Final public report of the ARCDEV project

Funded by:
EUROPEAN
COMMISSION UNDER THE
TRANSPORT
RTD PROGRAMME OF THE
4 TH FRAMEWORK PROGRAMME

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General overview of ARCDEV project

1. EXECUTIVE SUMMARY

General background

The marine transportation in the Arctic areas is becoming increasingly interesting for the European industry. This is mainly due to the growing importance of the Russian Arctic to EU. The possibilities of international shipping in the Arctic Russia has been studied during the latest years by Japan, Russia and Norway within the INSROP project. Traditionally European technology (from Finland and Germany) has been utilised in these areas. The main goal of the ARCDEV project was to demonstrate the viability of feasible Arctic marine transportation in the Arctic Russia taking advantage from the latest results of other EU research programs.

The ARCDEV project was performed by the leading European industry and research institutes in the field of Arctic Marine Transportation. The project team included strong industrial involvement from oil exploration and Arctic shipping to shipbuilding and high-tech information technology. The scientific aspects were guaranteed by research institutes and universities that are leading in the field of Arctic marine technology. The project was carried out in co-operation with the Russian Federation and leading Russian institutions engaged in arctic technology and research. The composition of project partners and main organisations involved in the project is presented in Chapter 2.

The objective was to develop technical and logisitics know-how, to enable safe, year-round traffic in the NSR.

Brief introduction

The **ARCDEV -**project compromised of the demonstration voyage and various research activities and investigations related to commercial shipping transport of hydrocarbons from Russian arctic to European market area. All work done during the project and voyage itself was carefully recorded, analysed and reported during the project. Main areas of research work covered the following aspects:

? ? Vessel and icebreaker performance in various Arctic environmental conditions during the voyage
? ? Data and experiences gathered from vessels to improve future desings of the ice-going vessels
? ? Assessment of weather, ice and sea conditions forecasting together in the Arctic sailing
? ? Space-borne remote sensing of sea ice conditions and implementation to practice for the ships
? ? Operational safety in means of environment, human lives and material preserve
? ? Cargo handling operations
? ? Legal and administrative aspects of navigating in Russian Arctic
? ? Economical and commercial attractiveness of Arctic transportation

The core of the ARCDEV project was a demonstration voyage, which was made to the Gulf of Ob in April—May 1998 (Figure 1) transporting the cargo to the port of Rotterdam in Netherlands.

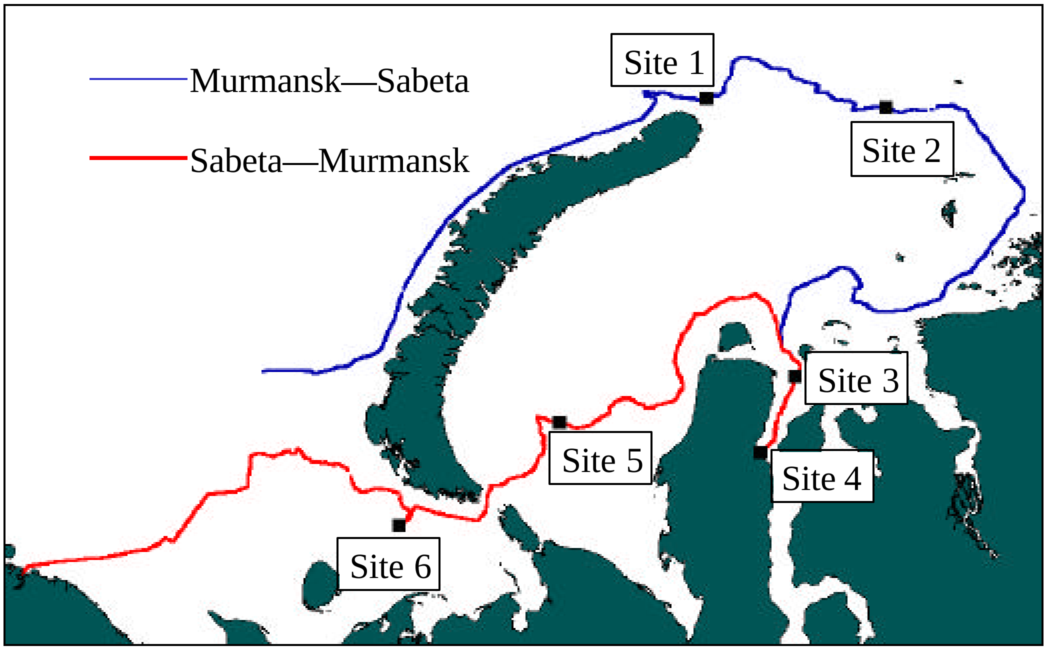


Figure 1 The ARCDEV route and the research site locations.

Vessels that took part in or assisted this voyage were:

- ? ? MT Uikku; cargo vessel
- ? ? IB Kapitan Dranitsyn; research platform
- ? ? NIB Rossiya; main assisting icebreaker
- ? ? NIB Vaygach; broke the channel in the Ob Bay area

Commercial, technical, scientific, legal, environmental and political aspects were considered in different Work Packages of the ARCDEV project. There were numerous measurements and data logging during the voyage to give information from the ship, the environment, the ice properties etc. From time to time the convoy stopped to study local ice properties in more detail.

In the project a Finnish owned 16 000 DWT tanker MT Uikku with a Russian icebreaker Kapitan Dranitsyn made a voyage to the northern part the Gulf of Ob to load gas condensate from an exploratory gas field. A Russian nuclear icebreaker Rossiya assisted the convoy. The gas condensate was then transported to international markets via Europe.

The project was divided in several Work Packages, which deal with the following topics:

- ?? WP 0 Co-ordination
- ?? WP 1 Commercial Aspects
- ?? WP 2 Legal and Regulatory Questions
- ?? WP 3 Ice conditions
- ?? WP 4 Ship Performance
- ?? WP 5 Ice Routing
- ?? WP 6 Navigation and Operation
- ?? WP 7 Tanker Loading Systems
- ?? WP 8 Ice Loads
- ?? WP 9 Required Ice Class for the Northern Sea Route
- ?? WP 10 Remote Service and Maintenance
- ?? WP 11 Environmental Protection
- ?? WP 12 Data Management
- ?? WP 13 Trafficability
- ?? WP 14 Navigation Simulation
- ?? WP 15 Co-ordination of the Russian participation
- ?? WP 16 Conclusions and Recommendations

Results in brief

The commercial side of the Arcdev hydrocarbon transportation was in the limits of the planned budget. In this respect, the voyage was commercially attractive, but we must notify that the gas condensate cargo transported has a high freight rate. To effectively transport for example crude oil, considerable cost saving must be achieved.

