Development of Arctic double acting shuttle tankers for the Prirazlomnoye project

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ABSTRACT

In April 2006, JSC Sevmorneftegaz (a wholly owned subsidiary of Gazprom), JSC Sovcomflot and FSUE Admiralty Shipyards signed a trilateral contract for the construction of two 70,000 tonne deadweight double acting Arctic shuttle tankers.

The ships have been designed for crude oil transportation between the Prirazlomnoye oil field development in the Pechora Sea and a Floating Storage and Offloading (FSO) unit moored off Murmansk.

The southern Pechora Sea in the vicinity of the Prirazlomnaya platform is covered in ice during the winter navigation season with ice first forming in November and sea ice cover can last until June. During "*hard*" winter seasons sea ice can form over 1.2 metres in thickness and temperatures can fall as low as minus 40˚C.

The hull form for the Prirazlomnoye tankers was developed by Aker Arctic Technology Inc. (AARC), based upon a double acting operation principle, for year round independent navigation in seasonal "*average*" ice conditions. The basic design package for the project has been supplied to FSUE Admiralty Shipyards by Aker Arctic Technology, Inc.

Dimensioning of hull structures for ice strengthening for the ships is in accordance with RS ice category LU6, with the stern of the vessel strengthened for bow design ice loads for double acting operation. The shuttle tankers are to be dual classed by Russian Maritime Register of Shipping and Lloyd's Register on delivery in 2009.

This is a paper on a unique shuttle tanker project now being built for year round oil export from the Pechora Sea, and the purpose of the paper is to introduce some of the technical characteristics of the project to the TSCF members.

The paper will describe the development of the shuttle transportation concept, winter season shuttle tanker operations, the layout and arrangement of the ships as well as key design features. The paper will also address the design of the hull structure for seasonal ice conditions as well as the selection of materials for low ambient temperatures.

It is intended that the paper will provide a reference document for follow on papers on the construction and in-service performance of the shuttle tankers, after entry into service, at a future TSCF meeting.

1 INTRODUCTION

This is a paper on a unique Arctic shuttle tanker project for independent navigation in winter season ice conditions to transport oil from the Prirazlomnaya oil production platform to a floating storage and offloading unit (FSO) unit moored in open water off the port of Murmansk. The tankers are now being constructed at FSUE Admiralty shipyards.

The purpose of this paper is:

- To provide the TSCF members and the shipbuilders meeting delegates a broad based introduction to the technical characteristics of the Prirazlomnoye shuttle tanker project
- To provide a public domain reference paper for a future paper detailing the construction and in-service performance of the shuttle tankers.

The paper addresses specific aspects of the design of the Prirazlomnoye shuttle tankers which may be of interest to TSCF members and shipbuilder meeting delegates, including:

- Development of the shuttle tanker design concept
- Winter season shuttle tanker operations
- Hull ice performance and model tests
- Comparison of the particulars of the Prirazlomnoye shuttle tankers with other recent Arctic and double acting tankers
- Descriptions of the general arrangement and midship section
- Hull ice strengthening and selection of materials

Notable aspects of the Prirazlomnoye shuttle tanker project include:

- It brings together and combines, in one project, the experience of the maritime industries of Russia in the design, build and operation of specialist ice-strengthened Arctic ships. This includes:
    - a leading operator of this type of ship, JSC Sovcomflot
    - a leading shipbuilder, FSUE Admiralty Shipyards
    - a leading Classification Society, Russian Maritime Register of Shipping.

- It draws on the best practices of JSC Sovcomflot for new-building specification, drawing approval and supervision from the in-house projects team of Unicom

- Through co-operation with the FSUE Admiralty Shipyards the most experienced designers of large double acting ships are involved with the participation of Aker Arctic Technology Inc. (AARC) and ABB.

- Through co-operation with Russian Maritime Register of Shipping the involvement of Lloyd's Register brings best classification practice for commercial oil tankers, which includes double acting tanker experience.

- It is also a very significant technological reference project in the Arctic shuttle tanker sector and for Russian shipbuilding which aligns with the plan for Russian shipbuilding industry to *"... develop, design, manufacture, (and) supply ... civilian shipping for the development of the (Russian) continental shelf ..."*

2 PRIRAZLOMNOYE OIL FIELD DEVELOPMENT

The two 70,000 deadweight Arctic tankers under construction at FSUE Admiralty Shipyards are intended to provide a year round shuttle service for crude oil transportation between the Prirazlomnoye oil field development and a Floating Storage and Offloading (FSO) unit moored off Murmansk.

The development of the oil field, the fixed ice resistant Prirazlomnoya platform, as well as the planned shuttle tanker operations are described in this section.

2.1 Prirazlomnoye oil field

The Prirazlomnoye oil field was discovered in 1989. It is located on the Pechora Sea shelf and is north of Varandey, about 50 km offshore. The water depth at the field location is 19 to 20 metres on average.

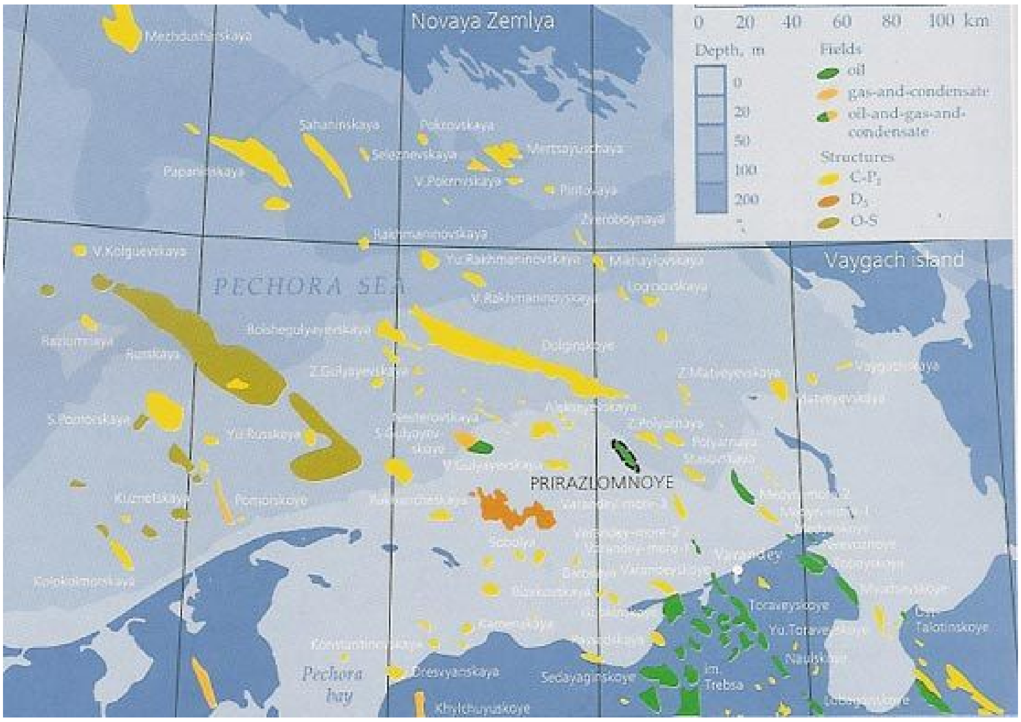


Fig. 1, Prirazlomnoye oil field location (*courtesy of offshore-technology.com*)

The total production estimates for the Prirazlomnoye oil field development is 75 million tonnes. Oil production is planned for a period of 25 years with a peak annual production of just over 6.5 million tonnes. For the development of the oil field a fixed ice resistant platform with oil storage facilities is to be installed.

2.2 Prirazlomnaya oil production platform

The Prirazlomnaya platform, is a fixed ice resistant steel structure designed for year round operation in the Pechora Sea, and is the first of its kind to be constructed in Russia.

Construction work for the Prirazlomnaya platform is being carried out by FSUE Sevmash in Severodvinsk on the White Sea and includes:

- Repairs and upgrades to existing topside structures and process plant from a UK North Sea sector production platform, the "*Hutton*" tension leg platform.
- Construction of an ice-resistant caisson, from four steel block sections.
- Fitting of the upgraded production and process plant topsides to the ice-resistant caisson.

These construction works were completed by FSUE Sevmash during the second half of 2006, and platform outfitting is on-going with the installation of additional equipment and modules. Fig 2 shows an exploded view of the components of the Prirazlomnaya platform and an impression of the installed platform in the Pechora Sea.

On site installation and commissioning of the Prirazlomnaya platform is planned during 2009, major activities for installation include drilling of forty production oil wells and loading of about 400,000 tonnes of solid ballast.

