.7. Schemes of development of oil fields of the Pechora Sea

This chapter dealt with the oil field development schemes and external transport products in the region in an integrated (synergistic) approach. This approach is based on the development of groups of closely spaced deposits to optimize the cost and to create the conditions for the joint development of large and relatively small marine deposits.

The first scheme of complex development - arrangement and development of each field is each field and onward transportation to the floating storage. The scheme of complex arrangement of the first variant is shown in Figure 11. The principal objects of the first scheme of complex arrangement are:

- offshore ice-resistant gravity based platform with the functions of drilling, production, processing, temporary storage and offloading of the oil as well as ice-resistant unit of the conductor with the functions of drilling, primary preparation and transportation of crude oil to the platform;
- marine transport-technological system provides transportation, oil storage, maintenance of the platforms;
- coastal infrastructure includes providing of the platform supply, delivery of the personnel, organization of production and maintenance of the platforms.

The second scheme of complex development. The Prirazlomnoye oil field has been entered primarily and the other fields would be operated later. One of the basic variants of the arrangement of the Pechora shelf deposits is their development taking into account the possibility of the using of the Prirazlomnoye oil field transport system. This variant provides self-arrangement of the Dolginskoye oil field and unification of the Prirazlomnoye, Medynskoe-more and Varandey-more fields as a separate group with the offloading of the crude oil from the platform of the Prirazlomnoye field. Thus, according to this scheme of arrangement two independent centers of offloading of the oil are organized from the Dolginskoye and Prirazlomnoye fields.

The scheme of complex arrangement of the second variant is shown in Figure 12. The principal objects of the second scheme of complex arrangement are:

- offshore ice-resistant gravity based platform with the functions of drilling, production, processing, temporary storage and offloading of the oil as well as ice-resistant unit of the conductor with the functions of drilling, primary preparation and transportation of the crude oil to the platform;
- marine transport-technological system provides transportation, oil storage, maintenance of the platforms;
- coastal infrastructure includes providing of the platform supply, delivery of the personnel, organization of production and maintenance of the platforms.

The third scheme of complex development aims at integration of the Prirazlomnoye, Medynskoe-more and Varandey-more oil fields in a separate group with the offloading of the oil from a detached external terminal and self-arrangement of the Dolginskoye field. Thus, according to this scheme of arrangement two independent centers of offloading of the oil are organized from the Dolginskoye and Prirazlomnoye fields. The scheme of complex arrangement of the third variant is presented in Figure 13.

The principal objects of the third scheme of complex arrangement are:

- offshore ice-resistant gravity based platform with the functions of drilling, production, processing, temporary storage and offloading of the oil as well as ice-resistant unit of the conductor with the functions of drilling, primary preparation and transportation of the crude oil to the platform;
- offshore ice-resistant gravity based offloading external terminal;
- marine transport-technological system provides transportation, oil storage, maintenance of the platforms;
- coastal infrastructure includes providing of the platform supply, delivery of the personnel, organization of production and maintenance of the platforms.

Additional offloading terminal with a buffer tank is situated in 22km from the Varandey-more field at the depth of 25 meters. This terminal will allow creating an additional system that ensures the safe offloading of the oil to the tankers.

The fourth scheme of complex development is an evolution of the third variant but the main difference is that it involves the organization of three independent centers of oil offloading from the Dolginskoye, Prirazlomnoye fields and external terminal.

This scheme provides self-arrangement of the Dolginskoye and Prirazlomnoye fields and Medynskoe-more and Varandey-more combining fields in independent group with the offloading of the oil from a detached external terminal.

Thus, according to this variant of the arrangement three independent centers of the offloading of the oil from the Dolginskoye, Prirazlomnoye fields and a detached external terminal are organized. The scheme of the arrangement of the oil fields at the specified version is illustrated in Figure14.The main advantage of this scheme in comparison with the third variant is the lack of an underwater pipeline with the length of 25 km from the Prirazlomnoye field to the external terminal.

The principal objects of fourth scheme of complex arrangement are:

- offshore ice-resistant gravity based platforms with the functions of drilling, production, processing, temporary storage and offloading of the oil as well as ice-resistant unit of the conductor with the functions of drilling, primary preparation and transportation of the crude oil to the platform;
- offshore ice-resistant gravity based offloading external terminal;
- marine transport-technological system provides transportation, oil storage, maintenance of the platforms;

- coastal infrastructure includes providing of the platform supply, delivery of the personnel, the organization of production and maintenance of the platforms.

Consideration of the four main variants of complex arrangement revealed the possibility of using common infrastructure of the region, organization of technological schemes and possible links between the development of the fields and the prospects of the Pechora shelf. The main characteristics of the different schemes of arrangement are presented in the Table 3. [1]

Under this scheme, we could consider 5 options for the Dolginskoye oil field development, but even if we're talking about comparison it will be too much information under discussion and we will pay attention to some of them.

Let's look at these options for the Dolginskoye oil field:

Option 1. Three gravity based platforms. Basic version.

Option 2. Platform and two subsea production systems.

Option 3. Three subsea production systems and a tie-in to an external point of offloading (could be like the Korchagina oil field storage ship (FPSO) on the Caspian Sea).

Option 4. Three subsea production systems and a tie-in to the Prirazlomnaya.

Option 5. Three subsea production systems and a pipeline to shore.

In our opinion the most preferable, reliable and realistic will be the second option. Let's take it to the consideration. It will be the fifth scheme of complex development.

The fifth scheme of complex development is an evolution of the fourth variant but the main difference is that it involves the organization of two integrated template systems and one gravity based platform for the Dolginskoye field. The South and the North parts of the Dolginskoye filed are located in 5 kilometers from middle part of the field, and can be developed with subsea installations.

- The installation for the North part will consist of a subsea template solution (4 templates) with 8 well slots, where 32 wells will be drilled and tied in to the Dolginskaya platform for processing.
- The installation for the South part will consist of a subsea template solution (4 templates) with 8 well slots, where 26 wells will be drilled and tied in to the Dolginskaya platform for processing.

This scheme provides self-arrangement of the Dolginskoye and Prirazlomnoye fields and Medynskoe-more and Varandey-more combining fields in independent group with the offloading of the oil from a detached external terminal.

Thus, according to this variant of the arrangement three independent centers of the offloading of the oil from the Dolginskoye, Prirazlomnoye fields and a detached external terminal are organized. The scheme of the arrangement of the oil fields at the specified version is illustrated in Figure15. The main advantage of this scheme in comparison with the fourth variant is the lack of an underwater pipeline with the length of 25 km from the Prirazlomnoye field to the external terminal and lack of two gravity based platforms.

The principal objects of fifth scheme of complex arrangement are:

- offshore ice-resistant gravity based platforms with the functions of drilling, production, processing, temporary storage and offloading of the oil as well as ice-resistant unit of the conductor with the functions of drilling, primary preparation and transportation of the crude oil to the platform;
- two integrated template systems (tied in to the Dolginskoye oil field platform);
- offshore ice-resistant gravity based offloading external terminal;
- marine transport-technological system provides transportation, oil storage, maintenance of the platforms;
- coastal infrastructure includes providing of the platform supply, delivery of the personnel, the organization of production and maintenance of the platforms.

Consideration of the five main variants of complex arrangement revealed the possibility of using common infrastructure of the region, organization of technological schemes and possible links between the development of the fields and the prospects of the Pechora shelf. The main characteristics of the different schemes of arrangement are presented in the Table 3. [1]

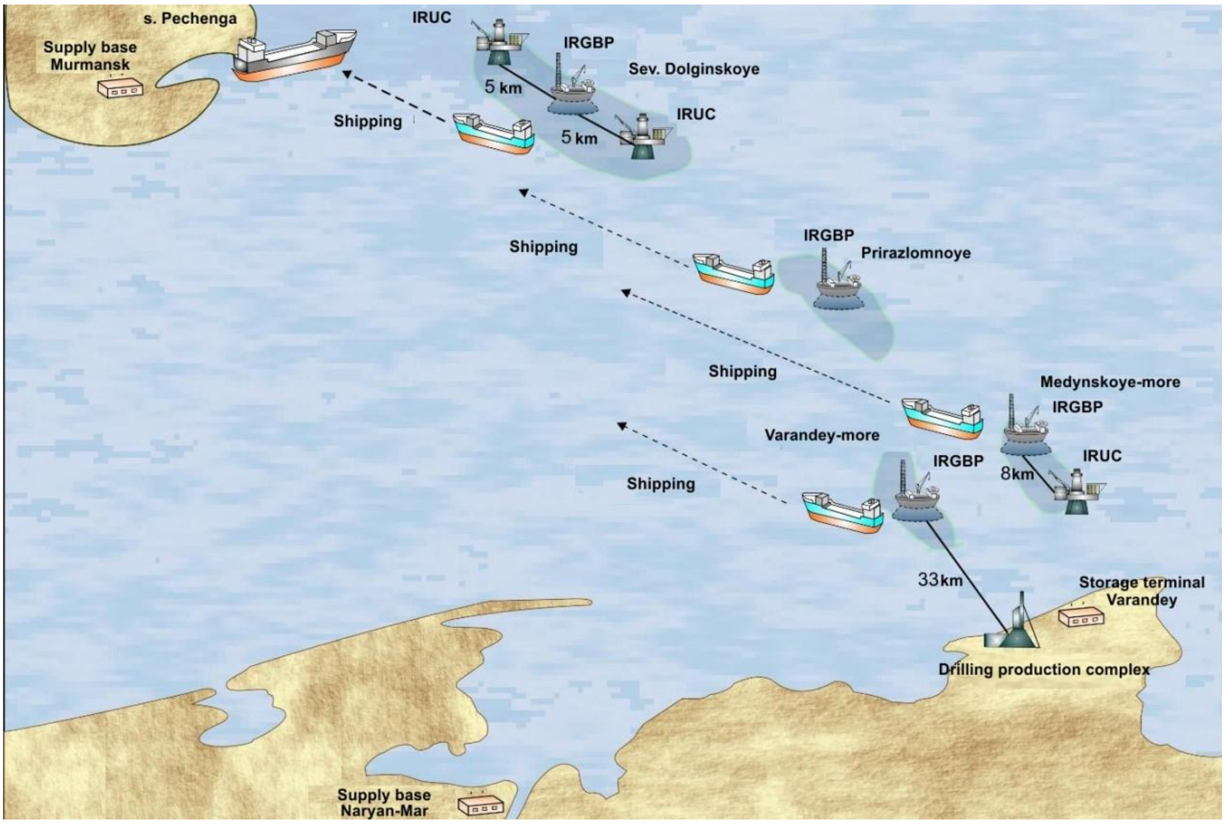


Figure 11. The scheme of complex arrangement of the first variant.

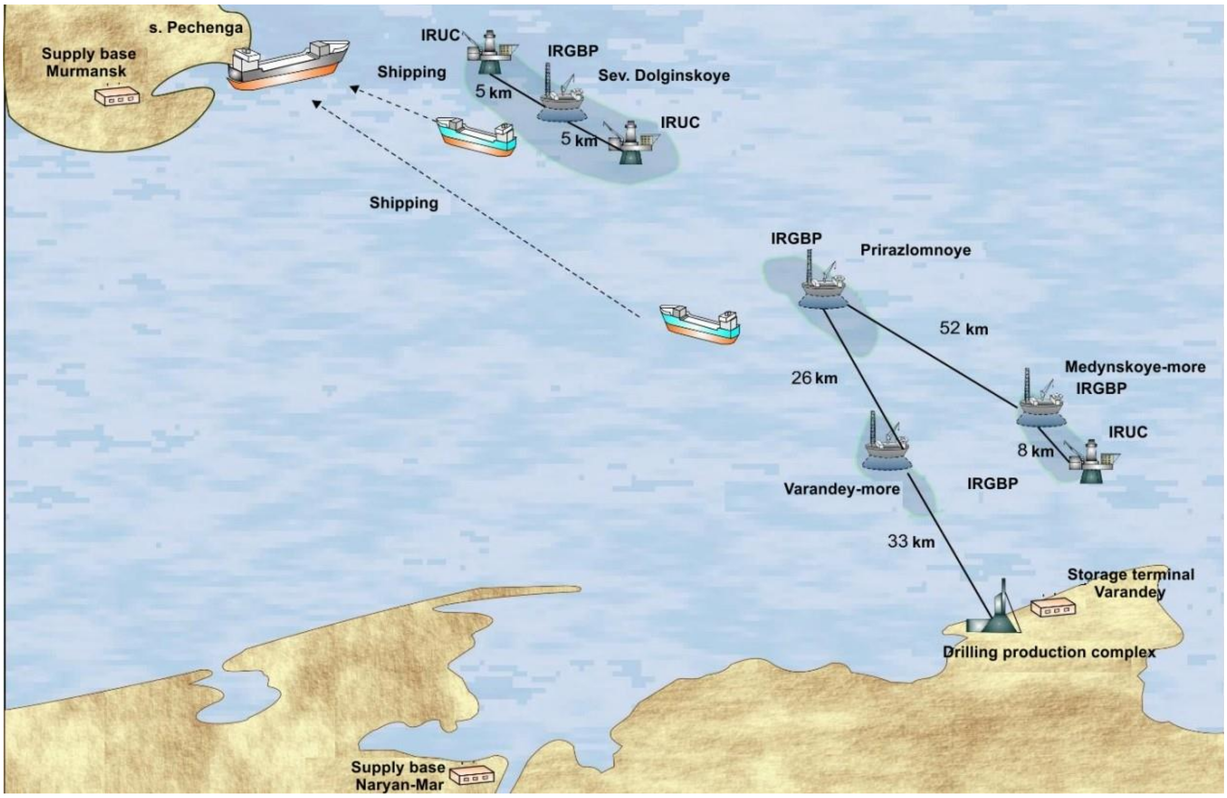


Figure 12. The scheme of complex arrangement of the second variant.

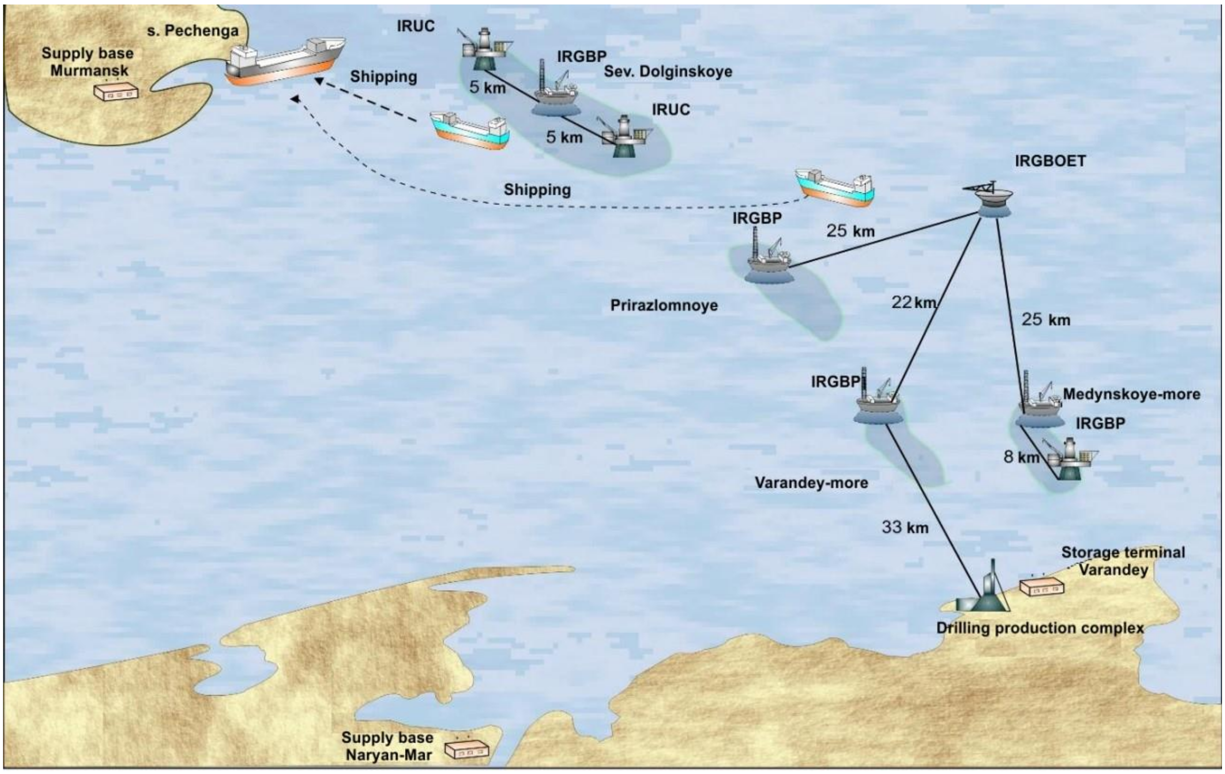


Figure 13. The scheme of complex arrangement of the third variant.