Legislation and regulatory aspects were studied and tried during the project and the voyage. Legislation and rules are existing in the Northern Sea Route but are not put clearly on practise. Fee policy for the NSR is stated in documents but is presently under rebuild and therefore unclear. Fee policy should not work on a case basis but instead having a stated tariff system for several years.
Insurance policy should be rationalised from the Russian side. Operating models similar to Europe would make insurance aspects easier and more effective from the ship operator and insurance company viewpoint.

Ice conditions were registered during the voyage with several methods. Traditional methods of human observations and direct physical measurements were done together with more sophisticated methods of EM-measurements (Electro Magnetic) and satellite image analysis. As a result a better correspondence with vessel performance was acquired with EM measurements than visual observations. Performance of direct ice property measurements was difficult in a commercial voyage due to lack of time at the stops. Ice data measured has a great value because ice conditions in winter 1997-1998 were exceptionally strong. Simultaneous measurements of satellite data, EM-measurements and direct measurements combined to vessel's performance information provide valuable dataset for the development of ice navigation tools.

Images from SAR satellites form a basis for ice routing tools. However, Arcdev voyage revealed the deficiency of SAR images. Interpretation is difficult even for the experienced person and possibility of severe misconclusion exists. Automatic image analysing algorithms are under development but are still far from practically acceptable level. Combining together present level of SAR images, communication with local icebreakers and flight recoinnance, an operational route selection can be made with reasonable efficiency.

The convoy was able to keep relatively good speed all the way, however, power levels used in M/T Uikku were exceptionally low thus indicating that more effective tactical navigation could be done to improve convoy performance. Also energy per nautical mile was low in Uikku showing the capability of icebreakers to clear the ice effectively for transporting ships.

The method adopted for tanker loading system with the gas condensate in the Arcdev was very rudimentary. Loading happened in ice near Sabeta. This loading arrangement can not be considered suitable for year-round operations when export of hydrocarbons on industrial level is needed. If oil and gas resources of the region are exploited, the recommendations of loading systems are given in the respective Arcdev reports.

Ice loads to the ship's hull were measured during the project. The ship operation profile has a significant influence on the ice-induced loads. Highest values were often connected to certain operation of the ship. Turning radius has a clear effect on the loads at the midship and aftship areas. The effect of the speed can be seen on the measured maximum values, especially on the bow and bow shoulder area. Measured values give support for practical application of models to predict ice loads also for navigation in Arctic waters.

Ice class development and harmonisation is recommended on the basis of Arcdev studies. The selection of ice class for the Arctic tanker will be made on the basis of ship's strength capacity against ice loads imposed. Type of navigation and ice conditions determine the ice loads. M/T Uikku has a Finnish-Swedish Ice Class Rules class 1A Super but is stronger than minimum class requirements. The voyage showed that such a class is insufficient for conditions and operation experienced during Arcdev. Especially loads that occurred on the ship bottom area needs more accurate definitions.

The environmental study in Arcdev focused on two basic aspects: Firstly, the environmentally safe navigation through the Northern Sea Route. Secondly, safe cargo operations on Yamal peninsula. The completion of these tasks was successfull and in co-operation with the Russian authorities.

Data Information Management (DIM) in the Arcdev project had an important role. Several separated research teams were working in different ships in an area where communication technolygy is not like in habitet areas. The DIM work consisted on collecting data from researchers and finally organising the project reporting providing deliverables for their long-term accessibility and sustainable use. A signifact role was also producing information to general public, in means of Internet and newspapers and magazine articles. Information management had a bigger role in the project than expected thus leading to heavy work load for DIM partners, 2% of funding was allocated to DIM but as a general rule for such a project 5% would be reasonable amount.

Training for persons who operate ships in Arctic waters has became an issue of importance. Arcdev dataset is in part of helping potential training organisations to develop practical applications for simulators which will fit to Arctic problematic. Several countries like, Canada, Finland, Norway, Sweden, Russia and Germany have shown their interest for such a development. In the near future a personal certificate for Arctic navigation will be required by international regulations.

Main conclusions

The voyage showed that the marine transportation of oil and gas condensate from the Russian Arctic to Europe is technically possible and safe even in very hard ice conditions. The cost level being more than 10 dollars per barrel is far beyond what would be feasible even with the current high oil prices. The main reasons for the high transportation cost were:

- small cargo volume (approx. 13.000 tons)
- route selection resulting in sailing distance increased to double
- operational mode resulting in usage of less than 50 % of the installed power of the tanker
- low loading rate of the temporary loading facility
- loss of two days in extra port calls for custom and immigration procedures
- high cost for icebreaker assistance (more than 2 dollars per barrel of transported cargo)

Most of these items are such that they can be improved through the development of technology, of traffic management systems and administrative systems. It has been shown that very important improvements can be achieved by developing an efficient route selection tool. The development of the cargo vessels and icebreakers to improve the effectiveness of the convoy operations is essential for the transportation economics. The development of the loading terminals as part of the transportation system will improve the overall economics. The increase of the cargo flow however requires long term investments in the tankers, the assisting fleet and loading terminals. Finally, there is a need to guarantee that transport operations are consistent with environmental friendly standards and objectives, R&D demonstrated that appropriate operational procedures supported by traffic management are fundamental. To observe these basic parameters and to make these investments happen, calls for a change in the legal framework and business environment. These changes can be achieved only through long term co-operation and open discussion between EU and Russia. It is thus recommended that a platform is developed to perform the technology development, to foster further the discussion and to demonstrate and validate results.

2. PARTNERSHIP

The ARCDEV Project is co-sponsored by and conducted under the

European Commission, Directorate General Transport – DG VII, ***(todate Dirctorate General for Energy and Transport – DG TREN)*** ***Waterborne Transport Research Programme***	EU

The project is lead, co-ordinated and managed by

Neste OYJ, ***Neste Shipping***	**NESTE**	FI

The participation and activities of the Russian members of the ARCDEV Consortium project is co-ordinated by

The Administration of the Northern Sea Route, ***The Russian Federation Ministry of Transport***	RU

The project is executed by a consortium of leading European companies and scientific institutions with profound and competent experiences in all kinds of marine topics of arctic environments and areas.