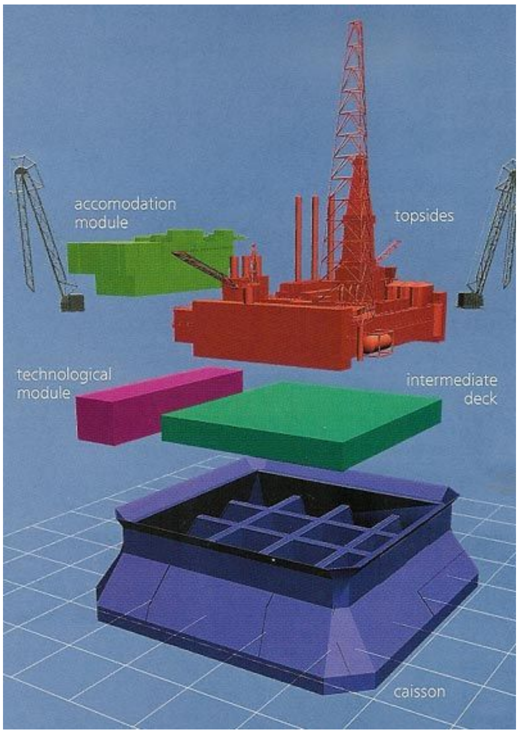


Fig. 2, Exploded view of components of the Prirazlomnaya platform (*left above*), and an impression of the installed platform in the Pechora Sea (*right above*) (*courtesy of offshore-technology.com*)

Daily oil production and storage capacity is planned (Badikov, 2007) as follows:

- Daily oil production capacity: 20,750 m^3 per day
- Caisson crude oil storage capacity for five days continuous production: 108,800 m^3

Some characteristics of the caisson structure for the Prirazlomnaya platform are (Badikov, 2007) as follows:

- Maximum caisson square section dimensions: 126 m x 126 m
- Floating displacement without solid ballast: 110,000 tonnes
- Platform mass when ballasted onto sea-bed berm with solid ballast: 506,000 tonnes

2.3 *Oil export from Prirazlomnaya platform by specialist shuttle tanker*

The two Arctic tankers have been designed for independent navigation in seasonal ice conditions found in the Pechora Sea on the shuttle route between the Prirazlomnaya platform and an FSO unit moored in year round ice free water off Murmansk. Offloading of oil to open water export is planned by using Aframax tankers from the FSO.

The planned operational cycle for the shuttle tankers includes:

- Cargo loading, through a bow loading system connected to the Prirazlomnaya platform, with maximum loading rate of 10,000 m^3 per hour at a specified cargo density of 0,834 t/m^3;
- Cargo transportation from the Prirazlomnoye oil field to the FSO unit moored off Murmansk;
- Cargo discharge with a maximum discharge rate of 8,600 m^3 per hour (corresponding to a 12 hour discharge time including stripping) from the shuttle tanker into the FSO via side manifolds.

Fig. 3, Artist impression of the Prirazlomnaya production platform and shuttle tanker (*courtesy of AARC*)

For oil offloading operations from Prirazlomnaya, as shown in the artist impression (Fig. 3), the shuttle tanker will sail into the polynya formed in the ice field in the lee of the platform. The oil offloading complex of Prirazlomnaya incorporates two offloading arms arranged at opposite corners of the platform. Connection is made between the tanker bow loading system and the offloading loading arm when the tanker is maneuvered close to the platform. For station keeping, during oil loading operations with the shuttle tanker in the polynya, a dynamic positioning system is fitted.

Maximum cargo loading rates for the shuttle tankers have been specified to achieve full cargo loading from the Prirazlomnaya platform within a typical interval of time between shifts in the direction of movement of the ice field due to the prevailing wind and currents. This is to mitigate any possible downtime of the tanker for disconnection and reconnection with the lee corner offloading arm that would occur with ice field movements.

3 WINTER SEASON AND ICE NAVIGATION IN THE PECHORA SEA

The southern Pechora Sea in the vicinity of the Prirazlomnaya platform is covered in ice during the winter navigation season with ice first forming in November and sea ice cover can last until June. During "*hard*" winter seasons thick sea ice can form over 1.2 metres in thickness and temperatures can fall as low as minus 40˚C.

This section briefly describes the sea ice and cold temperatures of the winter in the Pechora Sea, and some considerations for the selection of routes for winter navigation of the Prirazlomnoye shuttle tankers.

3.1 Pechora Sea ice conditions

ArcOp project report D3.1.3 (Saarinen et al, 2003) presents an analysis of the ice conditions of the Pechora Sea based upon long term historical measurements and ice charts prepared by the hydro-meteorological service of Russia.

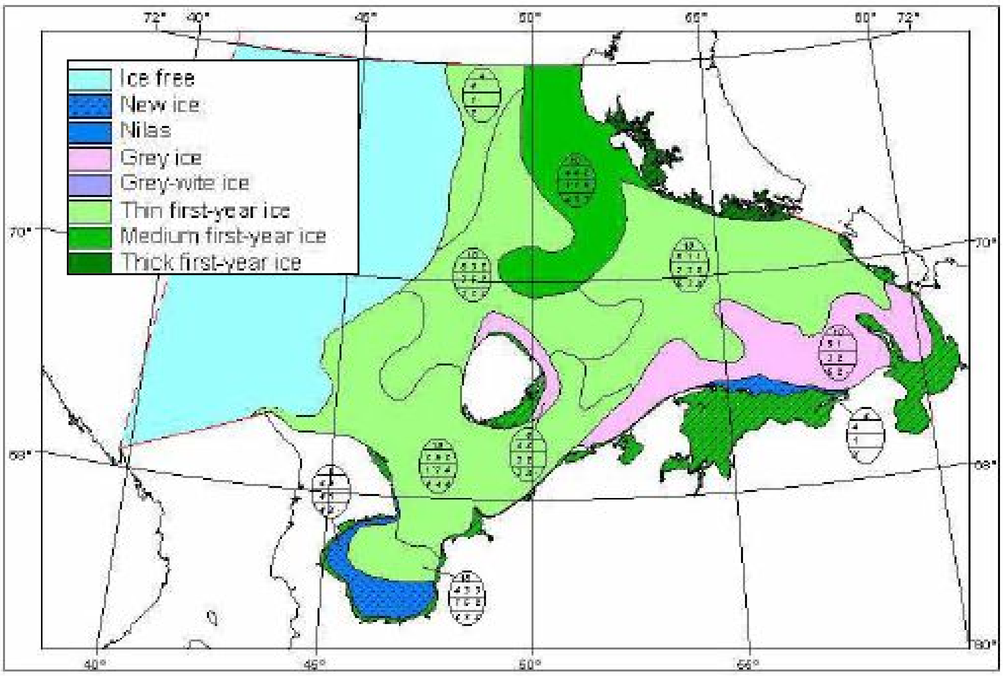
Ice conditions in the ArcOp report analysis were categorized into "*easy*", "*average*" and "*hard*" seasons, and seasonal ice formation in the Pechora Sea can be briefly summarised as follows:

- Thin (30-70 cm) first-year ice occurs in the Pechora Sea as late as February in "*easy*" seasons. During an "*average*" or "*hard*" winter season the initial formation of thin ice can occur in November.

- Medium (70-120 cm) first-year ice forms in March during an "*average*" winter season as shown in olive green in the ice chart, Fig 4.

- Thick first-year ice (>120 cm) is observed only in "*hard*" winter seasons in the Pechora Sea during the period April through June. In "*hard*" winter seasons high concentrations of thick first year ice mainly occur in the northern parts of the Pechora Sea near Novaya Zemyla

Fig. 4, Sea ice chart for "*average*" winter season for March (*courtesy of AARC, AARI*)



The Fig. 5 satellite photograph of the Pechora Sea in April 2002 gives a better impression of the sea ice conditions for an "average" season.

Fig. 5, Satellite photo of ice conditions during an "*average*" winter season in the Pechora Sea, April 2002 (*courtesy of NASA visible earth website*)

3.2 Ambient air temperatures in the Pechora Sea during the winter season

Ambient air temperatures for the Southern Pechora Sea area can be determined based upon recorded observations taken at the Varandey hydro-meteorological station (HMS), located on the shore of the Pechora Sea approximately 50 km south of the Prirazlomnoye oil field.

Monthly mean average air temperatures in the ArcOp project report (Saarinen et al, 2003) were calculated based on the absolute maximum and minimum temperatures for each month and from observations taken over a 40 year time period.

Every year there are eight months when the monthly mean average air temperatures fall below 0°C. Table 1 shows the monthly mean average air temperatures and the lowest observed air temperatures (at a standard time of observation) for the six coldest months, November to April.