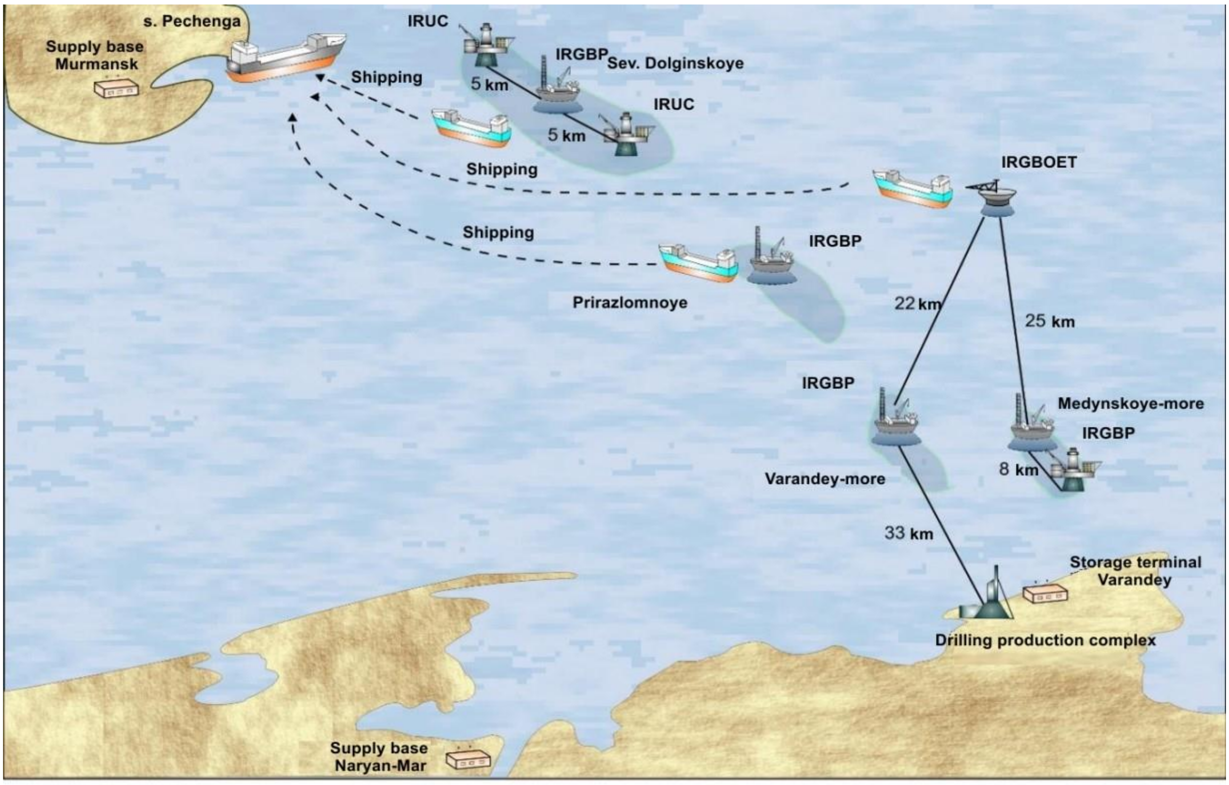


Figure 14. The scheme of complex arrangement of the fourth variant.

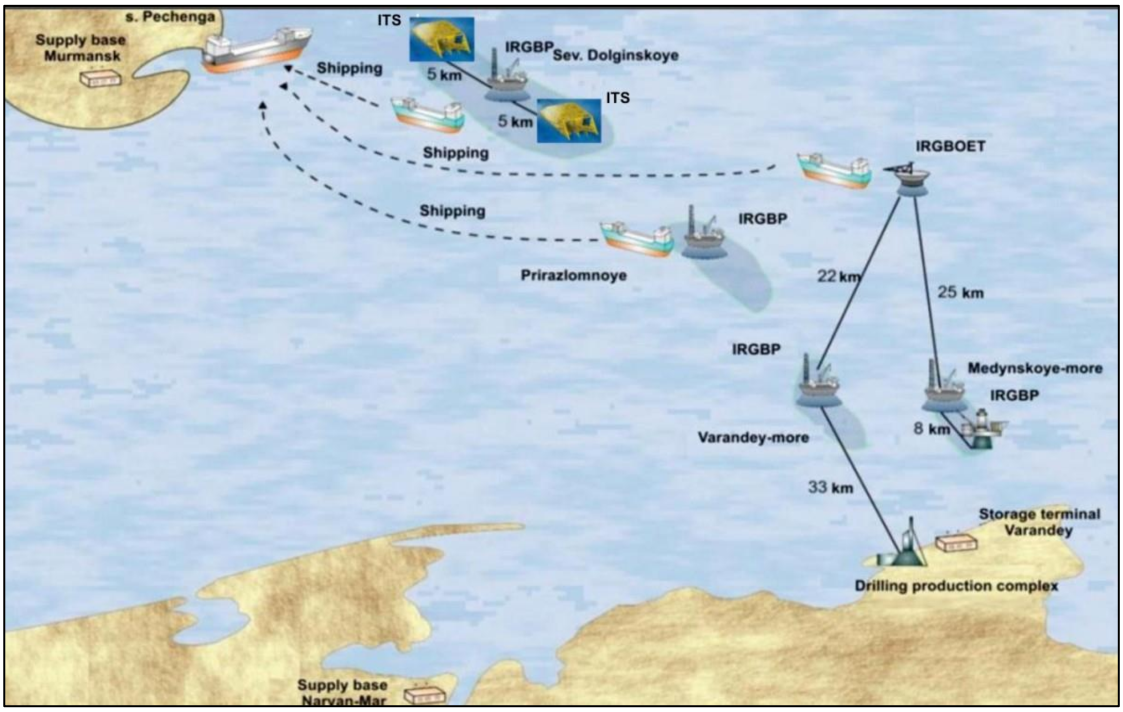


Figure 15. The scheme of complex arrangement of the fifth variant. Symbol: represents an integrated template.

Table. 3. The main objects of complex arrangement

Objects	Variants				
	1	2	3	4	5
Marine fixed structures					
Fixed structures in all, items	7	7	8	8	6
Fixed structures IRGBP (ice-resistant gravity based platforms): drilling and preparing of production, items	4	4	4	4	4
Ice-resistant unit of the conductor IRUC, items	3	3	3	3	1
Remote export terminals, items	-	-	1	1	1
Subsea production systems SPS, items	-	-	-	-	2
Interfield petroleum pipelines in all, km	51	129	123	98	98
Interfield water pipelines, km	51	51	51	51	51
Marine transport-technological system					
In the process of development on 8 million tons per year Shuttle tankers with deadweight, ths. tons/quantity, items	70/4 40/6	70/5 40/2	70/5 40/2	70/6 40/2	70/6 40/2
Multifunctional ice-breaker supplier, items	3	3	3	3	3
Ice-breaker with a capacity of 16 MW, items	1-4	1-2	1-3	1-3	1-3
Linear tankers with deadweight of 150 ths. tons	1-4	1-4	1-4	1-4	1-4
Terminal point of oil export with a capacity , distance, km	Pechenga 1098	Pechenga 1098	Pechenga 1123	Pechenga 1123	Pechenga 1123

Coastal infrastructure	
Main supply base, Murmansk	Pipe rack 8,0ths. sqr. m Storage platform 3,0ths. sqr. m Open platform for storage10,0 ths. sqr. m container platform 4,8 ths. sqr. m covered depot 2,0 ths. sqr. m Office premises 250 sqr. m System of pneumatic loading of bulk materials
Production base, Murmansk	Department of repairing and hiring of drilling and oil-field equipment with cathead having carrying capacity of 12,5 t - 1500 sqr. m. Depots for storage of equipment – about 1000 sqr. m, open platform with full gantry crane having carrying capacity of 12,5 t – 2000 sqr. m. Furnished berth, office premises – 800 sqr. M
Storage terminal, Naryan-Mar and Varandey	Workers' settlement for 150 places– dormitory, aid post, office, garage, depot of equipment, renewals and materials, workshops. Heliport – hangar for 3-6 helicopters, 2 helipads, workshops for equipment repair and others, premises for wet suits with checkroom, for gathering and instruction of shift teams.

4. CASE STUDY

4.1. Calculation of the oil production rates

Scheme of arrangement of a large oil field is largely dependent on maximum production rate Q_{max}, so that capacities of technological lines and facilities of offshore platforms, parameters of pipelines must be designed to ensure such production rate. With increasing Q_{max} is naturally decreases period of continuous production. Decreasing the level of production results in reduction of the technological equipment utilization coefficient, which reduces the efficiency of investment.

The only way to extend the so-called "oil rate-plateau" and avoid corresponding reduction of the technological equipment utilization coefficient to engage in the development "Satellite fields", located within a relatively close distances from the base large oil field, as volume of production from the base field is falling. [7]

For these purposes it is necessary to implement a complex arrangement of a group of fields, and so that to provide maximum efficiency of development.

Figure 16 shows scheme of such a complex consisting of a large base oil field and "satellite fields". For the integrated development scheme (shown in Figure 16) basic task can be formulated in a following way.

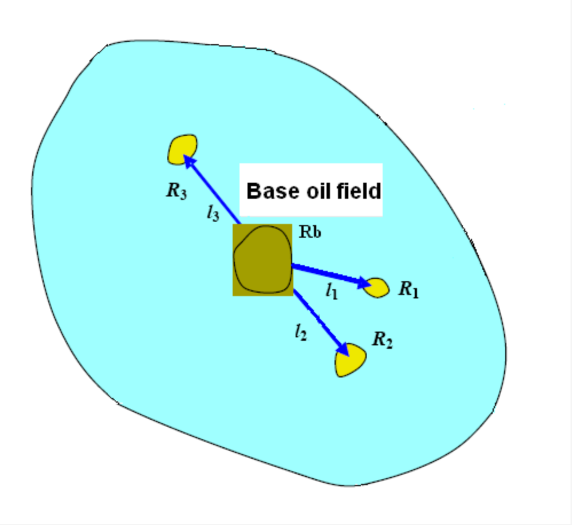


Figure 16. Large base oil field and "satellite fields".

Let assume that the dynamics of production of a basic field is determined. There are n - “satellite fields” shown in Figure 16 with reserves R1, R2 … Rn, and the distances l1, l2 ... ln to the base oil field. Required to determine the optimal scheme of complex arrangement of all of these fields, based on the maximum efficiency, by which we mean the net present value (NPV).

Based on the oil field data which is located in the Pechora Sea and the data about the region, respectively to the oil rate production and duration of the filed life exploitation, we have determined the exact number of the production wells.

Construction of seven offshore gravity based platforms and one well pad on the shore of the Pechora Sea are required for the development of the Prirazlomnoye, Dolginskoye, Varandey-more and Medynskoye-more fields. A project well stock for the group of fields includes 192 wells. [3], [4]

Calculation of the technological parameters of the development was made for each field and for the whole group of fields (Table 4).

Table. 4. Technological parameters of the development of oil fields

Parameter \ Oil Field	**Prirazlomnoye**	**Medinskoye-more**	**Varandey-more**	**Dolginskoye**	**Total**
Recoverable reserves of oil, mm tones	**70**	**139.9**	**41.8**	**235.8**	**481.5**
Duration of the development, years	**25**	**32**	**27**	**34**	
Number of wells:	**35**	**42**	**24**	**91**	**192**
production wells	*19*	*27*	*13*	*68*	127
Horizontal	18	27	13	0	
ingection wells	*16*	*15*	*10*	*22*	63
Horizontal	16	15	10	0	
exploration wells			*1*	*1*	2

Due to the fact that nowadays there is no history of the development for Dolginskoye, Medinskoye-more and Varandey-more oil fields it is impossible to apply displacement characteristics for the prediction of major parameters of development. In the future the field data will be collected and it will become possible to use well history matching and field performance analysis. [5], [6] Following are the calculations for Prirazlomnoe oilfield.

1. We have transferred daily production from barrels to tons:

   285000 barrels/day = 38101 t/day

2. We have considered, that the chosen offshore structure may has 16 multilateral wells with the following production rate:

$$Q_{1well} = \frac{38101}{19} = 2005\,\frac{t}{day}$$

3. We have determined the oil production rate from the horizontal part of the well, considering that one well has 3 down holes

$$Q_{1well} = \frac{2005}{3} = 668{,}4\,\frac{t}{day}$$

4. Cumulative oil production can be calculated in such way:

   $$\mathbf{Q_\Sigma = \sum_{i=0}^{n} Q_i},$$

   where Qi – production per year, tons; n – the number of years of production.
5. Oil recovery factor:

   $$\boldsymbol{\eta}_{\mathbf{oil}} = \frac{\mathbf{Q_\Sigma}}{\mathbf{V_{irr}}},$$

   where $\mathbf{Q_\Sigma}$ – cumulative oil production, mln.tons; $\mathbf{V_{irr}}$ – initial recoverable reserves of oil, mm tonnes.

In general, two different scenarios of the development have been calculated for the group of fields. These scenarios are different in rate of bringing-in of fields on production and in the levels of production per year (realistic - 8 mln. tones/year, and optimistic - 16 mln. tones/year). Dynamics of putting wells on planned oil production levels are 8 and 16 million tones/year are shown in Tables 6-7. Characteristics of the main parameters of the development for levels of oil production are 8 and 16 million tons/year are shown in the graphics (Figures 18-19). Calculation was made using the Eclipse (Schlumberger) which is a hydrodynamic simulation software package (Appendix. Tables 16 - 17).

Based on the forecast oil field data we have plotted over project's lifespans in "extraction-time" coordinates (Figure 17). We have considered that the first stage of the oil field development is 9 years and during this time 5% of oil from the recoverable reserves (*Qrec*) will be extracted, the second stage of the oil field development is 7 years and during this time 35% of oil from the recoverable reserves (*Qrec*) will be extracted, and the third stage of the oil field development is 24years and during this time 60% of oil from the recoverable reserves (*Qrec*) will be extracted.

Based on our calculations on the first stage of the field development 3500 thousands ton of oil will be recovered, on the second stage - 24500 thousands ton of oil, on the third stage - 42000 thousands ton of oil. In total 70000 thousands ton of oil will be recovered in this field (Table 5).

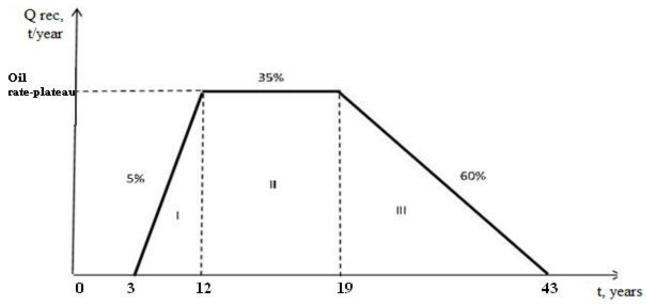


Figure 17. Project's lifespan

Table 5. Oil production on the stages

Production \ Field	Prirazlomnoye	Medinskoye-more	Varandey-more	Dolginskoye
Q 1 stage, mm tons (5% of Qrec)*	3,5	7	2,1	11,8
Q 2 stage, mm tons (35% of Qrec)	24,5	49	14,6	82,5
Q 3 stage, mm tons (60% of Qrec)	42,0	83,9	25,1	141,5
Total Production, mm tones	70,0	139,9	41,8	235,8

*Qrec - recoverable reserves of oil, mm tons.

Oil field lifespan has following stages:
I - Stage of the increasing production;
II - Stage of the sustained production (plateau);
III - Stage of the decreasing production.