Their activities and knowledge cover

?? oil and gas exploration, production, and transportation in arctic regions,

?? arctic marine operations, transportation, and cargo handling,

?? design, engineering, construction, and building of ice resistant vessels and cargo handling equipment,

?? classification guidelines and safety standards,

?? guidelines specification of guidelines for vessels and marine equipment used in arctic areas,

?? ice reconnaissance and routing,

?? polar and marine environmental research and technology,

?? ship and structure laboratory testing and modelling,

?? ship traffic and operation simulation,

?? marine communications,

?? applied oceanography, marine and polar research,

?? data and information management.

The ARCDEV Consortium comprises a team of companies and institutes from European Union member countries and Russia.

From European Union member countries following companies and institutions participate:

Earth Observation Sciences Ltd.	**EOS**	GB
Helsinki University of Technology	**HUT**	FI
Hamburg Ship Model Basin Ltd.	**HSVA**	DE
Institute of Ship Operation, Sea Transport and Simulation	**ISUSS**	DE
Kvaerner Masa Yards	**KMY**	FI
Lloyds Register	**LR**	GB
Aker – MTW Shipyard	**MTW**	DE
Nansen Environmental and Remote Sensing Center	**NERSC**	NO
REMTEC Systems Ltd.	**REMTEC**	FI
Tecnomare S.p.A	**TECNOMARE**	IT
Shell Vankor Development	**SHELL**	NL

Subcontractors:

Alfred Wegener Institute of Marine and Polar Research	**AWI** *contracted by HSVA*	DE
HYDROMOD Scientific Consulting	**HYDROMOD** *contracted by NESTE*	DE
Wartsila Diesel, ABB	*contracted by KMY*	FI

The Russian partners in the ARCDEVproject were:

State Research Center of the Russian Federation Arctic and Antarctic Research Institute	**AARI**	RU
Arctic Shipping Service	**AShS**	RU
Central Marine Research and Design Institute	**CNIIMF**	RU
State Research Center of the Russian Federation Krylov Ship Research Institute	**KSRI**	RU
Murmansk Shipping Company	**MSCO**	RU

3. OBJECTIVES

The verified oil and natural gas reserves in Northern Russia and in the Russian sector of the Arctic Ocean are very large. They are considered as the long term energy supply source for Western Europe.

Together with western oil companies and engineering firms Russia is in the process of developing technologies to produce and ship most of the oil to Western Europe. Instead of transporting the oil by pipelines through various foreign countries and across unsafe soil conditions many of the oil companies prefer the transportation by icebreaking tankers.

The conditions for maritime operations are extremely harsh in this region. While the Port of Murmansk never freezes, ice conditions become progressively more difficult eastward. East of the Taymyr Peninsula the route is covered by the thick ice throughout the year. In the western part up to Novaya Zemlia the ice conditions are comparable to those encountered in the Northern Baltic Sea. Generally the period of 3 to 6 months is navigable under open water conditions.

The current sea transportation system is based on heavily strengthened cargo vessels, which are assisted by large icebreakers. Cargo vessels are normally 20,000 dwt general cargo vessels and bulk carriers built in Finland and East Germany. The icebreaker fleet contains ten nuclear or diesel powered vessels which were built in Finland and Russia.

These icebreakers allow year round navigation up to Dudinka in the Yenisei River. This shipping has been so far State controlled and was therefore uneconomical for western commercial standards. In order to make the tanker transportation of oil from the Russian Arctic attractive for western oil and shipping companies, this transportation system has to be improved in various aspects.

The main objectives of the Arcdev demonstration voyage were concerned with

?? Operations of icebreaking tankers in the Arctic
?? Commercial aspects of such transportation system

Safe, reliable and economical operations of icebreaking tankers in the Arctic are affected by

Ship parameters:

?? shape of the icebreaking bow
?? hull structure to withstand ice impacts
?? propulsion system/propeller in ice
?? manoeuvring capability
?? ship hull roughness dimension/size

Ice parameters:

?? ice thickness
?? ice concentration (% of surface)
?? ridge size and frequency
?? degree of ridge consolidation
?? ice pressure due to wind and current

Navigational aids:

?? satellite pictures
?? routing advise
?? ice reconnaissance by helicopter or air plane

These parameters were used to develop a technical and commercial transportation scheme for oil tankers and the Russian arctic. The results gathered of these areas of interest were used to assess the commercial and technical situation of the present state.

Technical and scientific description of ARCDEV

1. INTRODUCTION

1.1. Vessels tasks and technical information

1.1.1 M/T Uikku

M/T Uikku is a 16 000 dwt tanker featuring a double hull and a double bottom with eight coated cargo tanks and two slop tanks. She is also equipped with the electric azimuth propulsion system Azipod, which makes her particularly suitable for arctic shipping and demanding ice conditions. Prior to commencement of the ARCDEV Demonstration and Exploratory Voyage M/T Uikku has undergone some upgrades and has received additional ice strengthening to make herself especially ready for operation in Arctic regions and ice conditions. During this maintenance period the research and measurement equipment was installed as well.
The special hull design and strengthening and the propulsion system of the motor tanker Uikku facilitates her to operate in arctic regions and to break ice of limited thickness. The Azipod propulsion system provides her optimum manoeuvring capabilities as essentially required in convoy operations with ice breaker assistance. The vessel can perform for instance a full turn with speed of more than 17 knots with a diameter of less than two times of her length. The achievable speed ahead and astern are almost identical. Her bow and front section are designed for both cruising in open waters and transiting in moderate ice conditions. In stronger ice the vessel can move astern making use of the special design of the aft section which is close by to ice breaker shapes. Whereas in ice conditions as typical for instance in the Northern Baltic Sea the vessel can operate almost always without any icebreaker assistance this is certainly required in arctic regions and especially in areas with old ice, pack ice fields and when crushing through pressure ridges.

M/T Uikku is able to utilise all available technology to make her voyage as feasible as possible. The research efforts during the voyage focussed on the operations of ice breaking tankers in the arctic. During the voyage special attention has been paid to the ship's parameters, the ice parameters and navigational aids. The evaluation of commercial aspects of this voyage comprises a major task of the ARCDEV project. Due to the very fragile ecosystems of the Russian Arctic environmental impacts have been carefully registered. Numerous data, information and observation were collected and recorded on the voyage. These are the basis for further investigations and evaluations . The evaluations and recommendations based on these data and results will serve as tools for planning of the future R & D work.
M/T Uikku is owned by the Nemarc Shipping Corporation, a joint venture shipping company owned by FORTUM and Kvaerner Masa-Yards. The company is established for oil transportation in the Arctic waters, and is the Finnish partner in ZAO Arctic Shipping Service based in Murmansk.