Temperature °C	November	December	January	February	March	April
Mean monthly average	-9.8	-5.8	-19.2	-18.9	-14.4	-11.0
Lowest observed	-35	-44	-43	-44	-41	-37

Table 1, Monthly mean and lowest air temperature observations for the six coldest months at Varandey *(courtesy of AARC, AARI)*

The lowest monthly mean average air temperature is approximately -19°C based upon historical observed data for the months of January and February.

3.3 Navigation routes in ice during the winter season

Depending upon the winter season ice conditions, it is envisaged that the shuttle tankers will sail on one of three routes, central, northern or southern, in a fully loaded condition from the Prirazlomnaya platform and in ballast condition on a return voyage.

The three routes vary in length from approximately 900 to 950 kilometres with the central shuttle route being the shortest, see Fig. 6.

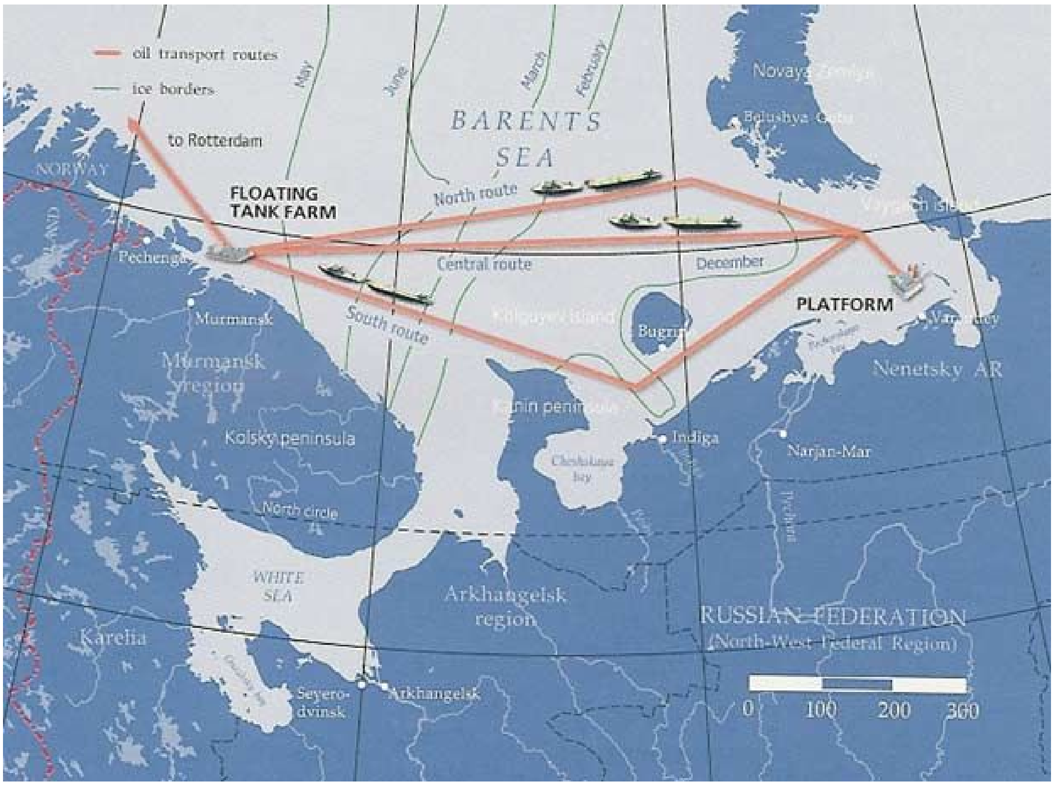


Fig. 6, Sketch of central, northern and southern Shuttle tanker routes
(*courtesy of offshore-technology.com*)

Young ice prevails in the Pechora Sea in the early winter navigation season and there is little need to consider ship routeing through the ice field as the shuttle tankers can maintain service speed without difficulty in such ice conditions.

After February, however, consideration needs to be given to ship routeing due to the formation of thicker first-year ice and as the conditions differ between each route, e.g. the formation of polynyas, medium and thick ice concentrations, ridged ice zones etc. This is to maintain the ship speeds in ice on each loaded and ballast passage, and to keep voyage times within the planned shuttle service schedule.

The length of the longest voyage in ice can vary depending on ice conditions in the Pechora Sea with longer voyages in ice occurring on the central and northern shuttle routes during "*average*" and "*hard*" winters. The longest voyage in ice of any route and seasonal ice condition is over 600 kilometres and occurs during April and May for the northern route in a *"hard"* winter.

Table 2, below, is a simple summary of the longest voyages in ice for the three shuttle tanker routes in "*easy*", "*average*" and "*hard*" winter navigation seasons based upon the ArcOp D3.1.3 report (Saarinen et al, 2003).

Table 2, Longest voyages in ice for the three shuttle tanker routes for different ice conditions

<table>
<tr><th colspan="2"></th><th colspan="8">Month of operation during winter season</th></tr>
<tr><th>Seasonal Ice Condition</th><th>Route</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th></tr>
<tr><td rowspan="3">Easy</td><td>Southern</td><td colspan="8">Longest voyage in ice</td></tr>
<tr><td>Central</td><td colspan="8" rowspan="2">Selection of optimum route in "easy" seasonal conditions to maintain ship speed in ice</td></tr>
<tr><td>Northern</td></tr>
<tr><td rowspan="3">Average</td><td>Southern</td><td colspan="5">Longest voyage in ice</td><td colspan="3"></td></tr>
<tr><td>Central</td><td colspan="8">Selection of optimum route in "average" seasonal conditions to maintain ship speed in ice</td></tr>
<tr><td>Northern</td><td colspan="5"></td><td colspan="3">Longest voyage in ice</td></tr>
<tr><td rowspan="3">Hard</td><td>Southern</td><td colspan="3">Longest voyage in ice</td><td colspan="5"></td></tr>
<tr><td>Central</td><td colspan="7">Selection of optimum route in "hard" seasonal conditions to maintain ship speed in ice</td><td>Longest voyage in ice</td></tr>
<tr><td>Northern</td><td colspan="3"></td><td colspan="4">Longest voyage in ice (April & May > 600 km)</td><td></td></tr>
</table>

An example of ship routeing is shown in Fig. 7 ice chart overleaf for a "*hard*" winter season. The northern route offers the easiest sailing conditions in ice with the best chance of maintaining service speed.

In this example (of the northern sailing route of the shuttle tanker in the "*hard*" conditions), the ship will operate in an open water polynya (south of Novaya Zemyla, Kara Gate and Vaygach Island) and then sail in grey and thin first-year ice conditions, as shown in the Fig. 7 ice chart, until at approximately 47^0 latitude the tanker encounters a narrow field of medium and hard first-year ice conditions.

For this case the double acting shuttle tanker could be operated bow ahead in the grey and thin ice conditions, and then turned so as to operate astern in the medium and heavy first-year ice encountered west of Kolguyev Island.

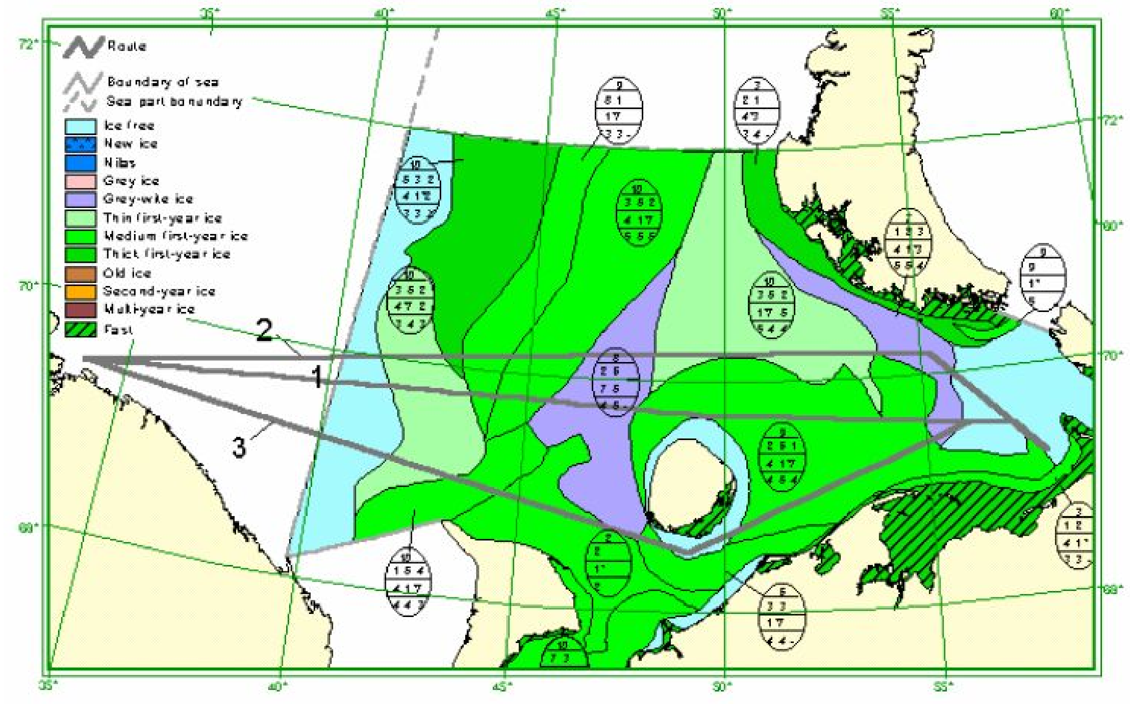


Fig. 7, Central (1), northern (2) and southern (3) shuttle routes superimposed on a "*hard*" season ice chart (*courtesy of AARC, AARI*)