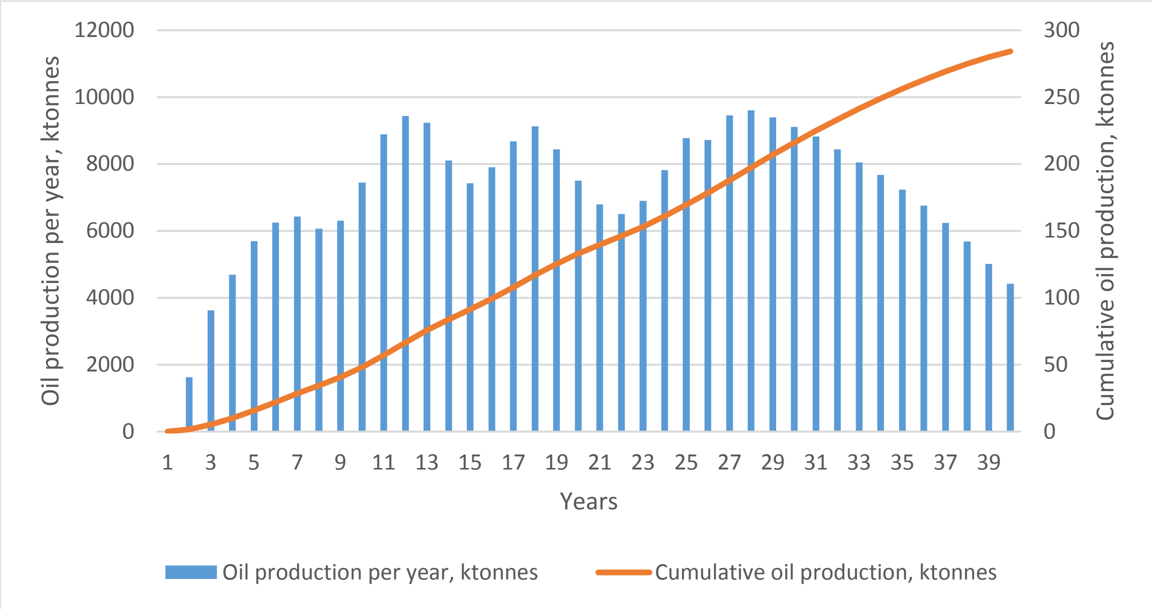


Figure 18. Project's lifespan. Characteristics of the main parameters of the development. Planned production level is 8 mln. tones/year

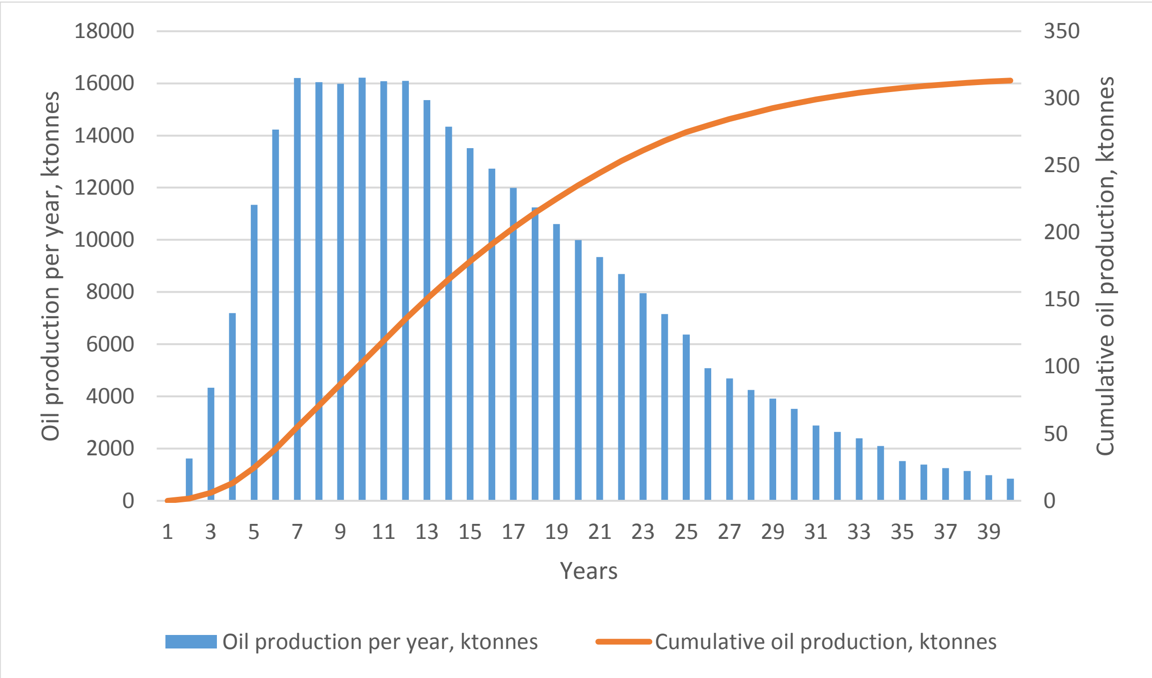


Figure 19. Project's lifespan. Characteristics of the main parameters of the development. Planned production level is 16 mln. tones/year

Table 6. The rate of putting wells on production. Level of oil production is 8 mln tones/year. Realistic scenario

Oil field	Platform. wells cluster	Years																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Prirazlomnoye	Platform 1	1	4	3	3	5	4	5	3	3	3	1																			
	Total	1	4	3	3	5	4	5	3	3	3	1																			
Medinskoye-more	Platform 1													6	7	5	4														
	Platform 2														6	7	5	2													
	Total													6	13	12	9	2													
Varandey-more	Well pad (onshore)																			3	3										
	Platform 1																				6	7	5								
	Total																			3	9	7	5								
Dolginskoye	Platform 1																									6	7	5	5	4	5
	Platform 2																								6	6	6	6	5	4	
	Platform 3																										6	6	5	6	3
	Total																								6	12	19	17	15	14	8
Total amount for the group of fields		1	4	3	3	5	4	5	3	3	3	1	0	6	13	12	9	2	0	3	9	7	5	0	6	12	19	17	15	14	8

Table 7. The rate of putting wells on production. Level of oil production is 16 mln. tones/year. Optimistic scenario

Oil field	Platform. wells cluster	Years																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Prirazlomnoye	Platform 1	1	4	3	3	5	4	5	3	3	3	1									
	Total	1	4	3	3	5	4	5	3	3	3	1									
Medinskoye-	Platform 1			6	7	5	4														
more	Platform 2				6	7	5	2													
	Total			6	13	12	9	2													
Varandey-	Well pad (onshore)				3	3															
more	Platform 1					6	7	5													
	Total				3	9	7	5													
Dolginskoye	Platform 1								6	7	5	5	4	5							
	Platform 2							6	6	6	6	5	4								
	Platform 3									6	6	5	6	3							
	Total							6	12	19	17	15	14	8							
Total amount for the group of fields		1	4	9	19	26	20	18	15	22	20	16	14	8	0	0	0	0	0	0	0

4.2. Offshore Structures

Of the proposed offshore structures we have chosen the Ice resistant gravity based platforms (D = 100 m. the wall angle α = 30 ° or 60 °) (Figure 20) for the oil fields, because the water depth in the Pechora sea is nearly 15-50 m. Consequently artificial islands are not applicable. Sloped walls of the platform have been selected based on the fact that there is a possibility of a collision of small icebergs with the platform.

Figure 20. Chosen Ice resistant gravity based platform [3]

4.3. Platform selection

Platform selection was made based on the calculation of global exposure horizontal load of ice on the wall per unit area of the offshore structure, where α - is the angle of the wall (ISO 19906).

$$\frac{F_H}{D} = \sigma_f \left[\frac{\rho_w g h^5}{E}\right]^{1/4} C_1 + zh\rho_i g C_2$$

$$C_1 = 0.68\left(\frac{\sin\alpha + \mu\cos\alpha}{\cos\alpha - \mu\sin\alpha}\right)$$

$$C_2 = (\sin\alpha + \mu\cos\alpha)\left(\frac{\sin\alpha + \mu\cos\alpha}{\cos\alpha - \mu\sin\alpha} + \frac{\cos\alpha}{\sin\alpha}\right)$$

Parameter suggested values: $\rho_{sea.water}$=1023 kg/m^3; ρ_{ice} = 900 kg/м^3; E = 9 GPA; g= 9.81 m/s^2; z = 5 m; μ = 0.2; σ_f– flexural ice strength (σ_f =500 kPa); h – average ice thickness (h=1.7 m).

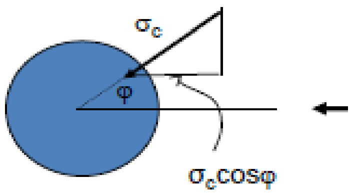
Results of the calculations:

Angle	C1	C2	F v max	Fv min
30	-1.85	2.75	1716.05	744.96
45	1.83	3.16	3500.37	1342.22
60	0.378	-1.82	-1463.33	-597.29

Hence, we can make a conclusion that the minimum load to the wall of the platform will be when the angle to the platform is equal to 60^0. [11]

We have determined global action on a vertical wall to make sure that its use is not possible.

Global action:



$$F = h \int_{-\pi/2}^{\pi/2} \sigma_c \cos\varphi R d\varphi = h\sigma_c 2R = \sigma_c D h$$

σ_c - unconfined compressive strength
D, R - diameter, radius of structure
h - ice thickness

We have obtained Fg = 24000 N, which exceeds the maximum load on the sloped wall when the angle to the platform is equal to 30^0.

4.4. Tankers

1. Based on the level of production from the platform and the distance to the port of shipment we have chosen:
   - Oil tanker PANAMAX (deadweight is 100 000 ton);
   - Number of tankers – 2;
   - Speed of the tanker in open water is 30 knots (55 km / h);
   - Speed of the tanker in ice is 7 knots (13 km / h);
   - Draught 16 m;
   - The distance to the port of shipment 3043 km (part of the way in the ice 548 km; part of the way in open water 2495 km;) (Figure 21)

- Time of the tanker running from the platform to the port of shipment is 65. 4 hour (back and forth 130.8)

2. Based on the time of the tanker running for shipment of the product, we can conclude that the two tankers will be sufficient to service the platform, even taking into account unforeseen circumstances delaying tanker en route for 1-2 days. However, as insurance against a serious disruption in the movement of tankers, their breakage, etc. oil storages should be placed on the platform with 50 thousand tons capacity.

Figure 21. The route of the tanker from the platform (A) to the port of shipment (B).
(*maps.google.ru)*

3. We have proposed that we will ship the product from the tankers in the port of Rotterdam in the Netherlands (Figure 22) where the water depth is 24 m, which allows to our tankers freely enter to the port.

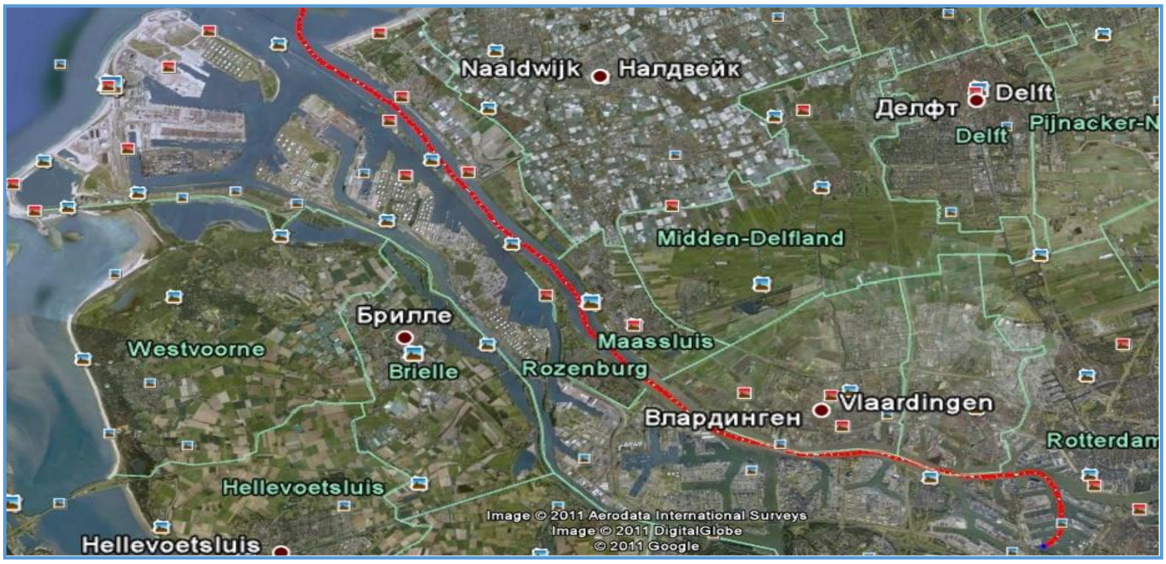


Figure 22. Port of Rotterdam (*maps.google.ru)*

4. Power supply unit is diesel unit which presents installation capacity of 10 MW, which provides the necessary traction when driving in open water and in ice, and at the same time meet modern environmental standards.
5. Based on the climatic conditions and seasonal water ice layer coating (with a maximum thickness of 1.7 m) the following decisions have been taken:
   - Usage the ship maintenance along the route of the tankers, namely icebreaker "Taimyr" (Figure 24), whose task will be escorting tankers over 548 km from the platform (in the way of the icebound waters) (Figure 23)

Figure 23. The icebound waters, where icebreaker "Taimyr" should escort tankers. (maps.google.ru)

Taymyr is a shallow-draft nuclear-powered icebreaker, and the first of two similar vessels. It was built in 1989 for the Soviet Union in Finland at the Helsinki New Shipyard by Wärtsilä by order of the Murmansk Shipping Company. [27]

Table 8. Taymyr icebreakers general characteristics

Class & type:	*Taymyr*-class nuclear icebreaker
Tonnage:	20.791 GT 6.237 NT 3.550 DWT
Displacement:	21.100 tonnes
Length:	149.70 m (491.1 ft)
Beam:	28.87 m (94.7 ft)

Draught:	7.5–9.0 m (24.6–29.5 ft)
Depth:	15.68 m (51.4 ft)
Installed power:	KLT-40M nuclear reactor (171 MW) 2 × GTA 6421-OM5 turbogenerators(2 × 18.400 kW)
Propulsion:	Nuclear-turbo-electric (AC/AC) Three shafts (3 × 12.000 kW); 4-bladed fixed pitch propellers
Speed:	18.5 knots (34.3 km/h; 21.3 mph) in open water 3 kn (5.6 km/h; 3.5 mph) in 2.2 m (7.2 ft) level ice
Crew:	100+ Accommodation for 138
Aviation facilities:	Helideck and hangar for Kamor Ka-32or similar helicopter

Figure 24. “Taymyr” icebreaker. [35]

4.5. Resistance force of ships on unbroken ice cover

We have determined needed resistance force of the ship and maximum thrust of the vessel.

1. The prediction equation for resistance (units MN) in unbroken level ice, normalized to a speed of 1 m/s, has the following form as reported by Frederking (2003).

$$\boldsymbol{R_{ice}} = \mathbf{0.015}\boldsymbol{HC}\cdot\boldsymbol{S}\cdot\boldsymbol{B}^{\mathbf{0.7}}\cdot\boldsymbol{L}^{\mathbf{0.2}}\cdot\boldsymbol{D}^{\mathbf{0.1}}\cdot\boldsymbol{h}^{\mathbf{1.5}}\cdot(\mathbf{1}-\mathbf{0.0083}(\boldsymbol{T}+\mathbf{30}))\cdot(\mathbf{0.63} + \mathbf{0.00074}\cdot\boldsymbol{\sigma_f})\cdot(\mathbf{1}+\mathbf{0.0018}(\mathbf{90}-\boldsymbol{\gamma})^{\mathbf{1.6}}\left(\mathbf{1}+\mathbf{0.003}\cdot(\boldsymbol{\beta}-\mathbf{5})^{\mathbf{1.5}}\right)$$

(*)

where

HC – hull condition factor;

S – factor for salinity of water;

B – ship beam (m);

L - ship waterline length (m);

D – draft (m);

h –equivalent ice thickness; $h = h_i+h_s$ (m) where h_i (m) and h_s (m) is ice and snow thickness;

T – ice surface temperature (^{0}C);

σ_f – flexural strength of ice (kPa);

γ – average bow flare angle at waterline (^{0});

β – average buttock flare angle at waterline (^{0}).

Resistance force of the vessel at speed less than 1 m / s R_{ice} = 3.54 MN;

2. Keinonen (1996) has also modified Eq.(*) to include the influence of speed . The additional resistance at speeds greater than 1 m/s is given by the following relation (units in MN):

$$\boldsymbol{R_{ice}}(v > 1\frac{m}{s}) = \mathbf{0.0}09\boldsymbol{HC}\cdot(\frac{\Delta\boldsymbol{v}}{(\boldsymbol{gL})^{\mathbf{0.5}}})\cdot\boldsymbol{B}^{\mathbf{1.5}}\cdot\boldsymbol{D}^{\mathbf{0.5}}\cdot h_i\cdot(\mathbf{1}-\mathbf{0.0083}(\boldsymbol{T}+\mathbf{30}))\cdot(\mathbf{1} + \mathbf{0.0018}(\mathbf{90}-\boldsymbol{\gamma})^{\mathbf{1.6}}(\mathbf{1}+\mathbf{0.003}\cdot(\boldsymbol{\beta}-\mathbf{5})^{\mathbf{1.5}})$$

where

$\Delta v = v - 1$(units m/s);

g =9.81 m/s^2

The velocity dependent component of resistance is linear in both v and h_i.

Resistance force of the vessel at speed more than 1 m / s R_{ice} (v>1м/s) = 5.79 MN;

3. The open water resistance (MN) is given by

$$R_{ow} = (Displ)^{1.1}(0.025F_n + 8.8F_n^5)/1000$$

where
Displ = $\rho_w LBDC_b$ (tons);
ρ_w – density of sea water (tons/m^3);
C_b – block coefficient;
$F_n = \frac{V}{\sqrt{gL}}$ (Floude number)

Resistance force of the vessel in open water R_{ow} = 1.49 MN;

4. The total resistance is given by the sum:

$$R = R_{ice} + R_{ice}(v > 1\ m/s) + R_{ow}$$

The total resistance force of the vessel R = 10.82 MN;

5. Open water thrust at maximum power absorbed (units MN) is

$$T_{ow} = 0.75P_s(0.122 - 0.0057v)$$

whereP is shaft power (units MW). Note that for an open fixed pitch propeller omly 75% of shaft power is absorbed at maximum speed.

Open water thrust of the vessel in open water at maximum power absorbed
T_{ow} = 7.13 MN;

6. Running in ice is an overload situation and the maximum thrust is given by:

$$T_{max} = P_s(1 - \frac{0.25v}{v_{max}})(0.111 - \frac{v(0.0057v_{max} - 0.011)}{v_{max}})$$

Maximum thrust of the vessel in ice conditions T_{max} = 29.66 MN.