General description and technical data

Main particulars

Length O.A. 164.4 m
Length B.P. 150.0 m
Breadth moulded 22.2 m
Depth moulded 12.0 m
Draught on summer freeboard 9.5 m
Corresponding deadweight 15 748 tons
Distance keel top antenna 39.0 m

Certificates

Solas 1974
Finnish Board of Navigation
Regulations St. Lawrence Seaway
Approved

Speed and consumption

Service speed 14.5 knots on maximum Draught at 50 % MCR

Consumption: Abt. 23 tons/24 hours I FO
max. 380 cSt for main diesel generators

Registered tonnage Gross Net

International 10936.3 t 5140.3 t
Panama 11751.6 t 7240.1 t
Suez 11749.7 t 9061.8 t

Builders

Werft Nobiskrug GmbH, Rendsburg, built 1977 Kvaerner Masa-Yards Inc.,

Helsinki New Shipyard rebuilt Azipod Conversion 1993

Propulsion machinery

Two WV 12 V 32/ABB diesel Generators, output 4.8 MW, one WV 12 V 22 HF/AEG diesel generator, Output 1.9 MW, one MaK 282 M 12/AEG diesel generator, output 2.3 MW and auxiliary machinery: two MTU/AEG diesel generators, output 2x520 kW, two blowers 2x13700 m'/h, air bubble system for navigation in ice

Classification

Det Norske Veritas +1 A 1 Tanker for Oil,
Ice 1 A Super, MV, EO, F
Inert Azipod-unit DNV Ice 10

Nautical equipment

S-band radar, X-band radar, Anticollision device/ARPA, two Gyrocompasses with autopilot, Satellite navigator, Decca navigator, Radiodirection finder, echo sounder, Speed log, vector navigation Computer

Signal letters

OIHQ

Bow thruster

One bow thruster, type Kamewa, 730 kW

Cargo control and monitoring

Onboard NAPA loading computer

Fuel oil/Diesel oil/Ballast water Capacities

- Fuel oil 1350 t
- Diesel oil 83 t
- Ballast water 5990 t

1.1.2 Nuclear icebreaker Rossiya

The nuclear icebreaker Rossiya and her sisterships Arctica, Sibir, Sovjetski Sojuz and Yamal are owned by the Russian Federation and operated by Murmansk Shipping Company. These icebreakers were built in St. Petersburg and are the world's most powerful and largest icebreakers.

Technical data

Length:	148.0 m	Two nuclear reactors
Width:	30.0 m	Two main turbo generators 37.500 hps each
Height to main deck:	17.8 m	Three propellers
Displacement:	23 460 tons	Power (machine): 55 MW
Service speed:	21 knots	Power (shaft): 49 MW
		Ice breaking capability : 2.25 m thick ice at 2 kts

Rossiya escorted the tanker M/T Uikku and the diesel powered icebreaker Kapitan Dranitsyn who served as are search platform from entering of the Kara Sea north of the island of Novaja Zemlia to the entrance of the Ob Bay and back through the Kara Gate. The route led through areas with the harshest ice conditions one can meet on the globe where pressure ridges and pack ice fields with ice thickness of more than 10 metres are met frequently. Today only such powerful and nuclear ice breakers like Rossiya and her sister ships and affiliate vessels can operate with reasonable safety, endurance and liability in such areas.

1.1.3 Nuclear Icebreaker IBN Vaygach

Vaygach and her sistership Taymyr are powerful shallow draft nuclear ice breakers of the third generation. They are specially designed for operations in the Siberian river mouths and estuaries. These icebreakers were built in Finland and fitted with the nuclear components of the propulsion system in St. Petersburg. They are owned by the Russian Federation and operated by Murmansk Shipping Company.

Technical data

Length:	151.8 m	One nuclear reactor
Width:	29.2 m	Two main turbo generators 25.000 hps (18.400 KW)
Height to main deck:	15.2 m	Each
Draught:	8.1 m	3 propellers
Displacement:	20.000 tons	
Service speed:	21 knots	

On the demonstration and exploratory voyage Vaygach broke the channel through the very heavy fast ice of Ob Bay to the loading place in Sabeta. Her shallow draught is required for safe and efficient navigation and operation in Siberian estuaries.

1.1.4 Diesel Icebreaker Kapitan Dranitsyn

Kapitan Dranitsyn is a powerful diesel-electric ice breaker owned by the Russian Federation and operated by Murmansk Shipping Company. Like several of her sister ships operating in the eastern and western parts of the Northern Sea Route and the Baltic Sea she was built in Finland. Within the last year she was modified and achieved the class as a passenger vessel in addition. Kapitan Dranitsyn has comfortable cabins, launges, a library and an auditorium plus some laboratory and office space which facilitates her as a research platform for up to 70 scientists and embarked personnel.

Technical data

Length overall	129.5	M
Ldwl	121.3	M
Breadth max	26.5	M
Breadth dwl	25.6	M
T max	8.5	M
Tdwl	7.5	M
D	12.3	M
Propulsion power	16.2	MW
Auxiliary power	3.9	MW

On the ARCDEV voyage Kapitan Dranitsyn served as a research vessel and provided research facilities, space and accommodation to the large ARCDEV research team. Route measurements and ice stations were conducted from the Kapitan Dranitsyn.

1.1.5 M/T Vilujsk

The tanker M/T *Vilujsk* (*Samotlor type*) made a voyage for transportation of gas condensate from Kharasavey in the same area and time as Arcdev took place.
Assessment of the commercial results of the trip of tanker *Vilujsk* on the delivery of gas condensate to Rotterdam has been carried out, taking into account by the way loading of ship with petroleum products bound for arctic points. Such trip is typical in the practice of sea navigation. The tanker arrived in port Kharasavey for loading gas condensate after unloading oil products in ports of Dickson and Dudinka. Calculation of operational and economical indices for the freighted tanker was made by actual report data of trip: Murmansk - Dickson - Dudinka - Dickson - Kharasavey - Murmansk - Rotterdam.