4 HULL ICE PERFORMANCE AND ICE MODEL TESTS

The shuttle tanker hull form was developed based upon a double acting operation principle. Ice model tests of the shuttle tanker hull form were carried out by AARC in 2005 with the objective of evaluating the ice going capability of the hull form as well as verifying full scale performance with the specification.

In this section we consider the double acting operation principle, the specified ice going performance of the shuttle tankers and the verification of the performance by ice model testing.

4.1 Double-acting operation principle

The double-acting principle was developed, and patented, by Aker Arctic Technology (AARC) (Juurmaa et al, 2001). For the Prirazlomnoye shuttle tankers the hull form is optimised for two modes of operation in first-year ice conditions:

- Astern operation in medium and thick first-year ice
- Ahead operation in thin and young ice conditions and open water

In a conventional hull form designed for operation in ice there has typically been a compromise in hull performance between open water (and thin ice hull performance) and hull performance in more severe ice conditions.

A double acting ship draws on operating experience and knowledge of the improved ice going performance of existing icebreakers arranged with bow propellers. The two basic hull-ice interaction mechanisms for improved ice going performance are (Heideman et al, 1996):

- Decreased hull ice resistance; due to "*washing*", or "*lubrication*", of the hull by the wake of the bow propeller
- Improved hull icebreaking performance; due to a slight pressure drop that occurs just ahead of the icebreaker due to water flow into the bow propeller

The first effect of hull washing by the wake of the bow propeller can be seen in underwater photographs of a self propelled model in an ice model test, see Fig. 8. These photographs show noticeably less broken ice along the bottom of the hull due to the wake of the bow propeller.

Fig. 8, Photographs from underneath a self propelled model in level ice showing fewer pieces of broken ice along the hull bottom due to the washing effect of the propeller wake
(*courtesy of Helsinki University of Technology*)

The propulsion solution chosen for the Prirazlomnoye Shuttle tanker for double acting operation is to fit twin Azipods (**Azi**muthing **Po**dded **D**rive). An Azipod is a podded, electric propulsion unit that rotates (azimuths) through a full 360^0 circle, and incorporates an electric motor and direct-drive propeller that allows full torque to be developed over the full speed range.

In operation it has been demonstrated that Azipods enable the ship to penetrate and cross ridged ice when running astern with a continuous slow speed, rather than ramming (the usual operational practice when crossing ice ridges when running ahead). The basic hull-ice interaction mechanisms, for ridge penetration and crossing ridges in astern operation with Azipods, is the flushing and milling of the submerged surface of the ice ridge by side to side turning of the Azipod units.

4.2 Shuttle tanker hull form and specified ice performance

The underwater hull form incorporates an icebreaking bow for operation ahead in young ice and thin first year ice conditions. As the tanker is designed for international trade, the bow shape is derived from a compromise of both ice operational performance as well as open water sea-keeping and performance in the Barents Sea and North Atlantic (for possible shuttle voyages from Murmansk in open water to European refineries).

The adopted bow form is a notable difference between the Prirazlomnoye project shuttle tankers and the Varandey project shuttle tankers being constructed for Pechora Sea service. In the case of the Varandey project a Forward & Aft Icebreaking concept has been adopted (Iyerusalimskiy, 2007**)** with an icebreaking bow form optimized for ice-breaking in medium and thick first-year ice conditions, and the difference between bow designs for the projects may be attributed to the different open water performance requirements of the two projects

For operation astern in medium and thick first-year ice conditions the stern of the Prirazlomnoye shuttle tanker is arranged with twin skegs and Azipods (**Azi**muthing **Po**dded **D**rive). The stern hull lines continue aft above the deepest load waterline (13.6 metre) for six frames before transition to a vertical transom stern.

The specified ice-going performance of the Prirazlomnoye shuttle tanker is as follows:

- 3 knots speed astern in first year level ice, 1.2 m thickness with 0.2 m of snow layer.
- 3 knots speed ahead in first year level ice, 0.5 m thickness.

Views of the bow and stern configuration of the hull are also shown in the Fig. 9 photographs of the model, used in the programme of ice model tests conducted at AARC in 2005.

Fig. 9, Photographs of bow and stern of shuttle tanker of 1:28 self-propelled model *(courtesy of AARC)*

4.3 Ice model testing

Ice model tests provide an accurate means to determine full scale performance of the hull in ice, this includes both hull/ice interaction characteristics of the hull as well as prediction of full scale performance in ice.

Ice model tests for the Prirazlomnoye shuttle tanker hull form were carried out in March and April 2005 with the objective of evaluating the ice going capability of the shuttle tanker and verifying the specified ice performance.

A 1:28 scale self propelled model was tested in the 60 metre long test section of the old AARC (former MARC) ice model basin in Helsinki. A self propelled model was chosen as model behaviour, including ice breaking characteristics, will more accurately simulate the ship in full scale. The predicted full scale speeds in level ice, based upon the ice model tests, exceeded the specification requirements as shown in Table 3.

Ice going capability of shuttle tanker	**Predicted full scale ship speed in level ice, knots**		**Full scale level ice conditions**
	Design draught	Ballast draught	
Ahead	5.0	-	0.5 metre thickness
Astern	3.9	4.6	1.2 metre thickness + 20 cm of snow

Table 3, Predicted full scale speed in level ice

The full test programme for the Prirazlomnoye shuttle tanker hull form considered a variety of different ice conditions and operational modes. The test programme is summarized in Table 4 below. An underwater view of the stern area and Azipods during a self propelled test astern in level ice is shown in Fig. 10.

Model test	**Astern**	**Ahead**	**Model test parameters**	**Model test simulation**	**Model test observations & predictions**
Level ice	✓	✓	1. Ship draught 2. Level ice thickness 3. Power	Simulation of ship operation in unbroken level ice	1. Ship speed performance in level ice 2. Hull resistance in level ice
Broken ice channel	✓	✓	1. Ship draught 2. Level ice thickness before preparation of channel in ice	Simulation of operation of ship with icebreaker assistance in narrow broken ice channel	1. Ship speed performance in broken ice channel 2. Hull ice resistance in broken ice channel
Break out of ice channel	✓	✓	1. Ship draught 2. Level ice thickness	Simulation of maneuvering in ship's own broken ice channel	1. Time and length needed for hull to turn out from channel
Ice ridge	✓	-	1. Ship draught 2. Ridge depth	Simulation of penetration and crossing of ice ridge	1. Ship speed performance in ridged ice 2. Hull ice resistance in ridged ice

Table 4, Summary of the ice model test programme for the Prirazlomnoye shuttle tanker

The predicted full scale speeds in a broken ice channel were found to be higher than those predicted for full scale operation in level ice e.g. 7.5 knots in full scale for astern operation in a broken ice channel. Maneuvering performance was confirmed with the model shuttle tanker hull able to break out of its own channel in astern operation. The model shuttle tanker hull was also able to penetrate ridges with full scale keel depth of 15 metres by running astern with a continuous slow astern speed and side to side turning of the Azipod units.