We have obtained that the power of the vessel in open water exceeds the resistance movement of the ship. Power of the vessel in ice conditions is greater than the total resistance; hence we can make the assumption that there is no need for additional support vessel as an ice-breaker. Nevertheless we have planned with use of icebreaker assistance because there are occurrence of unforeseen changes in weather and the occurrence of various emergencies in Arctic latitudes, so we have decided to play safe.

4.6. The pipeline design

The pipeline design includes the following design drivers:

1. Pipeline route;
2. Pipeline design:

- Flow issues → sizes;
- Temperature and pressure → wall thickness;
- Coating →corrosion protection and heat insulation;
- Corrosion protection;

3. Line pipe selection;
4. Pipeline installation;
5. On-bottom stability;
6. Upheaval and lateral buckling;
7. Freespan and correction. [9]

We considered a thin-walled pipe lines under internal and external pressure and made calculations for five schemes of development of oil fields of the Pechora Sea (look at chapter 2.7.). We used the diameters specified in Table 9 and other basic inputs from Table 9 to Table 11. The following methodology we applied. Example for the fifth scheme of complex arrangement for pipeline from the North integrated template structure to the base platform on the Dolginskoye oil field (Figure 25).

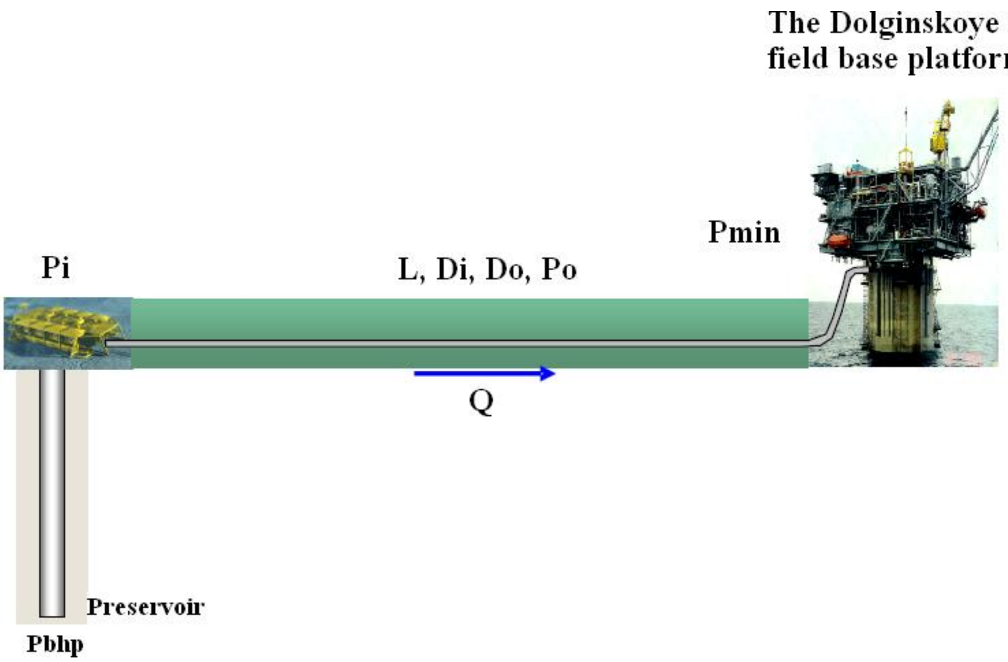


Figure 25. Part of the fifth scheme of arrangement.

Table 9. API 5L Pipe properties

Pipe diameter (nominal)	10"	12"	14"
Pipe outside diameter	273.1 mm	323.9 mm	355.6 mm
API 5L standard wall thickness	9.3 mm - 11.1 mm 12.7 mm 14.3 mm 15.9 mm 18.3 mm	9.5 mm 10.3 mm 11.1 mm 12.7 mm 14.3 mm 15.9 mm 18.3 mm	9.5 mm 10.3 mm 11.1 mm 12.7 mm 14.3 mm 15.9 mm 18.3 mm

Table 10. X65 steel properties

Parameter	SI Units
SMYS	448 MPa
Thermal coefficient for steel expansion	1.17E-5°C
Poisson's ratio of steel	0.3
Young's Modulus of steel	210 GPa

Table 11. Initial data for the example

Pipe Data	**SI Units**
Nominal Wall thickness, t_w	9.3 mm (Initial Guess)
Nominal pipe diameter, D_0	273.1 mm (Initial Guess)
Pipeline Length, L	5 km
Internal roughness, k	0.05 mm
Flowline well head pressure	450 bar
Minimum arrival pressure at top of riser on platform	350 bar
Constant Operating temperature	65 deg Celsius
Installation temperature	5 deg Celsius

Operating Data	**SI Units**
Flow rate, Q	40000 (cubic m per day)
Dynamic Viscosity	3.092E-3Pa.s
Contents Density	850 kg/m^3

Part 1.

We should find the diameter to meet the required process arrival conditions. We checked using a 10 inch nominal diameter and the initial guess value of wall thickness. Checked for the actual pressure drop and the diameter must be revised if needed to meet the allowable pressure drop requirements.

1. We assumed pipe nominal outside diameter and initial wall thickness:

   Do=273.1 mm; t = 9.3 mm.

2. We can calculate internal diameter of the pipe:

   $$\boldsymbol{D_i = D_0 - 2 \cdot t = 273.1 - 2 \cdot 9.3 = 254.5\ mm}$$

3. Reynolds number:

$$\boldsymbol{Re = \frac{v \cdot D_i \cdot \rho}{\mu} = \frac{4 \cdot Q}{\pi \cdot D_i^2}\frac{D_i \cdot \rho}{\mu} = \frac{4 \cdot N \cdot q_{1w} \cdot \rho}{\pi \cdot D_i \cdot \mu} = \frac{4 \cdot 32 \cdot 1250 \cdot 850}{3.14 \cdot 86400 \cdot 0.2545 \cdot 3.092 \cdot 10^{-6}} =
= 5.05 \cdot 10^8}$$

   where $\boldsymbol{Q = N \cdot q_{1w}}$ - flow rate, m^3/s.

   N- number of wells, q_{1w} – oil production from 1 well, m^3/day.

   Re> 2300→ turbulent flow.

4. Relative roughness:

   $$\boldsymbol{r = \frac{\varepsilon}{D_i} = \frac{0.05}{254.5} = 1.96 \cdot 10^{-4}}$$

   Using Figure 26 – Moody diagram we could find Darcy-Weisbach friction factor

   f = 0.0135

5. Actual pressure drop consists of two parts – head loss due to friction + static pressure head:

   $$\boldsymbol{\Delta p = \frac{f \cdot \rho \cdot v^2 \cdot L}{2 \cdot D_i} + \rho \cdot g \cdot h = \frac{0.0135 \cdot 850 \cdot 9.11^2 \cdot 5000}{2 \cdot 0.2545} + 850 \cdot 9.81 \cdot 50 =
   = 9.85\ \mathrm{MPa}}$$

6. We checked actual pressure drop to meet the allowable pressure drop requirements:

   $\boldsymbol{P_i - \Delta p > P_{min},}$

   $\boldsymbol{where\ P_i - flowline\ well\ head\ plessure, Mpa};$

   $\boldsymbol{P_{min} - minimum\ arrival\ pressure\ at\ top\ of\ riser\ on\ platform, Mpa}$

   $\boldsymbol{so}$

$\boldsymbol{45 - 9.85 = 35.15MPa > 35\ MPa}$ It’s ok!

$\boldsymbol{We\ should\ not\ revise\ and\ change\ pipe\ diameter\ or\ wall\ thickness}$.

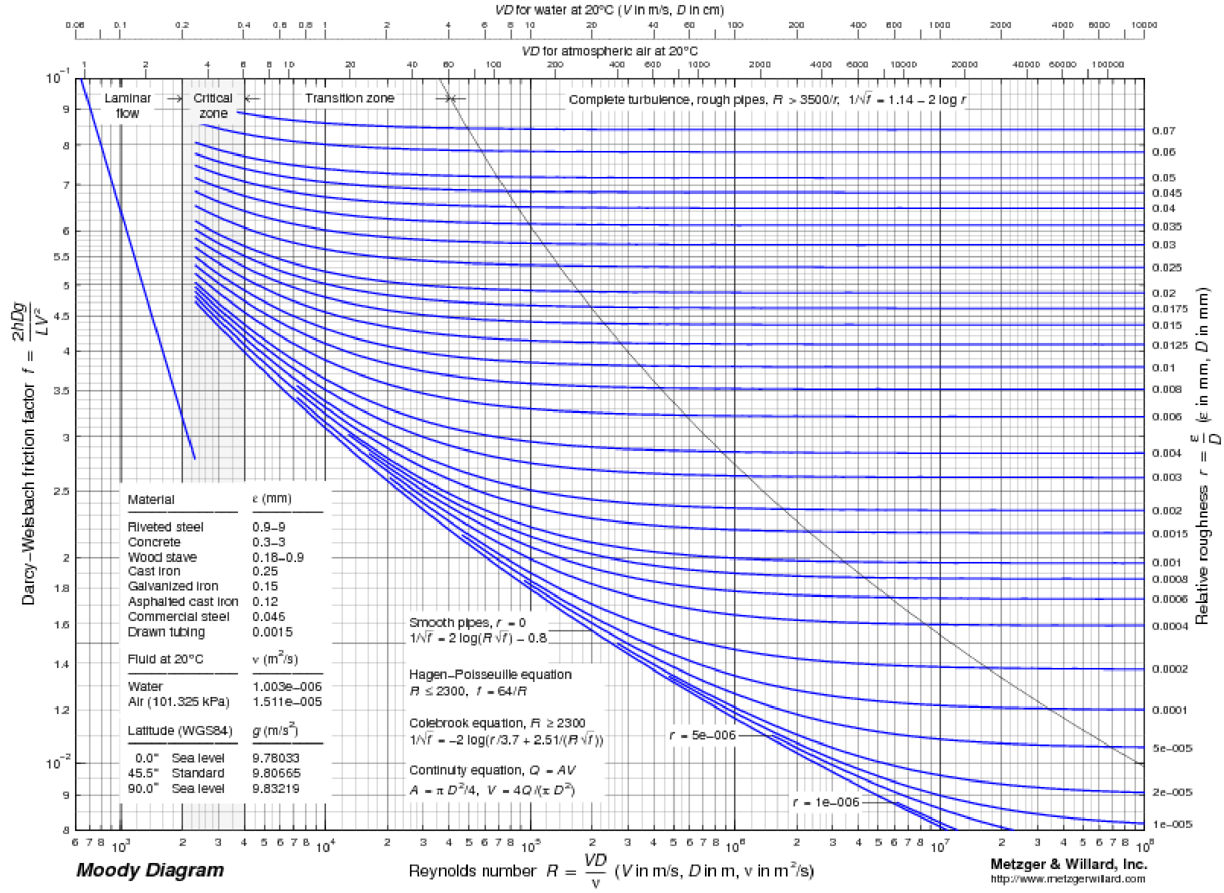


Figure 26. Moody diagram [9]

Part 2.

We determined the optimum wall thickness by using a design factor of 0.72. We checked and optimized the wall thickness of the pipeline based on hoop stress check. Used the following equation for hoop stress computation:

1. Hoop stress $\boldsymbol{s_H = \frac{p_i D_i - p_0 D_0}{2 \cdot t}}$

$$\boldsymbol{s_H = \frac{45 \cdot 0.2545 - 1025 \cdot 9.81 \cdot 50 \cdot 0.2731}{2 \cdot 9.3} = 608.34\ MPa}$$

2. We know that for API 5L X65 SMYS = 448 MPa (Line pipe grade designations come from API Spec 5L Specification for Line Pipe), so

$$\boldsymbol{SMYS \cdot design\ factor = 448 \cdot 0.72 = 322\ MPa}$$

Let’s check: $\boldsymbol{SMYS \cdot design\ factor > S_H \ \rightarrow 322MPa < 608.34MPa}$. It’s not OK!

3. We should optimize the wall thickness of the pipeline.

New wall thickness ***t’=18.3 mm***.

$$S'_H = \frac{45 \cdot 0.2545 - 1025 \cdot 9.81 \cdot 50 \cdot 0.2731}{2 \cdot 18.3} = 309.53MPa$$

$SMYS \cdot design\,factor > S_H \rightarrow 322MPa > 309.53MPa$. It's OK!

Part 3.

We assumed that a span located very close to subsea well (for the fifth scheme of arrangement). The pipeline is subjected to a residual axial tension of 100 kN and a bending moment of 50 kN. We computed combined stresses (Von Mises criterion) and assumed a design factor of 0.8.

Von Mises criterion $\sigma_{eq} = \sqrt{(\sigma_h^2 + \sigma_l^2 - \sigma_h \cdot \sigma_l}$

1. Moment of Inertia:

$$J = \frac{\pi}{64} \cdot (D^4 - (D - 2 \cdot t)^4) = \frac{3.14}{64} \cdot (0.2731^4 - (0.2731 - 2 \cdot 0.0183)^4) = \\ = 1.19 \cdot 10^{-4}$$

2. Bending stress:

$$\sigma_{bending} = \frac{M}{J} \cdot \frac{D}{2} = \frac{50 \cdot 10^3}{1.19 \cdot 10^{-4}} \cdot \frac{0.2731}{2} = 57.17\ MN$$

3. Longitudinal stress:

$$\sigma_l = \sigma_{axial} \pm \sigma_{bending} = \frac{4 \cdot F_{axial}}{\pi \cdot D^2} + \sigma_{bending} = \frac{4 \cdot 100 \cdot 10^3}{3.14 \cdot 0.2731^2} + 57.17 \\ = 58.87\ MN$$

4. Hoop stress:

$$\sigma_H = \frac{p_i D_i - p_0 D_0}{2 \cdot t} = \frac{45 \cdot 0.2545 - 1025 \cdot 9.81 \cdot 50 \cdot 0.2731}{2 \cdot 9.3} = 608.34\ MN$$

5. Von Mises criterion:

$$\sigma_{eq} = \sqrt{(\sigma_h^2 + \sigma_l^2 - \sigma_h \cdot \sigma_l} = \sqrt{(608.34^2 + 58.87^2 - 608.34 \cdot 58.87} \\ = 284.69\ MN$$

6. Let's check:

$SMYS \cdot design\,factor = 448 \cdot 0.8 = 358.4\ MN$

$SMYS \cdot design\,factor > \sigma_H \rightarrow\ 358.4MN > 284.69\ MN$. It's OK!

Comment: The wall thickness equal to 9.31 mm is enough to face pressure drop equal 9.85 MPa. But we had to change wall thickness due to impact of hoop stress and Von Mises criterion (final mean of wall thickness 18.3 mm). From the calculations, we see that as wall-thickness increases, hoop stress decreases, and total stability and reliability of pipeline increases.

Calculation for other schemes of arrangement you can see in the Tables 18-22 in Appendix. We used same methodology for these calculations which were made in MS Excel.

5. RISK ANALYSIS

5.1. Description of the system under consideration

We shall consider a three offshore marine operations - gravity based platform transportation to the place of installation, offloading process to the tanker which are carried out in the Pechora Sea, and subsea production system installation. The operation of transporting a platform to the production place is to be carried out by tow vessels.

We shall carry out an evaluation of the risk involved during those marine operations looking at:

- Risks to humans.
- Risk to the environment
- The asset risk

5.2. Qualitative accept criteria and risk matrix

Hazard severity category	Descriptive words	Probability rating				
		A	B	C	D	E
		Very likely	Likely	Possible	Unlikely	Very unlikely
1	Very high					
2	High					
3	Moderate					
4	Slight					
5	Negligible					

Qualitative accept criteria:

- not acceptable risk; - as low as reasonable risk; - in principle acceptable risk.

5.3. Hazid to identify the risk during platform transportation to the place of installation

Hazard severity category	Descriptive words	Probability rating				
		A	B	C	D	E
		Very likely	Likely	Possible	Unlikely	Very unlikely
1	Very high	**1**	**4**	**6**	**7**	
2	High	**2**		**5;8**	**9**	
3	Moderate					
4	Slight					
5	Negligible					

The process of platform transportation to the place of installation is very difficult and challengeable task due to harsh environmental and weather conditions in Arctic region (figure 27). This type of work requires the coordinated action of many people and should be carried out during the absence of ice in water area and in calm conditions. We consider that it is important to enumerate the issues that could influence transportation operation. Here is the Hazid list:

Figure 27. Platform transportation (shelf-neft.gazprom.ru)

1. Collision with fishing vessels navy vessels. DP lost vessels
2. High heave motion due to weather conditions such storm. high sea state
3. Salinity (depends where this platform or its parts coming from and where /when it's going to be transported)
4. Current (depends on the depth of the area and type of the platform)
5. Random icebergs and special areas with rare and unique mammals
6. Collapse during transportation due to not confident calculations and not incorporated coefficients for transportations / transits
7. Marine / navigation crew-not educated / experienced enough to transport such special type of the vessels
8. Lost DP. if it's a self-propelled vessel / lost DP on transit barge performing the transportation of platform / part of the platform
9. Human error such as "forecast provider" onshore supervising. etc.