Technical data

Overall length L	160 m
Breadth B	23 m
Depth H	12.9 m
GRT	12196
Capacity of cargo tanks	17940 m^3

2. COMMERCIAL ASPECTS

The ARCDEV project was partly performed as a commercial project exercise. Two tankers named Uikku and Vilujsk were used to find out the objectives of creating basic material on economics of marine transportation. The freight rate as well as operational cost, various fees and ice breaker assistance costs were gathered and reported within the project. The result showed ecomomical feasibility of the transportation operations in current situation and environmental conditons.

2.1. Commercial voyage of tanker Uikku

2.1.1 The transport economics

The transport costs have been fixed at a level which is equal to the average freight-market-rate and T/C hire as applied during the period January/March 1998. At the same time, Neste's past experience in Arctic navigation during the summer as well as the experience in winter navigation in the Canadian Arctic and Greenland has been taken into consideration.
Tables from Table 1 to Table 4 show economic calculations for voyage.

Table 1 The Budget - voyage calculation.

vessel	**mt " UIKKU "**		year	**1998**	voyage period	**April 21 - 00.00 Hrs / May 19 - 06.00 Hrs**	
voyage	in ballast from 96 Hrs prior to arrival Murmansk - Ob Bay (Sebeta) - Murmansk - DOP last Discharging Port						
currency : ECU = all in BOLD			**Exchange rates applied:**			**the ARCDEV voyage - expected time**	
amounts in font = local currency					**ECU**	**Voyage leg**	**Number of days**
				US$ 1	**0.9000**	Approach voyage	4.000000
				FIM 1	**0.1700**	Time in port	5.000000
				NLG 1	**0.45000**	Time at sea	19.250000
						Total time used	**28.250000**
cargo	quantity	daily hire in US$	**Total hire mt "Uikku"**	freight rate US$/Mton	brokerage %	comm. paid	**Net freight earnings**
gas condensate	13504 Mton	16000	452000.00 **406800.00**	65.00 **58.50**	0	0	877760.00 **789984.00**
Port disbursements			**Extra insurance**		**Cost of bunkers used**		
portdisb. in US $	disbursements	**disbursements**	US$ 100000.00	**90000.00**	Mton	price/Mton	**Bunker cost**
Murmansk (eastbound)	6000.00	**5400.00**			fuel oil 444.0	US $ 110	49284.00 **44355.60**
Murmansk (westbound)	12000.00	**10800.00**	**Icebreaker assistance**				
Discharge port (ARA -range)	22000.00	**19800.00**			diesel oil 198.0	US $ 170	33660.00 **30294.00**
Total port disbursements		**36000.00**	US $ 190000.00	**171000.00**	**Total bunker costs**		**74649.60**

Table 2 Timesheet of the "ARCDEV"- voyage.

(all times are stated in GMT - times)

mt " UIKKU "	DATE	TIME	TIME USED days	hrs	min	
APPROACH VOYAGE	21.04.98	05.25	-	-	-	
starts 4 DAYS prior to						
Arr. MURMANSK (roads)	25.04.98	05.25	4	-	-	s
Dept. MURMANSK (roads)	25.04.98	19.00	-	13	35	p
Arr. SABETTA	04.05.98	07.00	8	12	-	s
Dept. SABETTA	08.05.98	05.20	3	22	20	p
Arr. MURMANSK (roads)	13.05.98	22.30	5	17	10	s
Dept. MURMANSK (roads)	14.05.98	12.30	-	14	-	p
Arr. ROTTERDAM						
(anchorage)	19.05.98	08.50	4	20	20	s
(discharging berth)	19.05.98	14.35	-	5	45	s
Dept. ROTTERDAM (berth)	20.05.98	05.50	-	15	15	p
D.O.P. ROTTERDAM	20.05.98	06.45	-	-	55	s
	TOTAL TIME USED :		29	1	20	
		or :	29.055556 days			

	days	hrs	min	or days
Approach voyage	4	-	-	4.000000
Of which time in port	5	17	10	5.715278
sailing	23	8	10	19.340278
			TOTAL	29.055556

Table3 Voyage calculation - recap.

vessel **mt " UIKKU "**			year **1998**		voyage period **April 21 - 05.25 Hrs / May 20 - 06.45 Hrs**		
voyage in ballast from 96 Hrs prior to arrival Murmansk - Ob Bay (Sebeta) - Murmansk - DOP Rotterdam							
currency : ECU = all in BOLD amounts in font = local currency			**Exchange rates applied:**	(30.06.98)	**ECU**	**Time used for the ARCDEV - voyage**	
						Voyage leg	**Number of days**
				US$ 1	**0.9102**	Approach voyage	4.000000
				FIM 1	**0.1657**	Time in port	5.715278
				NLG 1	**0.4469**	Time at sea	19.340278
						Total time used	**29.055556**
cargo	quantity	daily hire in US$	**Total hire mt "Uikku"**	freight rate US$/Mton	brokerage %	comm. paid	**Net freight earnings**
gas condensate	10655.117 Mton	16000	464888.90 **423141.87**	65 **59.16**	0	0	692582.61 **630388.69**
Port disbursements			**Extra insurance**		**Cost of bunkers used**		
port - local currency	disbursements	**disbursements**	US$ 100000.00	**91020.00**	Mton	price/Mton	**Bunker cost**
Murmansk 25.04 - US$	6065.99	**5521.26**			fuel oil 675.5	FIM 439.65	296983.58 **49210.18**
Murmansk 13.05 - US$	11460.24	**10431.11**	**Icebreaker assistance**				
Rotterdam (disch) - NLG	44403.00	**19843.70**			diesel oil 88.0	FIM 708.12	62314.56 **10325.52**
Total port disbursements		**35796.08**	US $ 180188.00	**164007.12**	**Total bunker costs**		**59535.70**

Table 4 Cost comparison budget / reality.