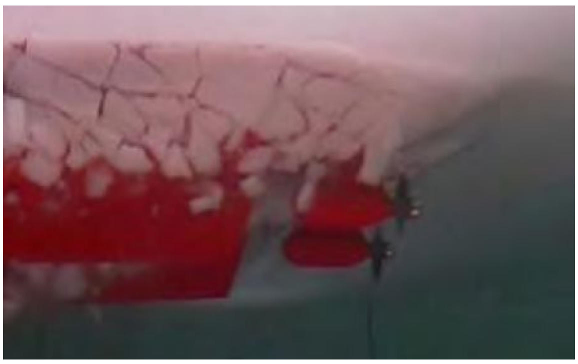


Fig. 10, Stern area during self propelled test astern in level ice at design draught *(courtesy of AARC)*

5. DESIGN CONCEPT, PRINCIPAL PARTICULARS AND ARRANGEMENTS

In this section we consider the origins of the shuttle tanker design concept. The principal particulars of the Prirazlomnoye shuttle tankers under construction at FSUE Admiralty Shipyards are compared with other recent Arctic and double acting ship projects. A description of the general arrangement, including figures, is included as well as a description of the midship section.

5.1 Shuttle tanker design concept

The original concept for the tankers was first discussed between Gazprom, Neste Shipping and Kvaerner Masa-yards in the mid 1990's after successful experimental Northern Sea Route voyages of the tanker "*Uikku*", which was the first-ever ship to have a high ice class pod drive installed.

The original plan for shuttle export service for the Prirazlomnoye oil field was based on a stern loading 15 metre draught Aframax size ship for which the parties developed full contractual design and documentation and performed both open water and ice model tests.

A Letter of Intent (LOI) was reached for building the first ship at Kvaerner Masa-Yards, and for operating it through a joint venture company to-be-established "*Gaznemarc*", with the ship to be used prior to the Prirazlomnoye platform installation in shuttle service for Neste Oil from North Sea oil fields.

After the August 1998 financial crises in Russia this plan could not proceed. The plans were gradually changed and Gazprom established the subsidiary JSC Sevmorneftegaz, who in turn in 2003 launched an international tender for the construction of two smaller ships.

Selection of the smaller ships was over concern with the draught and the stern loading effects in the shallow platform location where there was a risk of flushing of the supporting berm for the ice resistant platform. Consequently the concept ship was reduced in size with a draught less than 14 metres and with a bow loading system.

Based on a successful bid JSC Sevmorneftegaz awarded the construction contract at the end of 2004 to FSUE Admiralty Shipyards. Later on JSC Sevmorneftegaz started working towards a COA arrangement and this international tender was won by JSC Sovcomflot and the original shipbuilding contract was modified.

In April 2006, JSC Sevmorneftegaz, JSC Sovcomflot and FSUE Admiralty Shipyards signed a trilateral contract for the building of two 70,000 tonne deadweight double acting Arctic shuttle tankers. Keel laying for the first ship took place on 8th June 2007.

5.2 Shuttle tanker principal particulars and comparison with other recent projects

The principal particulars for the Prirazlomnoye shuttle tankers are shown in Table 5, with comparative data for other recent Arctic shuttle tanker and double acting ship projects. Comparative date is based upon public domain information sources and courtesy of SHI and AARC. It can be noted from Table 5 overleaf that there are three large commercial ships employing the double acting principle currently in service with a further six ships for Arctic service on order or under construction, including the two Shuttle tankers for the Prirazlomnoye project at FSUE Admiralty Shipyards.

Table 5, Comparison of Arctic shuttle tanker and double acting ship projects based upon public domain information and courtesy of SHI and AARC

Project general description		Arctic double acting oil shuttle tankers	Arctic bi-directional oil shuttle tankers	Arctic double acting container ship	Baltic double acting Aframax oil tankers
Designer - hull form		Aker Arctic Technology Inc.	Samsung Heavy Industries and Aker Arctic Technology Inc.	Aker Arctic Technology Inc.	Aker Arctic Technology Inc.
Designer - basic design		Aker Arctic Technology Inc.	Samsung Heavy Industries	Aker Finnyards	Sumitomo Heavy Industries
Builder		FSUE Admiralty Shipyards	Samsung Heavy Industries	Aker Finnyards (lead-ship) Aker Ostsee	Sumitomo Heavy Industries
Owner		Sovcomflot	Sovcomflot	Norilsk Nickel	Neste Oil
Numbers of ships		Two	Three	One + Four	Two
Ship names		-	Vasily Dinkov, 2007 delivery	Norilsk Nickel	Mastera, Tempera
Project status		Two under construction	One delivered 2007 Two under construction	One delivered 2006 Four under construction	One delivered 2002 One delivered 2003
Intended service		Oil loading at Prirazlomnaya platform in Pechora Sea and transportation to FSO unit moored off Murmansk or to refinery destinations in Northern Europe	Oil loading at Varandey tanker loading unit (TLU) in Pechora Sea and transportation to FSO unit moored off Murmansk	Loading Dudinka on River Yenisei of containerized metal products at and transportation to Murmansk and Rotterdam	Loading of oil in Northern Europe and transportation to ports in Finland. Shuttle trade from Primorsk to Finland
Hull form design		Double Acting	Forward & Aft Icebreaking	Double Acting	Double Acting
Deadweight, tonnes		70,000	70,000	14,500	106,000
Cargo capacity, m^3		~84,700	~85,000	-	-
Principal particulars	LOA, metres	258.75	257.0	164.31	252.00
	LBP, metres	235.77	234.7	160.24	230.00
	B, metres	34.00	34.0	23.10	44.00
	D, metres	20.80	21.0	14.35	22.50
	T, metres	13.60	14.0	9.0	15.3
Classification		Dual Class: RS & LR	Dual Class: RS & ABS	Single Class: RS	Single Class: LR
Specified ice performance		**Astern**: 3 knots in 1.5 m thickness first year ice + 20 cm snow, **Ahead**: 3 knots in 0.5 m thickness first year ice	**Ahead and Astern**: 3 knots in 1.5 m thickness first year ice + 20 cm snow	**Astern**: 2 knots in 1.5 m thickness first year ice + 20 cm snow	**Ahead and Astern**: 5 knots in 1.0 m thickness brash ice channel by FSICR requirements
Ice Class/ Category	Fore-ship	RS LU6 (Bow)	RS LU6 (Bow)	RS LU6 (Bow)	FSICR 1AS (Bow)
	Mid-ship	RS LU6	RS LU6	RS LU6	FSICR 1AS
	Aft-ship	RS LU6 (Stern as Bow)	RS LU6 (Stern as Bow)	RS LU7 (Stern as Bow)	FSICR 1AS (Stern as Bow)
Propulsion System	Type	Twin Azipod	Twin Azipod	Single Azipod	Single Azipod
	Main Engines	Wartsila 9L38 x 4	Wartsila 16V38 x 2, 6L38 x 1	Wartsila 12V32 x 3	-
	Power	17 MW (2 x 8.5 MW Azipods)	20 MW (2 x 10 MW Azipods)	13 MW (1 x 13 MW Azipod)	16 MW (1 x 16 MW Azipod)

5.3 Prirazlomnoye shuttle tanker general arrangement

Profile and section view extracts of the Prirazlomnoye shuttle tanker general arrangement plan are shown in Figs 11~12.

The key features of the general arrangement are described here:

A moderate icebreaking **bow** is arranged below the design load waterline. Twin 2000KW bow thrusters are fitted in a thruster space aft of fore peak tank, with an emergency fire pump room aft of the thruster space. A foc'sle deck is incorporated with an enclosed house arranged forward for bow loading and mooring equipment.

The **cargo section** of the ship is double hulled in compliance with latest international requirements and arranged with ten cargo oil tanks (for carriage of crude oil, oil products and gas condensates with specific densities between 0.70 t/m^3 and 1.025 t/m^3), five each port and starboard with plain longitudinal bulkheads. Two slop tanks are arranged thirty two frames forward of amidships between Cargo Tanks Nos. 2 and 3 (P&S). Electrically driven submerged cargo and ballast pumps are installed.

The **stern** has two main machinery spaces, an engine room forward with four Wartsila 9L38 main engines driving constant speed generators, and a pod room arranged aft for control and steering gear for pod azimuthing. Engine control room and switchboard rooms are arranged on the centerline on the deck below the main deck level. Fuel oil and service tanks are protectively located away from the side shell within the engine room space.

Cargo discharge manifolds are arranged on the **main deck** (P&S) **amidships** with twin hose handling cranes. A helideck, supported by pillars, is fitted on the **main deck forward** above the main deck centerline companionway. On the **main deck aft** there is a centerline accommodation block is arranged aft with an upper tier fully enclosed wheelhouse and bridge wings. Steering positions are forward and aft, and port and starboard outboard on the bridge wings. Twin funnel casings are arranged outboard port and starboard. There is an open stern working deck for mooring and a centerline free fall lifeboat at the stern.