5.4. Hazid to identify the risk during process of offloading

Hazard severity category	Descriptive words	Probability rating				
		A	B	C	D	E
		Very likely	Likely	Possible	Unlikely	Very unlikely
1	Very high	**1;10**	**3; 5; 8**	**4**	**7**	
2	High	**2**		**6**	**9**	
3	Moderate					
4	Slight					
5	Negligible					

The process of offloading in the Prirazlomnoe oil field is unique. System was made and installed by the company Aker Pusnes (Norway). It consists of the crane, mooring root and offloading hoses. Crane and tanker have integration computer programs which helps docking tanker to the platform. Tanker uses DP for the stable position near the offloading point. In our opinion it’s important to mention the issues that could influence process of offloading. Here is the list of Hazid factors:

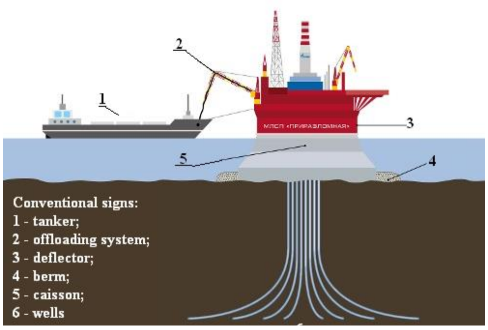


Figure 28. Offloading process [3]

1. Possibility of collision with random vessels with lost DP / fishing boats with fishing nets
2. High heave motion due to not accessed weather conditions during start and the whole period of offloading
3. Risk of uncontrollable turret movement during offloading
4. Shuttle tanker lost DP
5. SIMOPS
6. Harsh ice and weather conditions (weather forecast to be monitored prior and during offloading)
7. No maintenance / certification for offloading hoses
8. Collision between shuttle tanker and permanent structure
9. Not controlled pressure / volume during start/ ongoing process of offloading via hose system and connectors / offloading buoy
10. Not controlled disconnection of the sucking hoses during ongoing offloading - spills into the open sea
11. Not experienced crew on shuttle tanker (e.g. chambers. modules must be filled by following a special sequence) - can cause tanker's uncontrollable movements.

5.5. Hazid to identify the risk of subsea production system installation

Hazard severity category	Descriptive words	Probability rating				
		A	B	C	D	E
		Very likely	Likely	Possible	Unlikely	Very unlikely
1	Very high				**9**	**6; 12**
2	High			**1**		**5; 7; 8**
3	Moderate				**4**	
4	Slight			**10; 11**		**2; 3**
5	Negligible					

The installation process is a very challengeable task in Arctic. The identified hazards applicable for the SPS will be ranked to identify major hazards. There will be analyzed further and addressed during the detailed design. We consider that it is important to enumerate the issues that could influence installation operations. Here is the list:

Figure 29. Subsea unit installation [eninorge.com]

1. Unpredictable weather conditions
2. Engine break down
3. Poor sea fastening
4. Personal accidents
5. Loss of structural integrity (e.g. hull, ballast, support structure failure)
6. Loss of stability (e.g. ballast failure, cargo loads)
7. Loss of marine/utility systems (e.g. propulsion, power generation, failure of navigation system)
8. Loss of stability during lift operations
9. Vessel delay (due to big transfer distance)
10. Wire damage (due to big snap load in wire)
11. Lack of fuel (due to long installation operation)
12. Collision/impact (e.g. support vessel, passing vessel, stand-by vessel, aircraft crash on barge, including military, fishing vessels, naval vessels, including submarines), capsizing (due to heavy lift operations). [16]

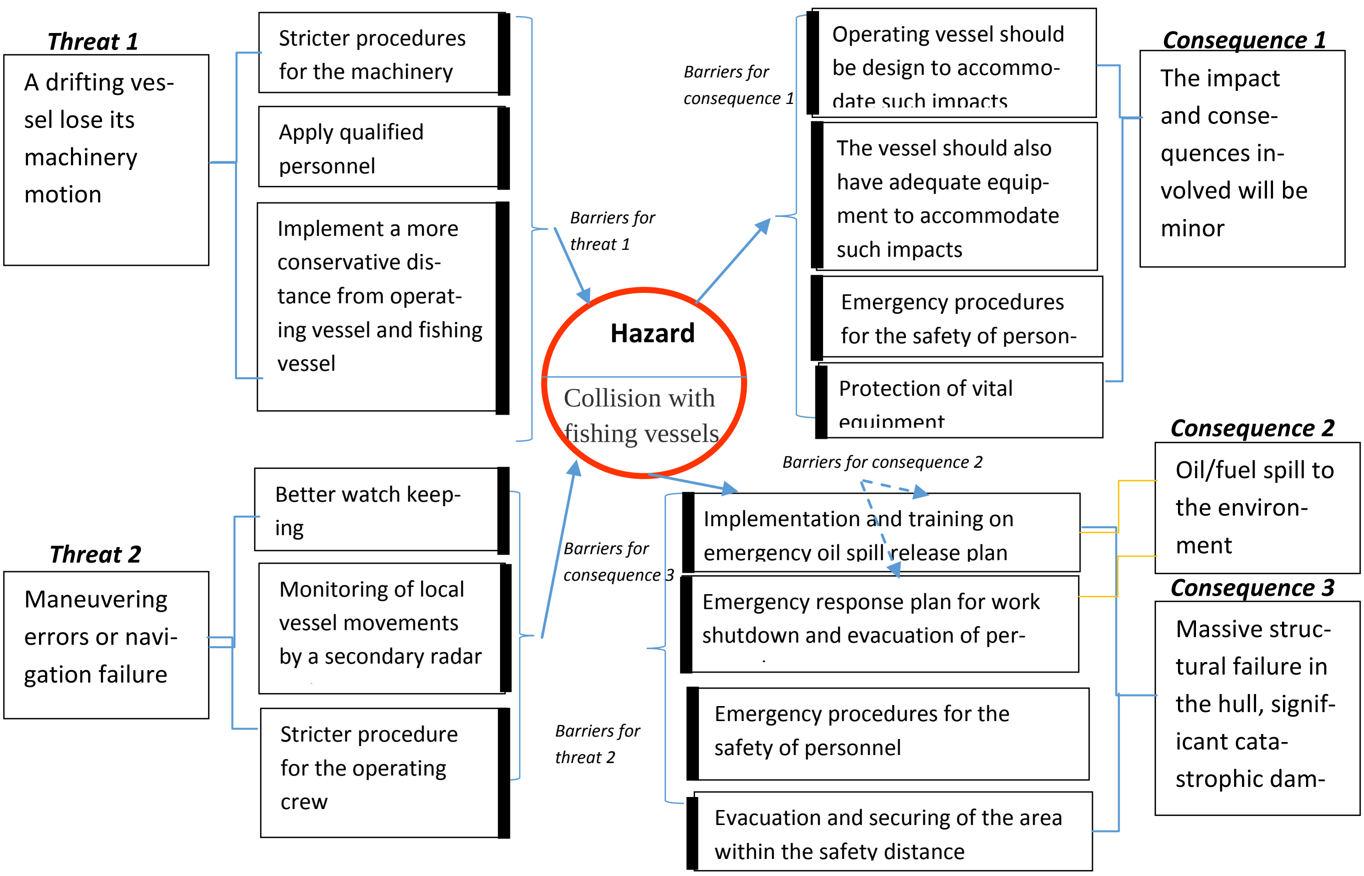
5.6. Bow-tie analysis

Bow-tie diagrams are a simple and effective tool for showing risk assessment results. The diagrams clearly display the links between the potential causes, preventative and mitigative controls and consequences of a major accident. Bow-tie diagrams may be used to display the results of various types of risk assessments and are useful training aids. [36]

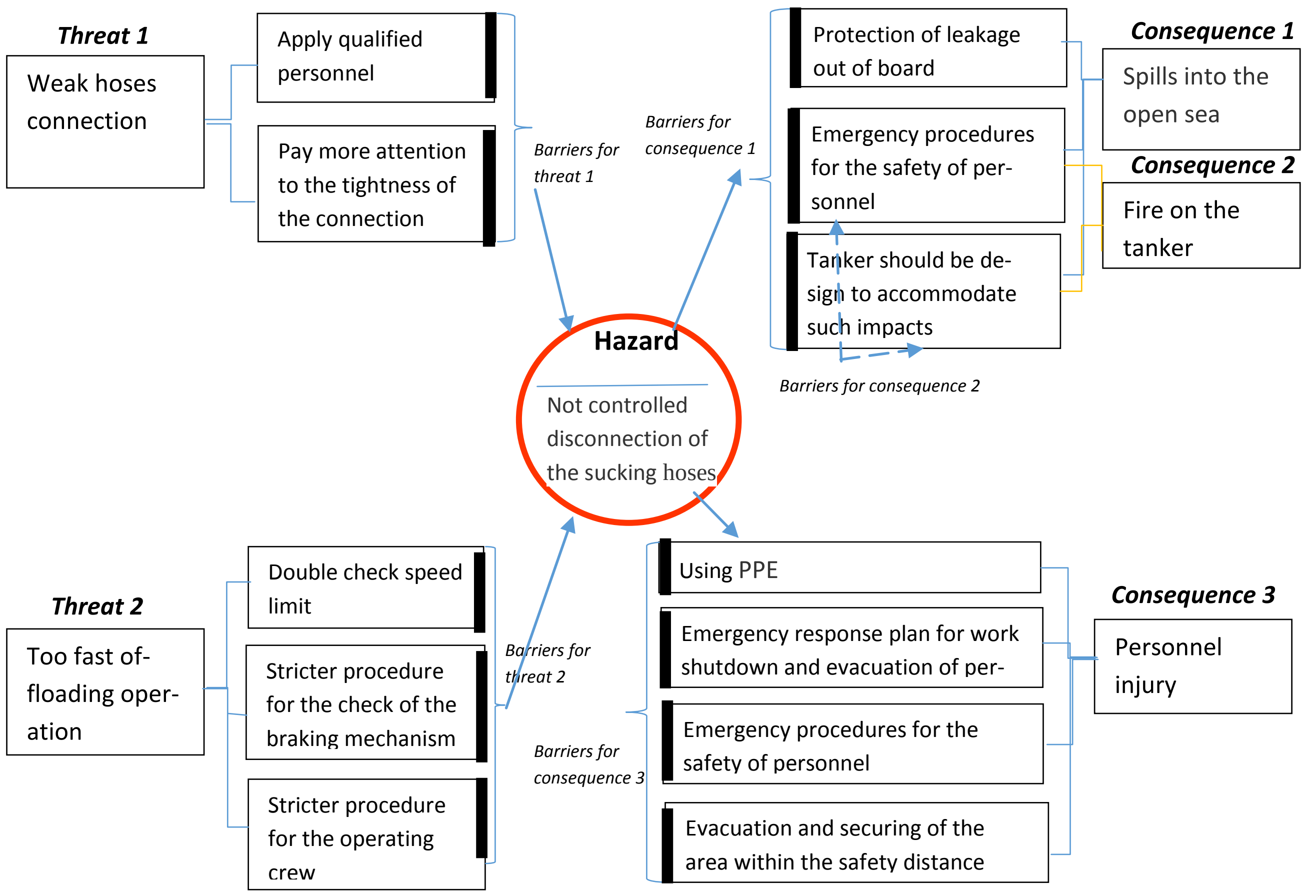
In the following bow-tie analysis the risks with the highest probability of occurrence and the most serious consequences are reviewed. There are high risk of collision with a fishing vessel, high risk of not controlled disconnection of the sucking hoses, and high risk of high heave motion.

Diagrams present threats, consequences and barriers which are necessary to take into account when we face with these challenges.

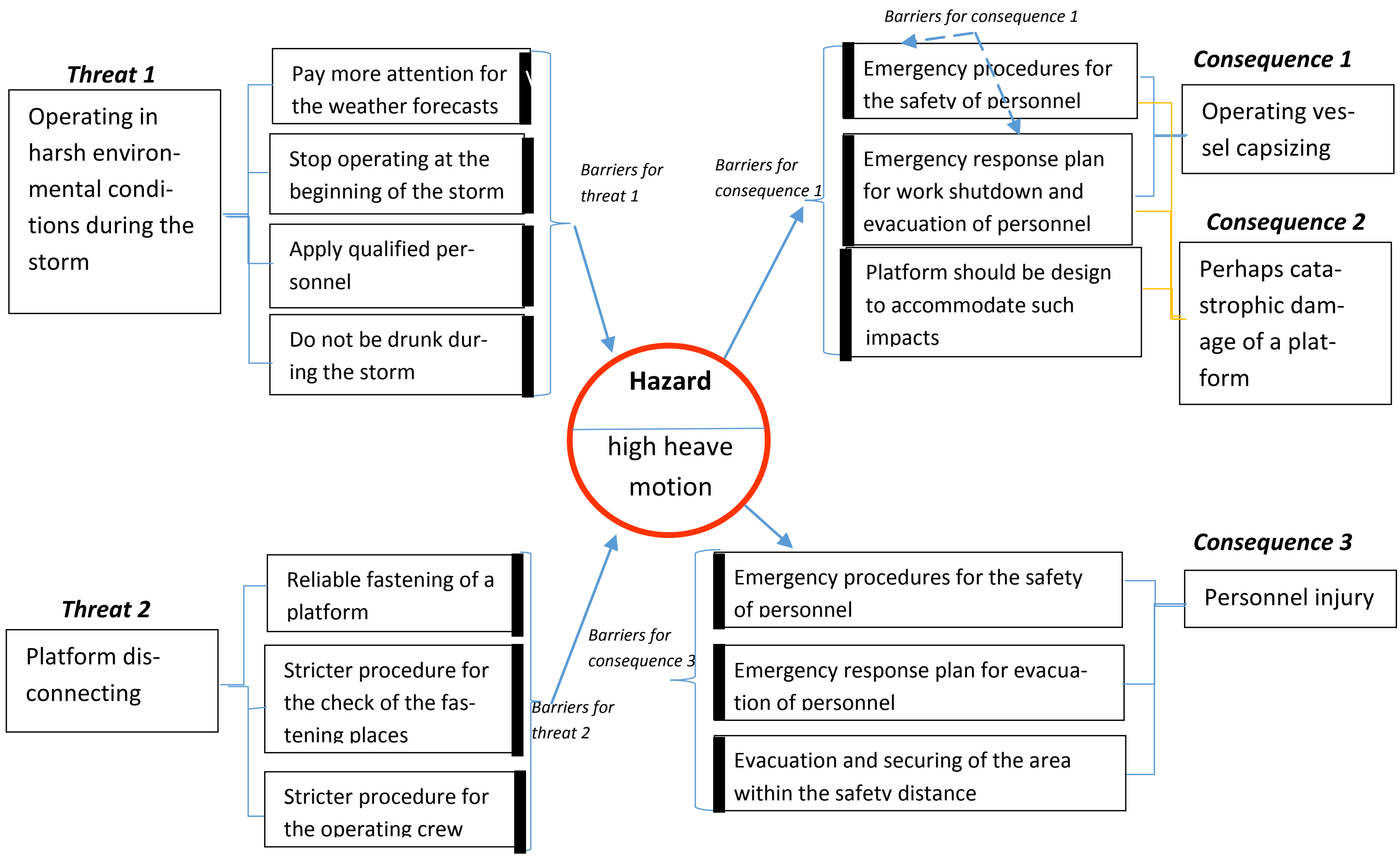
High risk of collission with a fishing vessel



High risk of not controlled disconnection of the sucking hoses



High risk of high heave motion



6. COST ANALYSIS

We have decided to evaluate and to compare from the economical point of view the first and the fifth scheme of complex arrangement of the Pechora sea oil fields. The first scheme of arrangement will be base variant. The fifth scheme will be preferable variant among other schemes of complex arrangement.

We have analyzed technical data and have chosen two different scenarios for the field development:

- Base case – the first scheme of arrangement (figure 11). As proposed there will be only ice-resistant gravity based platforms and ice-resistant unit of the conductor.
- Preferable case – the fifth scheme of arrangement (Figure 14). There will be two sub-sea production systems on the Dolginskoye oil field. (4 ITS with 8 well slots for the North part of the field and the same for the South part).

Module installation offshore is a challenging operation both when the modules are in the air and in the splash zone. Often the module faces the largest forces in its lifetime during installation. According to the weather and seasonal limitations installations shall therefore be carried out during the summer time (May to August/September).

Several types of vessels which could be applicable for this kind of installations are recognized. Due to heavy cargo transportation and heavy lift operations we have to be sure about the vessel's stability and response functions in waves.

An increasing challenge at the Pechora sea oil fields is o design, construct, and install offshore installations that give an acceptable return of the investments. However, the cost reduction elements suggested are valid for offshore field developments in general. The main cost reductions are obtained by:

- Maximum use of industry capability;
- Application of new organization principles;
- Focus on functional requirements;
- Shortened project execution time.

For each installation operation we need at least one Supply and one Diving support vessel. For the template transportation cargo barge are needed. Several types of crane vessels can contribute to the lifting operations: monohull, semi-submersible, crane vessel, crane barge or wet tow.