Description	**C O S T S**	
	BUDGET	**REALITY**
T/C hire	406800.00	423141.87
Port disbursements	36000.00	35796.08
Extra insurance	90000.00	91020.00
Icebreaker assistance	171000.00	164007.12
Bunkers	74649.60	59535.70
TOTALS :	**778449.60**	**773500.77**

2.1.2 Conclusions

By comparing the budget figures against the real voyage costs, see Table 4, we learn that the total costs incurred are just below the budget figures. Therefore, one can conclude that, from a commercial point of view, future voyages are justified. However, we should not overlook the fact that the cargo shipped under the Arcdev-voyage was a cargo of gas condensate, a product which can afford a higher freight rate than f.i. crude oil; the latter product facing historical low market prices. As a consequence, the transport costs should be reduced considerable.
Special attention should also be drawn to the expected production quantities of crude oil and other cargoes to be shipped from the Arctic region into the European market. To move the expected

volumes of crude oil in an economical way, bigger size vessels are needed and we anticipate that special tankers with a deadweight capacity of 90,000 up to 120,000, or more, will be required. The size of the vessel to be used will be influenced by the restrictions of the respective loading place(s). Even by using vessels of TDW 120,000, loading a full cargo of crude oil or product, a minimum of one vessel every two (2) up to three (3) days will be required to ship the expected cargoes available from the Russian Arctic.
For example, "Double Acting Tankers", the so called DAT-vessels will introduce a new concept of icebreaking tankers, whereby an adoption of the local infra-structure becomes a must. The new requirements do not only focus on the terminals, the mooring and the loading facilities, but shall also take into consideration what we will call **"ice-management"** related matters.

Amongst others, the ice-management related matters shall include the availability and application of :

- ice-routing based on the modern IT-technology,
- a good working Vessel Traffic Management system (VTMIS) combined with, in case of need,
- a proper working system for salvage, rescue and oil pollution fighting.

Besides what precedes, an environmental friendly operation has to be guarantied. Consequently, one shall not overlook the needs of icebreaker assistance, if required. Indeed, the use of nuclear icebreakers is in contradiction with the Savannah Convention.
In case a nuclear accident should happen, the Owner of the carrying vessel is not insured against all liabilities and therefore, in the long run, we are in favour to recommend the use of diesel-electrical icebreakers instead of nuclear ones.
The possible costs for icebreaker assistance should be based on the common carrier idea with fees only payable when an icebreaker is needed and used. The fees should be calculated on the basis of the type of icebreaker and the mileage or time used for the assistance. Also, tariffs should not have to be negotiated case by case and therefore the tariff scale should be made public in advance.
All Governmental services and standard navigational aids should be for account of the Russian Arctic Administrations and could, if necessary, be invoices to the user of said facilities as a kind of fairway due.

2.2. Commercial voyage of tanker *Vilujsk*

The round trip of tanker *Vilujsk* as a part of the ARCDEV Programme covered several separate route sections. The ship arrived in Murmansk from Hamburg loaded with oil products for Dickson and Dudinka and other points on the Yenisey river. After having been unloaded in ports of Dickson and Dudinka the tanker in ballast passed to Kharasavey to be charged with gas condensate. From here the cargo was delivered to Rotterdam with a call to Murmansk for customs clearing.
In accordance with the contract, daily freight rate of the lease of tanker *Vilujsk* to the west of longitude 50°E was 9000 USD and to the east of this meridian - 13500 USD.
Passage of the tanker along the Northern Sea Route from the ice edge to Dickson was carried out under the support of icebreakers *Arktika* and *Sovetskiy Soyuz*. On the Yenisey River the ship was escorted by icebreakers *Taimyr* and *Vaigach* and on section Kharasavey - ice edge - by icebreakers *Vaigach* and *Rossia*.
Payment for the icebreaker support and services of ice pilots as well the use of fuel and eventual ship dues at berthing points was at the expense of the charterer.

The estimation of expenses on the commercial voyage has been made by the following expense items:

- chartering of ship;
- fuel expenses;
- ship's dues in the Russian ports and in the port of Rotterdam;
- icebreaker assistance to the tanker on the Northern Sea Route and in the loading point;
- miscellaneous expenses to support the Arctic voyage.

Chartering expenses of tanker *Vilujsk* have been determined according to the above contracted freight rates and period of stay of the ship in corresponding zones of their application. Dates of the crossing of 50° meridian are determined by captain's en route reports.
The fuel expenses have been taken into account for the whole time of chartering.
Expenses of the icebreaker support are taken into account by the icebreaker dues for the escorting of the tanker along the route. Total amount of these expenses was determined in accordance with rates for the escorting of Russian ships established by the Murmansk Shipping Company and being equal for this ship on the average to 11.6 USD/t.
In others expenses of the provision for the arctic voyage included the surveyor inspection, captain's bonus and overtime of crew, expenses of the removal of draining bilge waters, ice pilot services. The latter expenses in consultation with the Murmansk Shipping Company on the average for the round trip amounted to about 220 USD /day.
Principal technical, operational and initial data of the chartered ship needed for making further calculations are shown in Table 5.

Table 5 Initial technical, operational and cost data needed for the estimation of economical results of the commercial voyage of tanker Vilujsk

Initial data	
Overall length **L**, m	160
Breadth **B**, m	23
Depth **H**, m	12.9
L x **B** x **H**, m^3	47472
GRT	12196
Capacity of cargo tanks, m^3	17940
Pumps delivery, m^3/h	2100
Rate of the ship's rent, USD/day	
?? to the west of 50° E	9000
?? to the east of 50° E	13500
Fuel price, USD/t	
?? diesel fuel	147
?? motor fuel	88
Ice pilot service, USD/day	220
Ice due, USD/t	11.6

2.2.1 Calculation of operational and economic indices of the delivery of gas condensate from Kharasavey

While calculating operational and economic indices of the delivery of gas condensate from Kharasavey to Rotterdam the use was made of the reported data of the round voyage Hamburg - Murmansk - Dickson - Dudinka - Dickson - Kharasavey - Murmansk - Rotterdam.
Duration of the round voyage on this direction was determined by en route captain's reports and presented in Table 6.

Table 6 Calculation of actual duration of the round trip in the delivery of gas condensate by tanker Vilujsk *during the commercial voyage in April-May 1998*

Showing	Direction of transportation		Totally
	to the Arctic	from the Arctic	per voyage
Total distance, miles	3995	2332	6327
- international waters			
?? prior to the arrival in Murmansk	1516		
?? Murmansk – Rotterdam		1611	
- Russian waters	2479		
Including:			
?? Murmansk – Dickson	1385		
?? Dickson – Dudinka	360		
?? Dudinka – Dickson	360		
?? Dickson – Kharasavey		374	
?? Kharasavey – Murmansk		721	
Duration of the round trip, days	50.2	16.4	66.6
Including:			
?? On the move	29.2	10.0	39.2
?? in open water	9.2	6.2	15.5
- in international waters			
Hamburg – Murmansk	5.7		5.7
Murmansk – Rotterdam		5.3	5.3
- in Russian waters	3.6	1.0	4.5
?? in ice	20.0	3.7	23.7
?? at berth	21.0	6.4	27.4
?? in Murmansk	7.9	0.6	8.5
?? at Dickson	5.8		5.8
?? at Dudinka	7.3		7.3
?? at Kharasavey		5.0	5.0
?? in Rotterdam		0.9	0.9

The total operational costs incurred in connection with the delivery of cargo from Murmansk to Dickson and to the ports of Yenisey River and from Kharasavey to Rotterdam have been determined with regard to the basic data obtained from the invoices submitted to the charterer and presented in

Table 7. From the above data the average cost of the delivery of cargo for the round trip was calculated.