5.3 Prirazlomnoye shuttle tanker midship section structural arrangements

Key features of the midship section structural arrangements are described below:

The **midship section** comprises a double bottom and side space with lower corner hopper tank space. A plain centerline longitudinal bulkhead is fitted and the main deck has an 800 mm camber. Cargo tank spaces are sub-divided by plain transverse bulkheads. The structure of the cargo tank envelope is constructed of 32 kg/mm^2 yield strength steel. Longitudinal framing is adopted throughout including the inner skin, hopper side plating, longitudinal bulkhead, inner bottom and double bottom structures.

The 2.3 metre height **double bottom** has a cellular structure with solid transverse floors arranged every fourth frame space and longitudinal girders at 4.0 metre spacing across the double bottom. The 3.1 metre width side skin space has four platform decks above the top of the hopper tank and web frames are arranged at every fourth frame space.

The side shell from the lower turn of bilge to the top of the **ice belt** is transversely framed. Ice frames are fitted at every frame space with ice stringers fitted between platform decks. 36 kg/mm^2 yield strength material is used for ice strengthening construction in the ice belt. Above the ice belt, longitudinal framing is adopted for side skin structure.

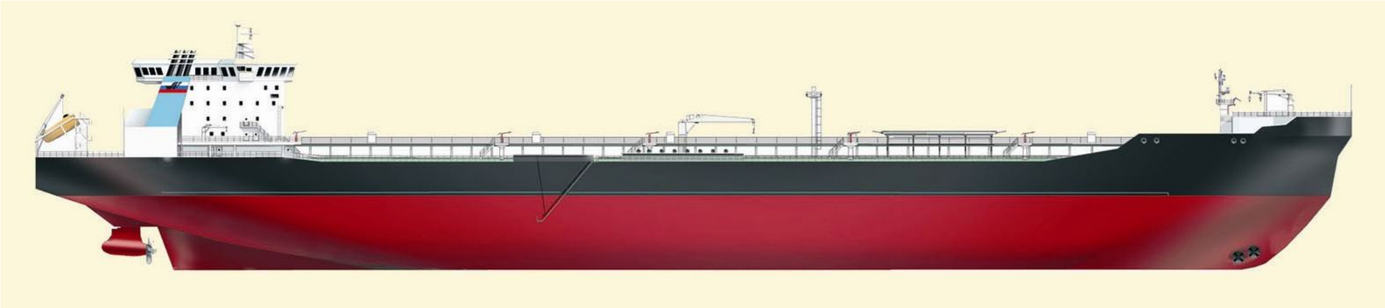


Fig. 11, Profile view of Prirazlomnoye shuttle tanker in SOVCOMFLOT colour scheme *(above)*; (*courtesy of AARC*)

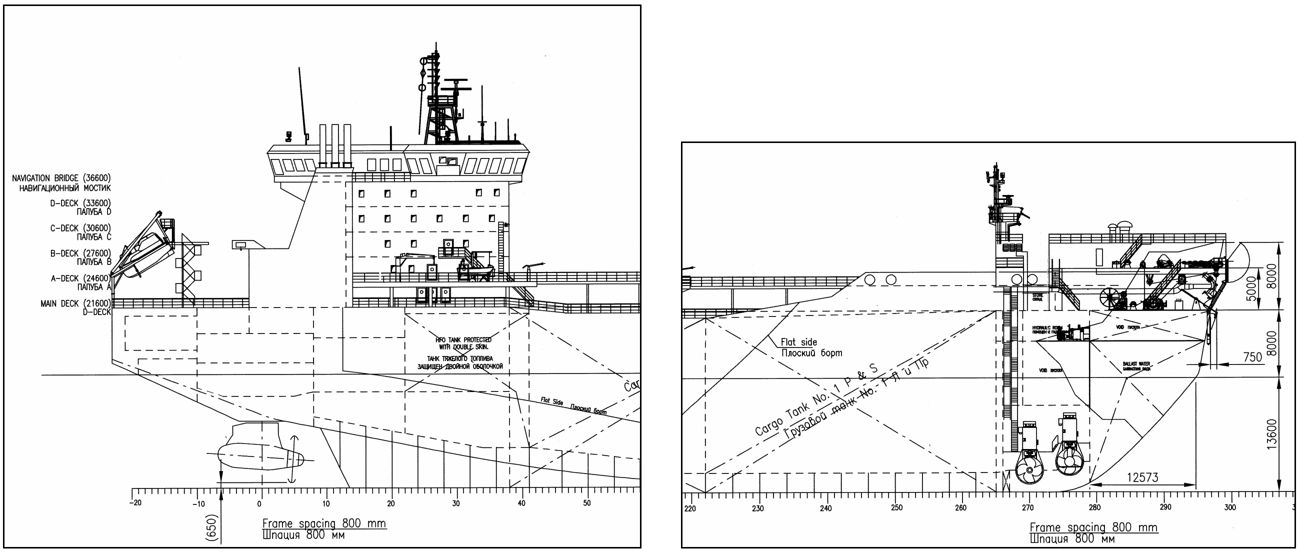
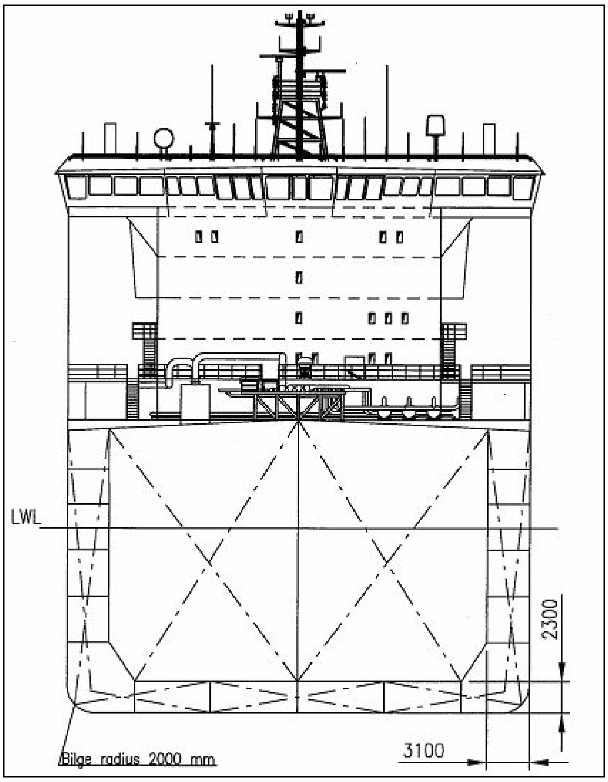


Fig. 12, Extracts of general arrangement plan showing aft end and fore end profile (*above*), and section view *(below)*;
(*courtesy of AARC*)



6 HULL ICE STRENGTHENING AND SELECTION OF MATERIALS

Dimensioning of hull structures for ice strengthening of the Prirazlomnoye shuttle tankers is in accordance with RS ice category LU6, with the stern of the vessel strengthened for bow design ice loads for double acting operation.

In this section we consider the permitted service and ice conditions for RS ice category LU6, as well as the ice loads and the strengthening applied to the Prirazlomnoye shuttle tanker for RS ice category LU6. This section also includes an introduction to the selection of materials for the hull, deck equipment and components.

6.1 Permitted service and ice conditions for RS ice category LU6

The specified RS ice category, LU6, to be adopted for the Prirazlmonoye shuttle tanker is one of nine RS ice categories introduced with the adoption of new ice rules and requirements by RS in 1999. Arctic ships are assigned ice categories LU4 to LU9 in RS rules, with LU9 being the highest ice category assignment.

The basic purpose of the RS ice categories (RS, 2003) is:

- To ensure ship safety for permitted service areas and ice conditions ("*ice service*")
- To identify permitted service areas and ice conditions ("*ice service*") that is independent of ship type or dimensions (i.e. dependant on ice category only)

The five Arctic seas for application of RS rules and ice categories to Arctic ships are shown in Fig. 13. They are:

- Barents Sea (includes Pechora Sea)
- Kara Sea
- Laptev Sea
- East Siberian Sea
- Chukchi Sea

Fig. 13, Russian Arctic sea areas

The permitted service areas and ice conditions for the selection of an RS ice category for an Arctic ship are determined considering:

- Navigation season – winter/spring navigation or summer/autumn navigation
- Service areas – for an Arctic ship the five arctic seas
- Ice conditions – easy, medium, hard or extreme
- Ship operation mode – independent or icebreaker assisted navigation

These conditions, for the selection of an ice category for an Arctic Ship, are summarised in a table in the RS rules (RS Rules, Part I, Ch. 2, 2005).