We have to include the transfer costs as well. Transfer costs are the costs for mobilization to site and demobilization of all vessels. Obviously, during logistic studies we have to examine the demand of the vessel market and order the vessels in advance. We have to admit that the transfer costs are very high. [16]

We have to admit that the drilling costs would be much higher since the horizontal parts of the wells will be longer. And it is very important to take into consideration the drilling cost in our analysis.

According to Tables 4, 5 and internal information of Gazprom-neft Company we could form initial data for our economical evaluation.

Table 12. Initial data. CAPEX

Object of expenditure	CAPEX. bln.rub	
	Base case	Preferable case
Gravity based platform	65	65
Unit of the conductor	25	-
Integrated Template structure	-	23,8
Well drilling	2,5	3
Well equipment	0,12	0,2
Supply vessel	3,24	3,24
Tanker	7,02	7,02
Supply base	0,57	0,57
Undewater pipeline	-	10,61

Table 13. Initial data. OPEX

Object of expenditure	OPEX, bln.rub	
	Base case	Preferable case
Platform tinning	0,429	0,429
Unit of the conductor tinning	0,165	-
Integrated Template structure tinning	-	0,157
Well drilling	0,04	0,05
Well equipment	0,008	0,008
Supply vessel	0,804	0,804
Tanker	0,932	0,932
Supply base	0,205	0,205
Undewater pipeline	-	0,05

We made calculations of two scenarios of putting wells into production. First option involves entering wells gradually and the second are more rapidly (Tables 6, 7).

Also we consider two different development variants for levels of oil production of 8 and 16 million tons/year (Figures 18-19)

To estimate the economical effectiveness of the cases we made calculations of NPV, net profit margin, and discounted profitability index

1. The time-discrete formula of the net present value (NPV):

$$NPV(i) = \sum_{t=0}^{N} \frac{R_t}{(1+r)^t}$$

where

t – the time of the cash flow;

r– the discount rate (the rate of return that *could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital;*

R_t – the net cash flow i.e. cash inflow – cash outflow, at time t. [30]

Table 14. NPV characterization

If...	It means...	Then...
NPV > 0	the investment would add value to the firm	the project may be accepted
NPV < 0	the investment would subtract value from the firm	the project should be rejected
NPV = 0	the investment would neither gain nor lose value for the firm	We should be indifferent in the decision whether to accept or reject the project. This project adds no monetary value. Decision should be based on other criteria, e.g., strategic positioning or other factors not explicitly included in the calculation.

2. Net profit margin or net profit ratio all refer to a measure of profitability. It is calculated by finding the net profit as a percentage of the revenue.

$$Net\ profit\ Margin = \frac{\sum_{t=1}^{n} Cash\ Inflow}{\sum_{t=1}^{n} Cash\ Outflow}$$

where *t* – number of year. [32]

3. Discounted Profitability Index (DPI) could be calculated using the following formula:

$$DPI = \frac{\sum_{t=0}^{N} \frac{CF_t}{(1+r)^t}}{\sum_{t=0}^{N} \frac{I_t}{(1+r)^t}}$$

where

DPI - discounted profitability index;
CF_t - cash flow for the period t;
I_t - the amount of investment costs in period t;
r - the discount rate;
n - the total number of intervals (steps periods) t = 0, 1, 2, ..., n.

If *DPI > 1* it means the investment would add value to the firm then the project may be accepted. [29]

Algorithm of the economical calculations and evaluation of investment effectiveness:

1. Cumulative oil production can be calculated in such way:

$$\mathbf{Q_{\Sigma} = \sum_{i=0}^{N} Q_i}$$

where Qi – production per year, tons; N – the number of years of production.

2. Calculations of Revenue were prepared using the following formula. We should convert Cumulative oil production from tons to barrels.
   We assumed
   – constant price of oil "Brent" P_{oil} = 80 $/barrel;
   – USD exchange rate P_{USD} = 1$=35.25 rubles;
   – oil density ρ_{oil} = 0.85 t/m^3;
   – 1 barrel =0.1589 m^3.

$$\boldsymbol{Revenue = \frac{Q_{\Sigma}}{0.1589 \cdot \rho_{oil}} \cdot P_{oil} \cdot P_{USD} = 6.2933 \cdot \frac{Q_{\Sigma}}{\rho_{oil}} \cdot P_{oil} \cdot P_{USD}}$$

$$\boldsymbol{Revenue\ unit\ of\ measure\ [bln.rub]}$$

3. Gross operational profit:

$$\boldsymbol{GOP = Revenue - OPEX_{\Sigma}}$$

where $\boldsymbol{OPEX_{\Sigma} = \sum_{t=0}^{N} OPEX_t}$, $\mathbf{OPEX_t}$ **– operating expenses per year, bln. rub**, **t – number of year**.

4. Tax on profit calculated with taking into account tax rate 20%:

$$\boldsymbol{T = 0.2 \cdot GOP}$$

5. After-tax profit:

$$\boldsymbol{Profit = GOP - T}$$

6. Cumulative balance of the total cash flow:

$$\boldsymbol{CF_{\Sigma} = \sum_{t=0}^{N} CF_t = \sum_{t=0}^{N} (Profit - CAPEX)_t}$$

7. Discounted balance of the total cash flow:

$$\boldsymbol{PV = \frac{CF_{\Sigma}}{(1+r)^t}}$$

where r – discount rate (12 %), t –year.

8. Net present value (NPV):

$$NPV = \sum_{t=0}^{N} PV$$

9. Discounted Profitability Index:

$$DPI = \frac{\sum_{t=0}^{N} \frac{CF_t}{(1+r)^t}}{\sum_{t=0}^{N} \frac{I_t}{(1+r)^t}}$$

where *DPI* - discounted profitability index;
CF_t - cash flow for the period t;
I_t - the amount of investment costs in period t;
r - the discount rate;
n - the total number of intervals (steps periods) t = 0, 1, 2, ..., n.

10. Net profit margin:

$$Net\ profit\ Margin = \frac{\sum_{t=1}^{n} Cash\ Inflow}{\sum_{t=1}^{n} Cash\ Outflow}$$

where *t* – number of year.

$$\sum_{t=1}^{n} Cash\ Inflow = Revenue$$

$$\sum_{t=1}^{n} Cash\ Outflow = \sum_{t=1}^{n} (CAPEX + OPEX + T)_t$$

Table 15. Results of calculations

Parameter	8 mln.t/year		16 mln.t/year	
	Base case	Preferable case	Base case	Preferable case
Number of years	30 (2013-2043)			
Cumulative oil production, mln.t.	212,4	212,4	392,4	392,4
Revenue, bln.rub	4434,3	4434,3	8192,7	8192,7
Gross operational profit, bln.rub	4169,8	4167,7	7766,8	7765,4
Tax on profits, bln.rub	834,8	834,4	1554,2	1553,9
After-tax profit, bln.rub	3335,0	3333,4	6212,6	6211,5
Discount rate	12%			
Cumulative balance of the total flow, bln.rub	2474,9	2345,4	5763,8	5747,2
Discounted balance, bln.rub	550,1	529,7	823,7	814,9
NPV, bln.rub	***550,1***	***529,7***	***823,7***	***814,9***
Discounted Profitability Index	***2,288***	***3,272***	***7,018***	***7,272***
Cash inflow, bln.rub	4434,3	4434,3	11040,1	11040,1
Cash outflow, bln.rub	1959,4	2088,9	3603,3	3636,8
Net profit margin	***2,26***	***2,12***	***3,06***	***3,04***

Discussion

As we see from Table 15 the Base case (with taking into account two scenarios of development "realistic" 8 mln.t/year and "optimistic" - 16 mln.t/year) has better economical parameters than the Preferable case. The Base case is the economically most attractive for the Pechora sea project (Appendix. Tables 23-30).

It is fair to say that the Preferable case is also economically attractive. Nevertheless it has a little bit worse NPV, DPI, and NPM due to additional challenges, lack of experience of subsea drilling and production in our country, lack of sufficient technology and special fleet for subsea operations and extra expenses. But this variant could alternatively be applied during the development of oil fields of the Pechora Sea.

It is necessary to mention that the NPV in two cases is positive, DPI > 1, and NPM >1. We can make the conclusion that such project of complex arrangement will be economically effective no matter which scenario we implement.

7. SENSITIVITY ANALYSIS

Investment project evaluations as well as research regarding criteria which represent the basis of this evaluation are performed through varying input values selected for the individual criteria. Due to the effect of different factors it is potentially possible that these input values are not realized in the future, which makes our final evaluation scores incorrect. If we want to take into consideration all possible consequences, we have to analyze, in advance, the effect of potential changes of the starting values on the final factual state or results obtained by the calculation using these values. This is performed through the procedures of the Sensitivity Analysis.

Sensitivity Analysis is the calculating procedure used for prediction of the effect of changes of input data on output results of one model. This procedure is often used in investment decision making related with the investment project evaluation under conditions of uncertainty.

Sensitivity Analysis of the effectiveness criterion for investment project evaluation is the calculation of the effect of changes of individual values on the final investment project evaluation. In other words, it is a procedure that analyses how the changes of certain input values (income, costs, value of investments, etc.), influence the total investment project evaluation. Applying this analysis it is possible to find the maximum or minimum points which one value may take while still allowing an investment project to be justified and acceptable for realization.

The basic purpose of the Sensitivity Analysis is therefore to get an insight into the impact of changes of different parameters on the total evaluation of certain investment project's validity.

Another goal is to define steps and actions to be exerted on certain factors in order to avoid possible unwanted changes of some input values and of the investment project evaluation

Sensitivity analysis is made for the Base case and Preferable cases. Project parameters (oil price, volume of oil production, CAPEX, OPEX, taxes) are alternately changed to the downside (-20%, -40%) and the upside (+20%, +50%), the new values of the NPV are calculated and entered in table 16.

For example, we calculated the NPV while the oil price decreased from 80 $/barrel to 64 $/barrel (Table 16). In such situation NPV will reduce to 474.74 bln. rub. Also we see how NPV changes if the price for oil increases for 20% to 96 $/barrel (NPV = 694.84 bln.rub)

Input values	NPV	Elasticity	Switch over

	60%	80%	100%	120%	150%		value, %
Oil price	239,98	457,31	529,68	694,84	890,96	0,68	-146,38%
Volume of oil production	239,98	463,40	529,68	673,97	890,96	1,25	-79,92%
CAPEX	591,45	545,22	529,68	498,23	451,63	-0,29	340,85%
OPEX	544,77	533,55	529,68	521,57	509,98	-0,07	1368,68%
Taxes	598,14	546,90	529,68	494,89	443,26	-0,33	307,60%

Table 16. Preferable case. Oil production 8 mln.tons/year.

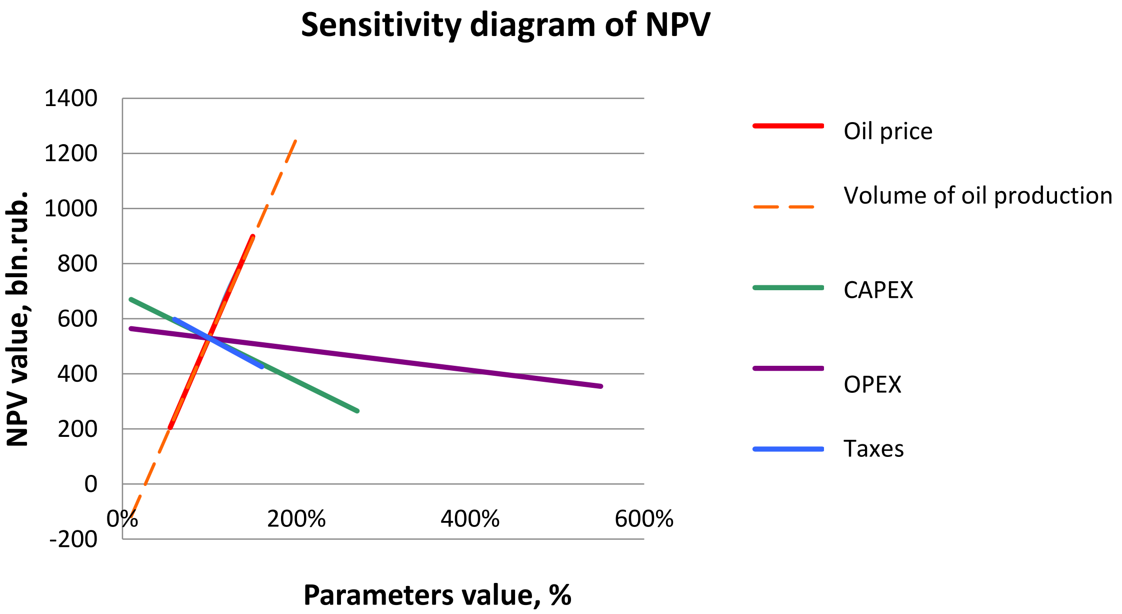


Figure 30. Sensitivity diagram / NPV

Table 17. Preferable case. Oil production 16 mln.tons/year.

Input values	NPV					Elasticity	Switch over value, %
	60%	80%	100%	120%	150%		
Oil price	348,32	698,22	814,86	1048,12	1398,03	0,72	-139,72%
Volume of oil production	347,96	709,02	814,86	1047,40	1397,12	1,30	-76,99%
CAPEX	921,52	841,67	814,86	760,62	680,17	-0,33	303,94%
OPEX	847,58	823,19	814,86	797,59	772,59	-0,10	978,22%
Taxes	922,86	842,03	814,86	759,95	678,49	-0,33	299,91%

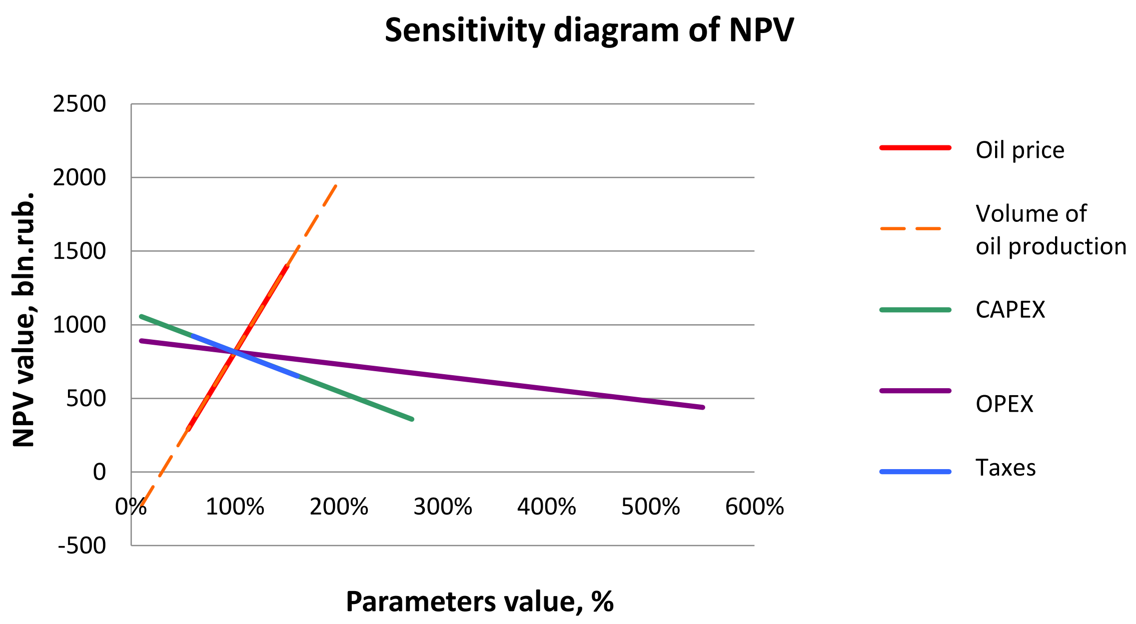


Figure 31. Sensitivity diagram / NPV

Discussion

The biggest impact on the value of the NPV come from the oil price and oil production volume. Thus, it can be concluded that these two parameters cause the greatest economic risk. The oil price is determined by the free oil market. Its value is influenced by the macroeconomic situation in the world and in a country. It is difficult to influence the oil price and to predict which value it will take during the implementation of an investment project.

The question of oil production volume lends itself to better control. It is necessary to maintain the level of production and to prevent its decline because a production reduction even by 20 percent will decrease the NPV by 105,84 billion rubles. Undertaking measures to stay within the budget during investment planning and realization is obviously essential.

As for CAPEX, OPEX and Taxes, the considered investment project is not very sensitive to changes of these parameters. Most likely, it is caused by the uniformity of inputs and by the long-term for the project realization. So it can be deduced that the investment project is sensitive to the oil price and to the production level both for the Base case and the Preferable case. These parameters should be closely monitored to exclude dropping of efficiency and profitability.

8. CONCLUSION

The analysis of the engineering-geological and hydrometeorological conditions of the regions of the Pechora Sea proves the possibility of construction of marine ice resistant platforms for using in these oil fields. Accounting for the production capacities of shipyards in the Russian Federation, steel or composite type (steel concrete) marine ice resistant platforms located in the coastal zone of the Pechora Sea may be recommended for the oil field development.