Table 7 Calculation of the actual cost of the delivery of gas condensate by tanker Vilujsk *during the commercial voyage in April-May 1998*

Showing	Direction of transportation		Totally
	to the Arctic	from the Arctic	per voyage
Cargo transported, ths. t	13050	9286	22336
Total expenses on the delivery of cargo to Rotterdam, ths. USD	1008	362	1370
Comprising:			
?? lease of ships	600.7	186.5	787.2
Including:			
?? Russian waters	549.7	131.3	681.0
?? International waters	51.0	55.2	106.2
?? fuel expenses	50.9	25.6	76.5
Including:			
?? Russian waters	37.8	16.1	53.9
?? International waters	13.1	9.5	22.7
?? ship dues	50.8	28.1	78.9
?? icebreaker support	180.9	78.0	258.9
?? provision for the arctic voyage	10.6	4.4	15.0
?? administration expenses	88.9	30.4	119.2
?? commission	25.2	9.1	34.3
Cost of the delivery of cargo, USD/t	77.2	39.0	61.3

It should be noted at the same time that this round trip while being a typical one is not the only alternative of the delivery of cargo for the Arctic. It is also worth considering versions of round trips to the Arctic with the delivery of cargo to one point of destination as well as with the transportation of gas condensate from Kharasavey to Rotterdam without being loaded in passing. In the latter case a ship is proceeding from Murmansk to a port of loading in ballast. On the basis of reported information on the considered round trip of tanker *Vilujsk* such calculations of the design character were carried out and gave the following results:

1. On route Hamburg - Murmansk - Dickson - Kharasavey - Murmansk - Rotterdam the duration of the round trip decreases on the average by 22 %, total expenses and cost of the delivery of cargo being reduced on the average by almost 20 %.
2. On route Hamburg - Murmansk - Kharasavey - Murmansk - Rotterdam the duration of the round trip is reduced more than 2.5 times, total expenses on the delivery of cargo - 1.9 times the cost of delivery, due to the decrease of the amount of the cargo transported, increasing 1.3times.

3. LEGAL AND ADMINISTRATIVE ASPECTS

Any vessel performing shipping actions in the Russian Arctic areas must comply with the strict control of Russian authorities. Aspects included are permission for the action, rules and regulations for classification and inspection of the vessel. Also aspects of formalities and fees collected in ports, immigration and custom formalities were found out in this work package.

3.1. Russian legislation applicable to Arcdev route

For sea traffic for the route from Murmansk to Ob Bay the following legislation and laws apply:

- The Law "On State Border on the RF" of 1993
- The decree on the Presidium of the Supreme Soviet of the USSR" on Economic Zone of the USSR" of 1984
- The Decree of Supreme Soviet of the USSR" On Measure to Improve Ecological Situation in the Regions of Extreme North and Sea areas adjoin the Northern Coasts of the USSR" of 1989
- The Decree of the Council of Ministers of the USSR of 1984 and 1985 promulgating "The List of Geographical Co-ordinates which Determine the Positions of the basic Lines for the calculation of the Width of Territorial Waters, Economic Zone and Continental shelf of the USSR.

The following documents are describing the regulations for navigating along the NSR aimed to ensure sea operations safety and marine environment protection:

1. Regulations for Navigation on the Seaways of the NSR of 1991

- Guide to Navigation through the NSR of 1996
- Provision on the NSR Administration of 1971

The international legal ground for regulation of shipping along the Northern Sea Route are provisions of Article 234 of the "UN Convention of the law the Sea, 1982 (LOSC 1982).

To call Arctic ports the foreign ship owners must use those ports which are listed by the government.

- For trading in Russian Economic zone a compulsory insurance is required and financial security issued for potential liability in case of marine environmental pollution.
- The present Russian legislation makes references to "UN Convention on the Law of the Sea" (LOSC 1982) in other words international law.
- The problem with NSR is that in practice it is considered by its legal status as domestic coastal cabotage.

By definition the ARCDEV project was an experimental voyage from Ob Bay carrying gas condensate to the western European market, in other words, international trade. In the event that in the future, the trade is considered coastal cabotage, the foreign ship owners are in a position, which will make the commercial adventure vulnerable by unforeseen detentions and unbudgeted additional costs. It is imperative also for commercial reasons that in the future, international trade is considered without any elements of cabotage procedures by authorities. As in our presentation of EU shipping policy we have stated that shipping activities of international nature must be handled by the coastal states in a way which, in practice, does not differ from the handling of domestic vessels. In 1999 the Committee of the Council of Federation on the affairs of the north and indigenous peoples suggested the following:

- To grant, stage by stage, an "international" status to the Northern Sea Route: to do this the Federal Authorities in association with the RRF Subjects concerned must ensure the fulfilment of the requirements meeting the status in question:
- To open a number of ports, stations and terminals (Dikson, Dudinka, Pevek, Tiksi) for calling by foreign vessels, to create in the above-mentioned ports, stations and terminals conditions for

servicing foreign vessels and activity of the boarder-guard, customs, sanitary and quarantine and other services exercising control at the State Boarder;

? ? To create conditions for raising the competitive capacity of the Arctic ports through reduction on taxes, stevedoring expenses, improvements of tariffs, generation of interest to be displayed by the exporters of goods in utilisation of the tonnage possessed by the Russian ship owners;

? ? To put into effect the "Regulations for the Icebreaker Fees on the Seaways of the Northern Sea Route". These rates should foster the development of the transit, regional export-import transportation of the goods;

? ? To develop and put into effect the new "Regulation for Navigation for the Seaways of the Northern Sea Routes". These regulations should take account of the provisions of the federal law "On the Internal Waters, Territorial Sea and Continuous Zone of the Russian Federation" of 1998 and the federal law "On the Exclusive Economic Zone of the Russian Federation", adoption of which is expected in 1999.