For the year round shuttle tanker service, (from the Prirazlomnaya platform in the Pechora Sea to an FSO moored off Murmansk), the Barents Sea service conditions in the RS rules apply. Extracts of navigation and ice conditions presented in the RS rules (Part I, Chapter 2, Table 2.2.3.4.1) for ice category LU6 for the winter/spring navigation season in the Barents Sea are shown in Table 6 below.

		Winter/spring navigation season in the Barents Sea			
Ice Category	**Type of ice navigation**	Extreme ice conditions *(average periodicity once in 10 years)*	Hard* ice conditions *(average periodicity once in 3 years)*	Medium* ice conditions *(average periodicity once in 3 years)*	Easy* ice conditions *(average periodicity once in 3 years)*
LU6	Independent navigation	LU6 category operation has an increased risk of hull ice damage	LU6 ice category operations allowed		
	Icebreaker escorted navigation	LU6 ice category operations allowed			
Note : * ice conditions in the RS Rules were derived from a separate analysis of observations of seasonal ice conditions from the data presented earlier in Section 3 and may not correspond.					

Table 6, "*Ice service*" for Barents Sea winter/spring navigation for RS ice category LU6

In the summer/autumn season in the Barents Sea independent and icebreaker escorted navigation is allowed for all ice conditions for the LU6 ice category.

6.2 Ice strengthening for RS ice category LU6

An ultimate strength philosophy is applied in formulations for scantling verification in the RS ice category rules where the ultimate load capacity of ice strengthened structures is greater than the ice loads

Ice loads are determined in accordance with the requirements of the RS rules (RS Rules, Part II, Ch. 3.10.3, 2005). Requirements for scantlings of ice-strengthened structures for compliance with LU6 ice category requirements are determined in accordance with formulations in the RS rules (RS Rules, Part II, Ch. 3.10.4, 2005).

For Arctic ice class ships the application of ice loads in the RS rules (RS Rules, Part II, Ch. 3.10.1.3, 2005) include vertical and horizontal regions ("A" forward, "B" midship and "C" aft) for the submerged hull. An intermediate forward region ("A_1" forward intermediate) is incorporated for the "*shoulder*" transition area between the forward and midship hulls.

For the Prirazlomnoye shuttle tanker project the RS rule ice loads applied to the aft region are based upon those determined considering the "*stern as a bow*" due to the proposed double acting operation of the ships. The design ice loads for the shuttle tanker hull for LU6 ice category are shown in Table 7.

Hull design ice loads		**Horizontal regions**				
		Aft		**Midship**	**Forward**	
Vertical regions	**Extent of region**	(*Aft*) Forward region A	(*Aft*) Intermediate region A_1	Midship region B	Intermediate region A_1	Forward region A
I	Between ice load WL and ballast WL	7300 kPa	6000 kPa	3900 kPa	5800 kPa	6600 kPa
II	Below region I to upper turn of bilge		3900 kPa	2000 kPa	3800 kPa	
II	Bilge strake		3900 kPa	1800 kPa	3800 kPa	
IV	From lower turn of bilge to CL on bottom		3000 kPa	600 kPa	2900 kPa	

Table 7, Matrix of hull design ice loads to RS LU6 requirements

Extracts of the ice strengthening plan, Fig. 14, show the regions of ice strengthening for fore and aft, where the Table 7 ice loads were applied. An envelope of waterlines based upon loading cases in the trim and stability manual was considered to determine the uppermost extent of the ice load waterline.

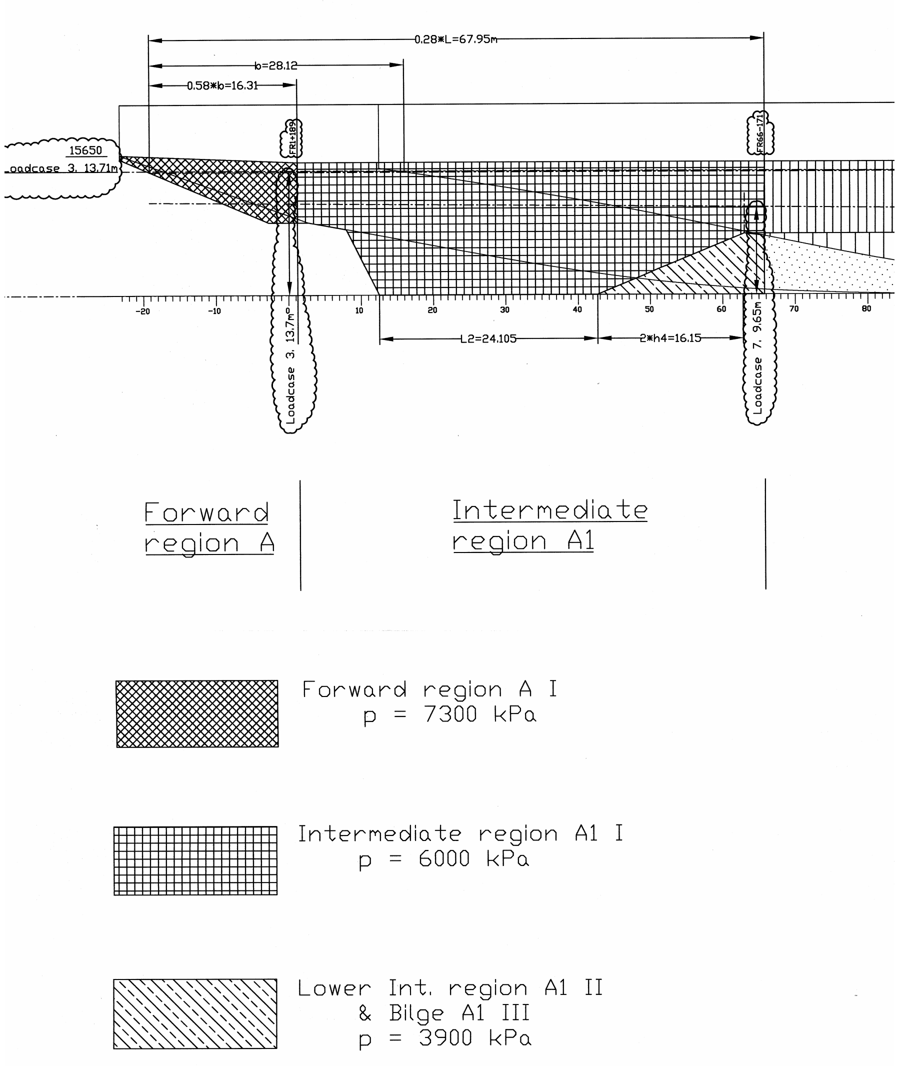
The key features of the hull ice strengthening adopted are described here and overleaf:

The shell in the **forward ("A") region** of hull ice strengthening is transversely framed throughout; with built section main and intermediate ice frames at 400 mm spacing. A 60 mm thickness stem bar is arranged with a 45 mm thickness radiused stem plate.

The bottom shell in the **forward intermediate ("A_1") region** of ice strengthening is longitudinally framed. At the edge of each of the vertical regions on the ship side (I, II and III) there is a 4 mm step down in shell plating thickness.

Closely spaced supporting platform decks and stringers are arranged in the **forward and forward intermediate regions** of ice strengthening.

The side shell in the **midship region** ice belt (vertical region I) between the ice load waterline and ballast waterline is strengthened with bulb sections for the main and intermediate ice frames at 400 mm spacing. Within the double side skin space there are platforms decks arranged vertically every 3.4 metres with intermediate ice stringers. The bottom shell (vertical region IV) is longitudinally framed throughout the midship region.