The substructure design shall take account of the limitations imposed by marine operations for the delivery and installation of platforms at site. Gravity-based type of marine ice resistant platforms may be considered for the design purposes. The thesis presents recommendations on the preferences of using gravity based platforms accounting for particular types of soil foundation. As shown in the thesis the artificial soil island type substructure incorporating a steel or composite caisson with a soil core or floating structures (FPSO) or SDC ("Sanmar") cannot be considered promising for the area.

We have discussed investigations of arctic offshore structures, types of offshore structures, transportation system for arctic conditions and the challenges of development of potential hydrocarbon fields in the Pechora Sea Area. As well we have done a case study where we have looked at an oil field development project. We have looked at the climatic conditions and complicating factors, have chosen a field development scheme, have estimated reserves under development have reviewed the shipment of raw materials and have made infield pipelines design. With regard to the tanker, we have chosen appropriate power, as well as their numbers and have justified the need for icebreakers.

We made comparison of two different cases which can be used for initial assessment of fields' arrangement. The main difference between them is that the second involves the organization of two subsea production systems and one gravity based platform for the Dolginskoye field. The first case does not imply using any subsea equipment.

Risky scenarios during platform transportation to the place of installation, during process of offloading, and during subsea production system installation have been analyzed.

Finally the economical calculations and evaluation of investment effectiveness was made. Obviously complex (joint) arrangement and development of the Pechora sea oil fields can increase the efficiency of these projects.

We can make the conclusion that a project of complex (joint) arrangement will be economically effective no matter which scenario of development we implement. However, it is necessary to take into account additional challenges if we want to use subsea production systems.

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10.APPENDIX

Table 16. Major parameters of the development. Planned production level is 8 ml.tones/year

Years	Oil production per year, ktonnes	Rate of production of recoverable reserves, %		Cumulative oil production, ktonnes	Oil recovery factor	Liquid production per year, ktonnes	Cumulative liquid production, mmtonnes	Water cut, %	Water injection, mmCM		Gas production, mmCM	
		Initial	Remaining						Per year	Cumulative	Per year	Cumulative
1	2	3	4	5	6	7	8	9	10	11	12	13
1	6	0	0	0,006	0	6	0	0	0	0	0,3	0,3
2	1619,9	0,6	0,6	1,626	0,002	1619,9	1,6	0	0,7	0,7	72,9	73,2
3	3622,6	1,3	1,3	5,249	0,005	3622,6	5,2	0	2,7	3,4	163	236,2
4	4681,3	1,6	1,7	9,93	0,009	4728,5	10	1	5,5	8,8	210,7	446,8
5	5693,6	2	2,1	15,623	0,014	5919,3	15,9	3,8	7,6	16,4	256,2	703,1
6	6248,5	2,2	2,3	21,872	0,02	6780,9	22,7	7,9	9,5	25,9	281,2	984,2
7	6427,1	2,3	2,5	28,299	0,026	7655,6	30,3	16	10,4	36,3	289,2	1273,5
8	6066,5	2,1	2,4	34,365	0,032	7953,1	38,3	23,7	10,6	46,8	273	1546,4
9	6302,9	2,2	2,5	40,668	0,038	8663,7	46,9	27,2	10,7	57,5	283,2	1829,7
10	7438	2,6	3,1	48,106	0,044	10250,6	57,2	27,4	11,6	69,1	333,6	2163,2
11	8883	3,1	3,8	56,989	0,053	12240,5	69,4	27,4	14,1	83,2	397,6	2560,9
12	9430,2	3,3	4,2	66,42	0,061	13363,2	82,8	29,4	17,5	100,8	421,8	2982,7
13	9232,1	3,2	4,2	75,652	0,07	14142,6	96,9	34,7	18,2	119	412,7	3395,4
14	8103,2	2,9	3,9	83,755	0,077	14145,3	111,1	42,7	17,7	136,7	362,2	3757,6
15	7424,8	2,6	3,7	91,18	0,084	14382,9	125,5	48,4	17,3	154	333,9	4091,4
16	7904	2,8	4,1	99,084	0,092	15635,2	141,1	49,4	19,1	173,2	365,6	4457
17	8679,5	3,1	4,7	107,763	0,1	17091,4	158,2	49,2	20,9	194	411,7	4868,7
18	9121,2	3,2	5,2	116,884	0,108	18273,1	176,5	50,1	22,3	216,3	439,8	5308,5
19	8435,2	3	5	125,32	0,116	18520,8	195	54,5	22,3	238,6	407,6	5716
20	7502,2	2,6	4,7	132,822	0,123	18515,6	213,5	59,5	21,9	260,5	361,6	6077,7
21	6794,4	2,4	4,5	139,616	0,129	18608,8	232,1	63,5	21,6	282,1	327	6404,7
22	6507,3	2,3	4,5	146,124	0,135	18815,1	250,9	65,4	21,4	303,5	312,4	6717,1

1	2	3	4	5	6	7	8	9	10	11	12	13
23	6892	2,4	5	153,016	0,141	19520	270,5	64,7	21,6	325,1	329,8	7046,9
24	7819,5	2,8	6	160,835	0,149	21184,4	291,6	63,1	23,1	348,2	372,7	7419,6
25	8771,3	3,1	7,1	169,606	0,157	22558,4	314,2	61,1	25	373,3	417	7836,6
26	8713,9	3,1	7,6	178,32	0,165	16127,1	330,3	46	19	392,3	415,2	8251,8
27	9449,3	3,3	8,9	187,77	0,174	17352,4	347,7	45,5	20,7	413	449,1	8700,8
28	9606,5	3,4	10	197,376	0,182	18170,4	365,8	47,1	22	434,9	455,9	9156,8
29	9396,5	3,3	10,8	206,773	0,191	18555,9	384,4	49,4	22,2	457,2	445,6	9602,4
30	9102,4	3,2	11,8	215,875	0,2	18793,1	403,2	51,6	22,4	479,5	431,4	10033,7
31	8821,8	3,1	12,9	224,697	0,208	18984,5	422,2	53,5	22,4	502	418,1	10451,9
32	8439,2	3	14,2	233,136	0,215	19088,9	441,3	55,8	22,4	524,3	400,1	10851,9
33	8048,8	2,8	15,8	241,185	0,223	19191,7	460,5	58,1	22,3	546,7	381,5	11233,4
34	7675,3	2,7	17,9	248,86	0,23	19166,2	479,6	60	22,1	568,8	363,6	11597,1
35	7231,1	2,5	20,5	256,091	0,237	19111	498,7	62,2	21,9	590,7	342,4	11939,5
36	6749,5	2,4	24	262,841	0,243	19046,6	517,8	64,6	21,7	612,4	319,7	12259,1
37	6233,9	2,2	29,2	269,075	0,249	18923,4	536,7	67,1	21,3	633,7	295,1	12554,2
38	5684,7	2	37,6	274,759	0,254	19002,2	555,7	70,1	21,2	654,9	269,3	12823,6
39	5007,6	1,8	53,1	279,767	0,259	18422,1	574,1	72,8	20,3	675,2	237,1	13060,7
40	4413,9	1,6	100	284,181	0,263	18186,1	592,3	75,7	19,9	695,1	193,9	13254,5

Table 17. Major parameters of the development. Planned production level is 16 ml.tones/year

Years	Oil production per year, ktonnes	Rate of production of recoverable reserves, %		Cumulative oil production, ktonnes	Oil recovery factor	Liquid production per year, ktonnes	Cumulative liquid production, mmtonnes	Water cut, %	Water injection, mmCM		Gas production, mmCM	
		Initial	Remaining						Per year	Cumulative	Per year	Cumulative
1	2	3	4	5	6	7	8	9	10	11	12	13
1	6	0	0	0,006	0	6	0	0	0	0	0,3	0,3
2	1619,9	0,5	0,5	1,626	0,002	1619,9	1,6	0	0,7	0,7	72,9	73,2
3	4333,2	1,4	1,4	5,959	0,006	4333,2	6	0	3	3,7	194,6	267,7
4	7196,5	2,3	2,3	13,156	0,012	7263,6	13,2	0,9	6,9	10,6	324,6	592,3
5	11344,7	3,6	3,8	24,5	0,023	11696,7	24,9	3	13,9	24,5	520,2	1112,6
6	14233,1	4,5	4,9	38,734	0,036	15137,1	40,1	6	21,3	45,8	660,8	1773,4
7	16198,6	5,2	5,9	54,932	0,051	18400,6	58,5	12	25,2	71	758	2531,4
8	16039,5	5,1	6,2	70,972	0,066	19927,8	78,4	19,5	26,1	97,1	751,6	3283
9	15982	5,1	6,6	86,954	0,08	21430,7	99,8	25,4	27	124	748,2	4031,2
10	16219,7	5,2	7,2	103,173	0,095	22948,9	122,8	29,3	28,7	152,7	759,1	4790,3
11	16075	5,1	7,7	119,248	0,11	24080,2	146,8	33,2	30,2	182,9	752,2	5542,5
12	16087,2	5,1	8,3	135,336	0,125	25305,4	172,2	36,4	31,5	214,5	752,9	6295,4
13	15354,7	4,9	8,6	150,69	0,139	26123,5	198,3	41,2	32,4	246,9	718,9	7014,3
14	14343,5	4,6	8,8	165,034	0,153	26508,9	224,8	45,9	32,4	279,2	671,9	7686,2
15	13517,4	4,3	9,1	178,551	0,165	26746,2	251,5	49,5	32,2	311,5	633,3	8319,5
16	12731,8	4,1	9,5	191,283	0,177	26937,6	278,5	52,7	32,1	343,6	596,7	8916,2
17	11999,3	3,8	9,8	203,282	0,188	27042	305,5	55,6	31,9	375,4	562,4	9478,6
18	11240,8	3,6	10,2	214,523	0,198	27117,1	332,6	58,5	31,6	407,1	527	10005,5
19	10609,9	3,4	10,7	225,133	0,208	27176,5	359,8	61	31,4	438,5	497,5	10503
20	9989	3,2	11,3	235,122	0,217	27223,6	387	63,3	31,2	469,7	468,6	10971,6
21	9346,3	3	12	244,468	0,226	27340	414,4	65,8	31,1	500,8	438,5	11410,1
22	8692,8	2,8	12,6	253,161	0,234	27118,7	441,5	67,9	30,6	531,4	408	11818,1
23	7959	2,5	13,2	261,12	0,241	26844,3	468,3	70,4	30	561,5	373,5	12191,6
24	7162,8	2,3	13,7	268,283	0,248	27005,8	495,3	73,5	29,9	591,3	336,1	12527,7

1	2	3	4	5	6	7	8	9	10	11	12	13
25	6372,1	2	14,2	274,655	0,254	26902,1	522,2	76,3	29,4	620,8	299,2	12826,9
26	5078,9	1,6	13,2	279,734	0,259	19113,5	541,3	73,4	21,1	641,9	239,7	13066,7
27	4684,8	1,5	14	284,419	0,263	19240,3	560,6	75,7	21,1	663	221,2	13287,8
28	4242,9	1,4	14,7	288,662	0,267	18883,8	579,5	77,5	20,6	683,6	200	13487,8
29	3913,1	1,2	15,9	292,575	0,27	18923,9	598,4	79,3	20,5	704	184,3	13672,1
30	3519,2	1,1	17	296,094	0,274	18589,8	617	81,1	20	724	165,4	13837,5
31	2888,1	0,9	16,8	298,982	0,276	14733,5	631,7	80,4	15,8	739,8	133,9	13971,4
32	2637,1	0,8	18,5	301,619	0,279	14713	646,4	82,1	15,7	755,6	122,4	14093,8
33	2391,2	0,8	20,6	304,01	0,281	14404,6	660,8	83,4	15,3	770,9	111,1	14204,9
34	2104,1	0,7	22,8	306,114	0,283	13764,2	674,6	84,7	14,6	785,5	82,6	14287,5
35	1517,2	0,5	21,3	307,632	0,284	8217,7	682,8	81,5	8,8	794,2	71,3	14358,8
36	1387,6	0,4	24,8	309,019	0,286	8089,3	690,9	82,8	8,6	802,8	65,2	14424,1
37	1251,1	0,4	29,7	310,27	0,287	7832,5	698,7	84	8,3	811,1	58,8	14482,9
38	1138,5	0,4	38,4	311,409	0,288	7704,1	706,4	85,2	8,1	819,2	53,5	14536,4
39	980,6	0,3	53,7	312,389	0,289	7594,3	714	87,1	7,9	827,2	46,1	14582,5
40	845,1	0,3	100,1	313,234	0,289	7475,8	721,5	88,7	7,8	835	39,7	14622,2

Table 22.The pipelines calculation results for the fifth scheme of arrangement.

Parameter	Fifth					
	Pipeline from North part to the Dolginskoye base platform	Pipeline from South part to the Dolginskoye base platform	Pipeline from DPC to IRGBP Varandey-more	Pipeline from IRGBP Varandey-more IRGBP to Prirazlomnoe plat-form	Pipeline from IRUC to Me-dynskoye-more	Pipeline from Medynskoye-more IRGBP to Prirazlomnoe
Part 1						
Water depth [H], m	50	50	18	18	19	18
Length [L], m	5000	5000	33000	26000	8000	52000
Outside diameter [Do], mm	273,1	273,1	323,9	323,9	273,1	355,6
API 5L standard wall thicknesses [t], mm	9,3	9,3	9,5	9,5	9,3	9,5
Flow rate [Q], m3/day	40000	32500	10000	30000,00	25000	52500
Pressure drop [Δp], Mpa	9,85	6,67	1,74	11,26	6,03	41,55
Part 2						
Type of material	X65 steel	X65 steel	X65 steel	X65 steel	X65 steel	X65 steel
SMYS, Mpa	448	448	448	448	448	448
Design factor	0,72					
SMYS*design factor, Mpa	322,56	322,56	322,56	322,56	322,56	322,56
S_h, Mpa	608,34	608,34	558,57	558,57	476,09	882,40
Checking [SMYS*design factor≥S_h]	not OK	not OK	not OK	not OK	not OK	not OK
New standard wall thicknesses [t], mm	18,3	18,3	18,3	18,3	14,3	18,3
S_h, Mpa	309,53	309,53	290,64	290,64	314,89	459,03

Checking [SMYS*design factor≥S_h]	OK	OK	OK	OK	OK	not OK*
Part 3						
Axial tension [F_{axial}], kN	100	100	100	100	100	100
Bending moment [M], kNm	50	50	50	50	50	50
Design factor	0,8	0,8	0,8	0,8	0,8	0,8
Inertia moment [J], m^4	1,19E-04	1,19E-04	2,06E-04	2,06E-04	9,76E-05	2,76E-04
Bending stress [$\sigma_{bending}$], MN	57,17	57,17	39,36	39,36	69,96	32,16
Longitudial stress [σ_L], MN	58,87	58,87	40,57	40,57	71,67	33,17
Hoop stress [σ_h], MN	309,53	309,53	290,64	290,64	314,89	459,03
Equivalent stress [σ_{eq}], MN	284,69	284,69	272,63	272,63	272,63	443,38
SMYS*design factor	358,40	358,40	358,40	358,40	358,40	358,40
Checking [SMYS*design factor≥σ_{eq}]	OK	OK	OK	OK	OK	not OK*

*Notice: Due to long distance (52 km) from Medynskoye-more IRGBP to Prirazlomnoe oil field platform we got unacceptable results. We have to overcome these challenges and so that we should:

- select another type of steel to face a higher stresses;
- select bigger external diameter and wall thickness of the pipeline;
- decrease well head pressure and use pumps to transport hydrocarbons.

Table 23. Expenditures. Base case. Planned production level is 8 mlm. tones/year

№	Value	Costs for 30 years, bln.rub
1	**Capital expenditures, bln.rub/year**	
	Stationary platform on the Dolginskoye field	65
	Drilling units on the Dolginskoye field in quantity of 2 pieces	50
	Tankers for oil export from the Dolginskoye field in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Stationary platform on the Varandey more	65
	Drilling unit on the Varandey more in quantity of 1 piece	25
	Tankers for oil export from theVarandey more in quantity of 2	14,04
	Supply vessels in quantity of 2 pieces	6,48
	Stationary platform on the Medinskoye more	65
	Drilling unit on the Medinskoye more in quantity of 1 piece	25
	Tankers for oil export from the Medinskoye more in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Bringing a well into production	480
	Well equipment	23,04
	Onshore storage base	0,57
	Total investments on an annual basis, bln.rub	860,17
2	**Operating expenditures, bln.rub/year**	

Stationary platform on the Prirazlomnoye field	9,725
Tankers for oil export from the Prirazlomnoye field in quantity of 2	44,6
Supply vessels in quantity of 2 pieces	38,2
Stationary platform on the Dolginskoye field	2,003
Drilling units on the Dolginskoye field in quantity of 2	0,31
Tankers for oil export from the Dolginskoye field in quantity of 2	11,048
Supply vessels in quantity of 2	9,256
Stationary platform on the Varandey more	4,148
Drilling unit on the Varandey more in quantity of 1	0,98
Tankers for oil export from theVarandey more in quantity of 2	20,368
Supply vessels in quantity of 2	17,296
Stationary platform on the Medinskoye more	6,722
Drilling unit on the Medinskoye more in quantity of 1 piece	1,97
Tankers for oil export from the Medinskoye more in quantity of 2	31,552
Supply vessels in quantity of 2	26,944
Bringing a well into production	7,68
Well equipment	1,536
Onshore storage base	6,15
Total operating expenditures on an annual basis, bln.rub	264,488

Table 24. Calculations. Base case. Planned production level is 8 mlm. tones/year

Year	1	2	3	4	5	6	7	8	…	27	28	29	30
Oil production, mln.t/year	0,1	0,3	2	4	6	8	8	8		8	8	8	8
Cumulative oil production, mln.t.	0,1	0,4	2,4	6,4	12,4	20,4	28,4	36,4		188,4	196,4	204,4	212,4
Oil price, USD/barrel	80												
Revenue, bln.rub	2,09	5,70	41,76	83,52	125,28	167,04	167,04	167,04		167,04	167,04	167,04	167,04
Gross operational profit, bln.rub	-2,07	1,40	37,51	79,27	120,93	162,74	162,69	162,79		153,65	153,75	153,80	154,09
Tax on profits, bln.rub	-0,41	-0,28	-7,50	-15,85	-24,19	-32,55	-32,54	-32,56		-30,73	-30,75	-30,76	-30,82
After-tax profit, bln.rub	-2,48	1,12	30,01	63,42	96,75	130,19	130,15	130,23		122,92	123,00	123,04	123,27
Discount rate	0,893	0,797	0,712	0,636	0,567	0,507	0,452	0,404		0,047	0,042	0,037	0,033
Cumulative balance of the total flow, bln.rub	-5,67	-15,03	7,12	62,67	146,32	266,03	383,09	505,46		2202,49	2286,19	2372,55	2474,86
Discounted balance, bln.rub	-5,06	-7,46	15,76	35,31	47,46	60,65	52,95	49,42		3,68	3,50	3,23	3,41
NPV, bln.rub	-5,06	-12,52	3,24	38,55	86,01	146,66	199,61	249,03		539,96	543,46	546,69	**550,10**
Discounted Profitability Index	**2,29**												
Cash inflow, bln.rub	2,09	5,70	41,76	83,52	125,28	167,04	167,04	167,04		167,04	167,04	167,04	167,04
Discounted cash inflow, bln.rub	1,9	4,5	29,7	53,1	71,1	84,6	75,6	67,5		7,8	7,0	6,2	5,6
Total discounted cash inflow, bln.rub	**903,684**												
Cash outflow, bln.rub	-7,76	-15,06	-19,61	-27,96	-41,63	-47,33	-49,98	-44,67		-88,65	-83,34	-80,68	-64,73
Discounted cash outflow, bln.rub	-6,93	-12,00	-13,96	-17,77	-23,62	-23,98	-22,61	-18,04		-4,16	-3,49	-3,02	-2,16

Total discounted cash outflow, bln.rub	**353,6**	
Net profit margin of discrounted expences	**2,56**	
Net profit margin	**2,26**	

Table 25. Expenditures. Base case. Planned production level is 16 mlm. tones/year

№	Value	Costs for 30 years, bln.rub
1	**Capital expenditures, bln.rub/year**	
	Stationary platform on the Dolginskoye field	65,00
	Drilling units on the Dolginskoye field in quantity of	50,00
	Tankers for oil export from the Dolginskoye field in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Stationary platform on the Varandey more	65,00
	Drilling unit on the Varandeymore in quantity of 1 piece	25,00
	Tankers for oil export from theVarandeymore in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Stationary platform on the Medinskoye more	65,00
	Drilling unit on the Medinskoye more in quantity of 1	25,00
	Tankers for oil export from the Medinskoye more in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Bringing a well into production	87,50
	Well equipment	4,20
	Onshore storage base	0,57
	Total investments on an annual basis, bln.rub	448,83

2	**Operating expenditures, bln.rub/year**	
	Stationary platform on the Prirazlomnoye field Tankers for oil export from the Prirazlomnoye field in quantity of 2	10,73
	Supply vessels in quantity of 2 pieces	46,60
	Stationary platform on the Dolginskoye field	40,20
	Drilling units on the Dolginskoye field in quantity of 2 pieces	10,30
	Tankers for oil export from the Dolginskoye field in quantity of 2	7,92
	Supply vessels in quantity of 2	44,74
	Stationary platform on the Varandey more	38,59
	Drilling unit on the Varandey more in quantity of 1	11,15
	Tankers for oil export from theVarandey more in quantity of 2	4,29
	Supply vessels in quantity of 2	48,46
	Stationary platform on the Medinskoye more	41,81
	Drilling unit on the Medinskoye more in quantity of 1 piece	11,15
	Tankers for oil export from the Medinskoye more in quantity of 2	4,29
	Supply vessels in quantity of 2	48,46
	Bringing a well into production	41,81
	Well equipment	7,68
	Onshore storage base	1,54
	Total operating expenditures on an annual basis, bln.rub	6,15

Table 26. Calculations. Base case. Planned production level is 16 mln .tones/year

Year	1	2	3	4	5	6	7	8	…	27	28	29	30
Oil production, mln.t/year	0,1	0,3	2	4	6	8	10	12		16	16	16	16
Cumulative oil production, mln.t.	0,1	0,4	2,4	6,4	12,4	20,4	30,4	42,4		344,4	360,4	376,4	392,4
Oil price, USD/barrel	80												
Revenue, bln.rub	2,09	5,70	41,76	83,52	125,28	167,04	208,80	250,56		334,08	334,08	334,08	334,08
Gross operational profit, bln.rub	-2,07	1,40	33,16	70,37	111,79	153,84	191,47	233,37		321,51	321,51	325,58	329,64
Tax on profits, bln.rub	-0,41	-0,28	-6,63	-14,07	-22,36	-30,77	-38,29	-46,67		-64,30	-64,30	-65,12	-65,93
After-tax profit, bln.rub	-2,48	1,12	26,52	56,30	89,43	123,07	153,17	186,70		257,21	257,21	260,46	263,71
Discount rate	0,893	0,797	0,712	0,636	0,567	0,507	0,452	0,404		0,047	0,042	0,037	0,033
Cumulative balance of the total flow, bln.rub	-5,67	-15,03	-106,89	-168,97	-92,64	19,96	24,51	203,34		4982,41	5239,62	5500,08	5763,80
Discounted balance, bln.rub	-5,06	-7,46	-65,38	-39,46	43,31	57,04	2,06	72,23		12,06	10,77	9,74	8,80
NPV, bln.rub	-5,06	-12,52	-77,91	-117,36	-74,05	-17,00	-14,95	57,28		794,38	805,15	814,88	**823,69**
Discounted Profitability Index	**7,02**												
Cash inflow, bln.rub	2,09	5,70	41,76	83,52	125,28	167,04	208,80	250,56		334,08	334,08	334,08	334,08
Discounted cash inflow, bln.rub	1,9	4,5	29,7	53,1	71,1	84,6	94,4	101,2		15,7	14,0	12,5	11,2
Total discounted cash inflow, bln.rub	**1457,0**												
Cash outflow, bln.rub	-7,76	-15,06	-133,62	-145,60	-48,94	-54,45	-204,25	-71,72		-76,87	-76,87	-73,62	-70,36
Discounted cash outflow, bln.rub	-6,93	-12,00	-13,96	-17,77	-23,62	-23,98	-22,61	-18,04		-4,16	-3,49	-3,02	-2,16

Total discounted cash outflow, bln.rub	**353,6**	
Net profit margin of discrounted expences	**2,56**	
Net profit margin	**2,26**	

Table 27. Expenditures. Preferable case. Planned production level is 8 mlm. tones/year

№	Value	Costs for 30 years, bln.rub
1	**Capital expenditures, bln.rub/year**	
	Stationary platform on the Dolginskoye field	64,00
	Subsea units on the Dolginskoye field in quantity of 2	45,60
	Tankers for oil export from the Dolginskoye field in quantity of 2	12,04
	Supply vessels in quantity of 2	4,48
	Stationary platform on the Varandey more	64,00
	Drilling unit on the Varandeymore in quantity of 1	22,80
	Tankers for oil export from theVarandeymore in quantity of 2	12,04
	Supply vessels in quantity of 2	4,48
	Stationary platform on the Medinskoye more	64,00
	Drilling unit on the Medinskoye more in quantity of 1 piece	22,80
	Tankers for oil export from the Medinskoye more in quantity of 2	12,04
	Supply vessels in quantity of 2	4,48
	Bringing a well into production	576,00
	Well equipment	38,40
	Onshore storage base	0,57
	Pipelines to the subsea units	19,22

	Total investments on an annual basis, bln.rub	987,95
2	**Operating expenditures, bln.rub/year**	
	Stationary platform on the Prirazlomnoye field	9,73
	Tankers for oil export from the Prirazlomnoye field in quantity of 2	44,60
	Supply vessels in quantity of 2	38,20
	Stationary platform on the Dolginskoye field	2,00
	Subsea units on the Dolginskoye field in quantity of 2	0,20
	Tankers for oil export from the Dolginskoye field in quantity of 2	11,05
	Supply vessels in quantity of 2	9,26
	Stationary platform on the Varandey more	4,15
	Drilling unit on the Varandey more in quantity of 1	0,98
	Tankers for oil export from theVarandey more in quantity of 2	20,37
	Supply vessels in quantity of 2	17,30
	Stationary platform on the Medinskoye more	6,72
	Drilling unit on the Medinskoye more in quantity of 1 piece	1,90
	Tankers for oil export from the Medinskoye more in quantity of 2	31,55
	Supply vessels in quantity of 2	26,94
	Bringing a well into production	9,60

	Well equipment Onshore storage base Pipelines' maintenance	1,54 6,15 0,35
	Total operating expenditures on an annual basis, bln.rub	266,58

Table 28. Calculations. Preferable case. Planned production level is 8 mln .tones/year

Year	1	2	3	4	5	6	7	8	…	27	28	29	30
Oil production, mln.t/year	0,1	0,3	2	4	6	8	8	8		8	8	8	8
Cumulative oil production, mln.t.	0,1	0,4	2,4	6,4	12,4	20,4	28,4	36,4		188,4	196,4	204,4	212,4
Oil price, USD/barrel	80												
Revenue, bln.rub	2,09	5,70	41,76	83,52	125,28	167,04	167,04	167,04		167,04	167,04	167,04	167,04
Gross operational profit, bln.rub	-2,08	1,36	37,48	79,24	120,88	162,70	162,64	162,76		153,34	153,46	153,57	153,63
Tax on profits, bln.rub	-0,42	-0,27	-7,50	-15,85	-24,18	-32,54	-32,53	-32,55		-30,67	-30,69	-30,71	-30,73
After-tax profit, bln.rub	-2,49	1,09	29,98	63,39	96,71	130,16	130,11	130,21		122,67	122,77	122,86	122,91
Discount rate	0,893	0,797	0,712	0,636	0,567	0,507	0,452	0,404		0,053	0,047	0,042	0,037
Cumulative balance of the total flow, bln.rub	-6,26	-17,97	2,41	56,20	136,91	254,27	368,38	488,99		2094,86	2169,72	2247,82	2345,41
Discounted balance, bln.rub	-5,59	-9,34	14,51	34,19	45,80	59,46	51,62	48,71		3,21	3,13	2,92	3,26
NPV, bln.rub	-5,59	-14,93	-0,42	33,77	79,56	139,02	190,64	239,35		520,37	523,50	526,42	**529,68**
Discounted Profitability Index	**3,27**												
Cash inflow, bln.rub	2,09	5,70	41,76	83,52	125,28	167,04	167,04	167,04		167,04	167,04	167,04	167,04
Discounted cash inflow, bln.rub	1,9	4,5	29,7	53,1	71,1	84,6	75,6	67,5		7,8	7,0	6,2	5,6
Total discounted cash inflow, bln.rub	**903,684**												
Cash outflow, bln.rub	-8,35	-17,41	-21,38	-29,73	-44,57	-49,68	-52,92	-46,43		-98,67	-92,18	-88,93	-69,45
Discounted cash outflow, bln.rub	-7,45	-13,88	-15,21	-18,89	-25,29	-25,17	-23,94	-18,75		-4,63	-3,86	-3,32	-2,32

Total discounted cash outflow, bln.rub	**374,0**	
Net profit margin of discrounted expences	**2,42**	
Net profit margin	**2,12**	

Table 29. Expenditures. Preferable case. Planned production level is 16 mlm. tones/year

№	Value	Costs for 30 years, bln.rub
1	**Capital expenditures, bln.rub/year**	
	Stationary platform on the Dolginskoye field	65,00
	Subsea units on the Dolginskoye field in quantity of 2	47,60
	Tankers for oil export from the Dolginskoye field in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Stationary platform on the Varandey more	65,00
	Drilling unit on the Varandeymore in quantity of 1	23,80
	Tankers for oil export from theVarandeymore in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Stationary platform on the Medinskoye more	65,00
	Drilling unit on the Medinskoye more in quantity of 1 piece	23,80
	Tankers for oil export from the Medinskoye more in quantity of 2	14,04
	Supply vessels in quantity of 2	6,48
	Bringing a well into production	105,00
	Well equipment	7,00
	Onshore storage base	0,57
	Pipelines to the subsea units	21,22

	Total investments on an annual basis, bln.rub	464,33
2	**Operating expenditures, bln.rub/year**	
	Stationary platform on the Prirazlomnoye field	10,73
	Tankers for oil export from the Prirazlomnoye field in quantity of 2	46,60
	Supply vessels in quantity of 2	40,20
	Stationary platform on the Dolginskoye field	10,30
	Subsea units on the Dolginskoye field in quantity of 2	7,54
	Tankers for oil export from the Dolginskoye field in quantity of 2	44,74
	Supply vessels in quantity of 2	38,59
	Stationary platform on the Varandey more	11,15
	Drilling unit on the Varandey more in quantity of 1	4,29
	Tankers for oil export from theVarandey more in quantity of 2	48,46
	Supply vessels in quantity of 2	41,81
	Stationary platform on the Medinskoye more	11,15
	Drilling unit on the Medinskoye more in quantity of 1 piece	4,16
	Tankers for oil export from the Medinskoye more in quantity of 2	48,46
	Supply vessels in quantity of 2	41,81
	Bringing a well into production	9,60

	Well equipment	1,54
	Onshore storage base	6,15
	Pipelines' maintenance	1,25
	Total operating expenditures on an annual basis, bln.rub	427,27

Table 30. Calculations. Preferable case. Planned production level is 16 mln .tones/year

Year	1	2	3	4	5	6	7	8	…	27	28	29	30
Oil production, mln.t/year	0,1	0,3	2	4	6	8	10	12		16	16	16	16
Cumulative oil production, mln.t.	0,1	0,4	2,4	6,4	12,4	20,4	30,4	42,4		344,4	360,4	376,4	392,4
Oil price, USD/barrel	80	80	80	80	80	80	80	80		80	80	80	80
Revenue, bln.rub	2,09	5,69	41,74	83,48	125,21	166,95	208,69	250,43		333,90	333,90	333,90	333,90
Gross operational profit, bln.rub	-2,08	1,36	33,04	70,14	111,47	153,55	191,19	233,10		321,36	321,36	325,42	329,48
Tax on profits, bln.rub	-0,62	-0,41	-9,91	-21,04	-33,44	-46,07	-57,36	-69,93		-96,41	-96,41	-97,63	-98,85
After-tax profit, bln.rub	-2,70	0,95	23,13	49,10	78,03	107,49	133,84	163,17		224,95	224,95	227,79	230,64
Discount rate	0,893	0,797	0,712	0,636	0,567	0,507	0,452	0,404		0,047	0,042	0,037	0,033
Cumulative balance of the total flow, bln.rub	-6,47	-18,32	-114,11	-183,94	-121,9	-27,22	-42,51	111,07		4283,85	4508,80	4736,60	4967,23
Discounted balance, bln.rub	-5,78	-9,45	-68,18	-44,37	35,20	47,97	-6,91	62,03		10,55	9,42	8,52	7,70
NPV, bln.rub	-5,78	-15,22	-83,41	-127,78	-92,58	-44,61	-51,53	10,50		652,85	662,27	670,79	**678,49**
Discounted Profitability Index	**7,28**												
Cash inflow, bln.rub	2,09	5,69	41,74	83,48	125,21	166,95	208,69	250,43		333,90	333,90	333,90	333,90
Discounted cash inflow, bln.rub	1,9	4,5	29,7	53,1	71,0	84,6	94,4	101,1		15,7	14,0	12,5	11,1
Total discounted cash inflow, bln.rub	**1456,2**												
Cash outflow, bln.rub	-8,56	-17,54	-137,53	-153,30	-63,19	-72,26	- 223,98	-96,85		-108,95	-108,95	-106,11	-103,27
Discounted cash outflow, bln.rub	-7,64	-13,99	-97,89	-97,43	-35,85	-36,61	-101,3	-39,12		-5,11	-4,56	-3,97	-3,45

Total discounted cash outflow, bln.rub	**777,7**	
Net profit margin of discrounted expences	**1,87**	
Net profit margin	**2,36**	