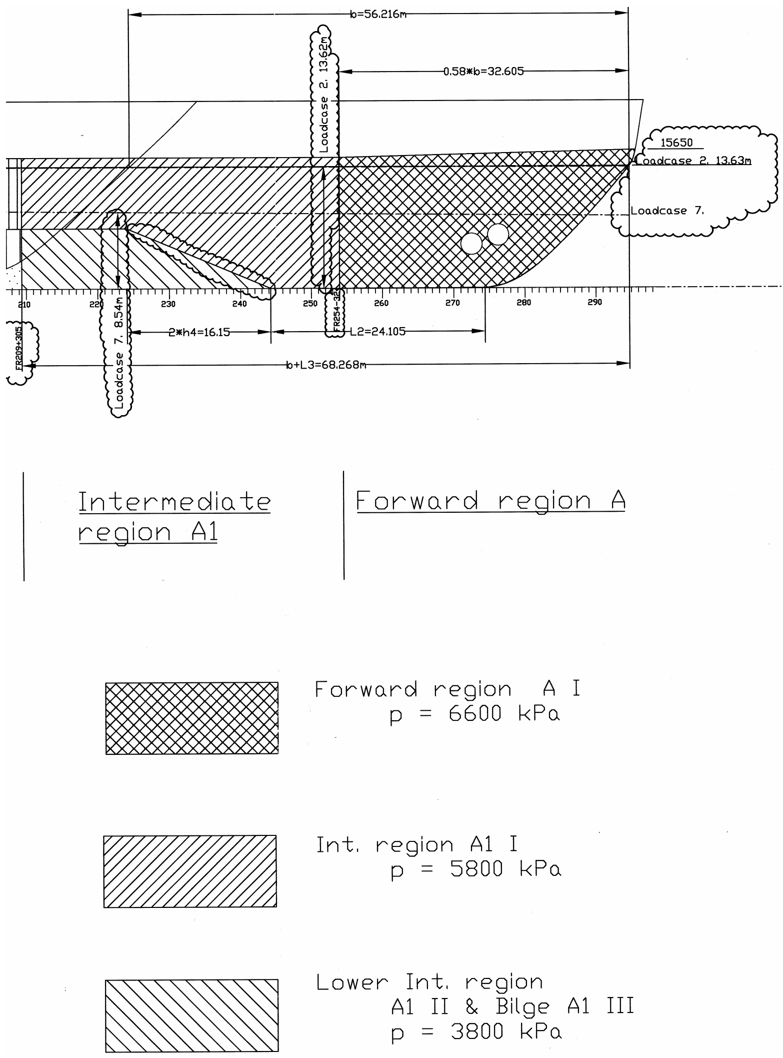


Fig. 14, Forward region "A" and intermediate region "A_1" of ice strengthening in aft hull (*left*) and forward hull (*right*) from ice strengthening plan *(courtesy of AARC)*

The ice strengthening in the **aft ship (forward "A" and forward intermediate "A_1" regions)** is transversely framed throughout. Below the pod room space and in the aft peak tank space a cellular construction is arranged with solid floors at every frame. Within the pod and engine room space built section main and intermediate ice frames at 400 mm spacing are fitted. Closely spaced supporting platform decks and intermediate ice stringers are arranged in the aft ship perpendicular to the shell. Skeg structures are enclosed aft by 46 mm thickness plating and taper at the stern end to an ice knife.

6.3 Selection of materials for exposed hull structure and deck equipment

The specification requirement is for deck machinery, cargo equipment, communication equipment and all other equipment exposed to ambient temperature to be designed and certified for minus 40ºC temperatures.

Table 8, below, summarises the exposed deck equipment and components where low temperature service requirements are to be considered for selection of materials.

Table 8, Exposed deck equipment and components for low temperature service

Deck equipment functions	Equipment items	Major component(s) for equipment
Mooring equipment	Windlass	
		Foundation bolt
	Mooring winches	
	Chain stopper	
	Anchors	
	Anchor cables	
	Bollards	
	Roller fairleads	
	Emergency towing system	Aft strong point
		Storage drum/winch
Cargo equipment	Bow loading system	
	Hose handling cranes & other lifting appliances	
Piping and valves	Exposed deck piping	
	Exposed deck valves	
Electrical, automation & navigation equipment	Exposed deck electrical equipment	Cables
		Electrical equipment
	Exposed deck automation equipment	
	Radio equipment	
	Navigation & communication equipment	
Life saving appliances	Rescue boat	
	Life boat	
	Life rafts	
	Davits for life boats and life rafts	
Miscellaneous non-metallic Components, parts and equipment	Paint for hull	
	Seals	Doors, hatches etc
		Windows etc
	Gaskets & sealing rings	Fire main pipe-work
		Cargo system pipe-work
	Hoses	Fire
		Hydraulic
	Deck foam monitors	
	Foam	
	Grease for deck machinery	

For selection of materials for deck equipment and components a hierarchy of requirements and standards for low temperature service is to be applied which includes:

- Specification requirements
- Russian Register rule requirements
- Lloyd's Register rule requirements
- Flag requirements
- National standards

For the Prirazlomnoye project shuttle tankers a class notation "*Winterisation D(-40)*" is to be assigned on the basis of the specified winterization measures agreed between the builder and buyer (LR Provisional Rules, Section 1.3, 2006).

The basic purpose of the LR provisional rules for winterization of ships is:

- To provide a prescriptive rule standard of protection against cold temperatures and the effects of icing on the operation of the ship
- To provide for consideration of alternative means of compliance with the prescriptive rule standards of winterization protection, with each prescriptive requirement having a goal or objective to achieve
- To complement international regulations and national guidelines, e.g. the IMO Arctic Guidelines, and the Requirements of the Northern Sea Route Administration (NSRA)

The requirements for hull structure materials exposed to low ambient temperatures of both RS rules (RS Rules, Part II, Ch. 1.2.3, 2005) and LR rules (LR Provisional Rules, Section 2.1, 2006) are complied for the specified lowest ambient temperature of minus 40ºC.

7 CO-OPERATION WITH RUSSIAN ORGANISATIONS

The basic design package for the project has been supplied to FSUE Admiralty Shipyards by Aker Arctic Technology, Inc (AARC). The shuttle tankers are to be dual classed by Russian Maritime Register of Shipping (RS) and Lloyd's Register (LR) on delivery in 2009.

In this final section we briefly highlight some of the challenges and experiences for co-operation between the Russian shipyard and the Finnish designers, as well as the terms of reference applied for co-operation between RS and LR for achieving dual classification.

7.1 Co-operation between FSUE Admiralty Shipyards and Aker Arctic Technology Inc.

The basic design and classification approval design package is being supplied to the shipyard, FSUE Admiralty Shipyards, by the developers of the shuttle tanker concept, Aker Arctic Technology Inc. (AARC) of Finland.

This is the first time for such a co-operation model to be adapted to co-operation between a leading Russian shipyard and a foreign designer in its whole coverage.

Specific challenges in this co-operation for both parties have been due to different industrial cultures, different organizational structures, different management and project coordination practices, and finally different equipment procurement practices.

Due to these challenges the whole design task has consumed more time and effort than is usual, but the construction, however, is proceeding according to plan.

7.2 Co-operation between RS and LR for dual classification

The Prirazlomnoye shuttle tankers are being constructed under RS and LR survey for dual classification, and are to comply with the latest International Convention requirements, including the applicable regulations and requirements of both the Cyprus and Russian flag.

The following RS class notations will be assigned:

KM(*) LU6(2) A1 нефтеналивное (ОРП)

The following LR class notations will be assigned:

✠ 100A1 Double Hull Oil Tanker, ESP, ShipRight (SDA, FDA, CM), LI, ✠ LMC, UMS, IGS, NAV1, IBS, ICC, SPM, BLS, Helicopter Landing Area, EP(P), DP(AA), Winterization D (-40)

In a notable departure, from earlier dual class practice the agreement for dual classification for the Prirazlomnoye shuttle tanker project establishes terms of reference for determining work share and service contributions of RS and LR based upon the respective technical strengths of the two co-operating class societies.

From these terms of reference an agreement was reached between all parties for provision of dual classification services by RS and LR on the following basis:

- **Plan Approval** - division of work scope between RS and LR
- **Surveys during construction** - sharing of work scope between RS and LR

8 CONCLUDING REMARKS

The first Prirazlomnoye Arctic shuttle tanker project, Hull No. 02750, was keel laid at FSUE Admiralty Shipyards, St Petersburg on 8th June 2007 as shown in Fig. 15 overleaf. These unique shuttle tankers, in addition to being a very significant technological reference project for Russian maritime industries, also present an opportunity for all the project engineers and designers to gain valuable experience for future Arctic projects.

The paper has addressed specific aspects of the design of the Prirazlomnoye shuttle tankers which may be of interest to TSCF members and the shipbuilders meeting delegates, including:

- Development of the shuttle tanker design concept
- Winter season shuttle tanker operations
- Hull ice performance and model tests
- Comparison of the particulars of the Prirazlomnoye shuttle tankers with other recent Arctic and double acting tankers
- Descriptions of the general arrangement and midship section
- Hull ice strengthening and selection of materials

The purpose of this paper has been:

- To provide the TSCF members and the shipbuilders meeting delegates a broad based introduction to the technical characteristics of the Prirazlomnoye shuttle tanker project

It is the intention of the authors to update the TSCF members at a future shipbuilders meeting with a follow up paper on construction and in-service performance of the Prirazlomnoye shuttle tankers.

Fig. 15, Keel laying of Hull No. 02750 at FSUE Admiralty Shipyards, St Petersburg on 8th June 2007 (*courtesy of FSUE Admiralty Shipyards*)

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