3.2. Comments to the legislation

2. In the Project's Proposal Technical Annex, following have been stated amongst other things:

? ? *"At the present, the all year round navigation is carried out up to the Yenisei River. The eastern part of the route is operated only during a short summer season of 2 to 4 months. The current freight volume is 2 million tonnes a year, but earlier the volume has peaked at 7 million tonnes. The sea route along the North Russian coast was opened for international use in 1991."*

? ? *"The commercial use of nature resources in North Russia is in the mutual interest of both Russia and the European Union. In order to realise these interests, the creation of the transportation system between the EU countries and the Arctic regions has a priority status. It is the advantage of the EU as well as Russia that no time is lost as the development times are always long."*

The facts that cargo volumes have been relatively insignificant and the current down trend is today in total 2 million tonnes in cargo volume constitute a situation where the business activities must be created almost from nil, powered with radical and innovative measures by entrepreneurial operators. Thus the Russian supportive legislation would be optimally encouraging, meaning incentives and not any unfounded restrictions of alien commercial approach.

3. The Committee suggests: "to grant, stage by stage, an "international status" to the Northern Sea Route".

A relevant question is how to attract foreign ship owners, investors, and bankers to enter into the project, which as such is high risk project. What does it mean to state development "stage by stage to international status"? In the long, future development must be run oriented towards commercial goals. The key issue is to create the volume "explosion" of cargoes and that competition of available cargoes must be fair with all companies who are participating in a high risk project. In our opinion, the phrase "international status" would mean that ship owners would be able rely upon the fact that the business environment shall be predictable and obey all customary procedures of global free trade.

4. The Committee has stated:

"to open a number of ports, stations and terminals for calling foreign vessels…"

Do they mean that those facilities shall be opened physically or, alternatively, that they are opening the market and inviting foreign investors to approach the market as to infrastructure and passing and applying western type legislation regulating investments, taxation and competition law? We presume that the committee means physical opening, but the latter wider interpretation of "opening" should be encouraged and targeted. Furthermore, the future infrastructure would be more versatile including services which are necessary for smooth trading without disruptions.

5. The Committee has suggested:

"to create conditions for raising competitive capacity of the arctic ports through reduction of taxes, stevedoring expenses…

…generation of intestates to be displayed by the exporters of goods in utilisation of the tonnage possessed by the Russian shipowners."

How to combine these goals, which are prima facie in discrepancy. There have been proposals and articles in the press, which are advocating monopolistic solutions for the exportation of oil products from Russia to Western Europe? Lower taxes and tariffs can be surely achieved through legislation and administrative procedures. The positive trend with decreased costs for stevedoring terminal activities cannot be achieved without tools of market economy, in other words, passing laws and regulations in favour of environment of competition.

6. The Committee has proposed:
"to put into effect the "regulations for the Icebreaking Fees…"

The well-founded question is whether the goal for reasonable fees of ice-breaker assistance can be achieved merely by administrative directives and guidelines without any further, more profound actions. Ice-breaker services are an "essential facility". There are ten diesel and nuclear powered ice-breakers available for NSR. Those icebreakers are managed by MSR and FESCO. Due to the fact that ice-breaker assistance is "*conditio sine quo*" for trading in NSR, it is important to analyse how the market could be provided with best possible quality service at a reasonable level of costs. The ice-breaker services along NSR are today monopolistic and we have not seen any indication that the situation would change in the future. In the long term, it is necessary to invite foreign competition for ice-breaking services. The current international trend with ice-breaker design is to build sc. multipurpose ice-breakers which can provide services world wide, but in the short term some kind of basic rules of competition law would be applied to icebreaker services in NSR. From an experimental and demonstration-oriented voyage from Ob Bay to Murmansk and previous experiences we may draw a conclusion that not only the fees for ice-breaker services are excessively high but there are questionable elements in the services provided which would be counteracted by western type competition laws.

It is noteworthy that the same company which is competing with western ship owners is running ice-breaking services. It is an obvious conflict of interests in case the company which has the essential facility, i.e., ice-breaking services; is in competition on cargoes in the same relevant market. Furthermore, the final act of ship access to the selected route is a contract between the ship owner and the ice-breaker owner (Master on one hand, and the representative of the MSCO or FESCO on the other hand). Thus the competitor may at, his discretion, deny access to the selected route.
The regulations request a mandatory insurance and financial responsibility issued by the foreign ship owners who are entering into Economic Zones of Russia.

With regard to the ice-breakers' responsibilities and insurance cover we wish to point out following:
- According to Regulation for Ice-breaker leading Article 3.1., the ice-breaker Master and her owner bear no liability for damage caused to the vessel by ice leading. If the Master of vessel led by ice-breaker or State Ice Pilot has damaged, through his wrong manoeuvres, either the ice-breaker or another vessel, the liability, in accordance with RF legislation, will lie with the ship owners.
- The said type of exoneration of responsibility is not uncommon in trade, but we have to bear in mind that some of the assisting ice-breakers are nuclear powered, constituting additional complexity as to liability issues.
- It is common knowledge, that nuclear related risk are beyond the scope of cover under all marine insurance policies. Thus any kind of nuclear related incident or liability would be sorted out in a way that bona fide ship owners would be held harmless. Uninsured nuclear risks are alien to western operators and an obstacle to make reliable risk assessment for investors. In a logical sense those who gain profits from using optional nuclear fuel would solve the problems with additional insurance costs and liabilities in case of incidents. The same kind of solution should be applied as in the western world with nuclear plants which means that all liability related to nuclear fuel is for the account of the operator of the plant. The assisted vessel cannot choose what kind of fuels are used on ice-breakers. In a competitive insurance market there are certainly capacities to provide additional nuclear liability cover for those who are running ice-breaker services commercially.

7. "To develop and put into effect the new "Regulation for Navigation on the Seaways of the Northern Sea Routes"

NSRA is still issuing "permissions" after inspections of the vessel according to "Requirements for the Design; equipment and Supplies of the Vessels Navigating along NSR". This kind of applications of "permissions" may cause additional delays, which are considered to be on the account of ship owners under most charter parties. Therefore it might be advisable that standard printed charter parties should be added with relevant rider clauses providing the ship owners protection for circumstances which are beyond their control. Provided that NSR would in the future be a customarily run commercial operation, it would necessary to harmonise the procedures by authorities with the rest of the world. Even if the international law with relevant conventions provides extensive rights for the coastal countries those rights should not be taken as "de minims".

NSR is today, with regard to the nature of authorities' practices, classified as "coastal cabotage". The objective of ARCDEV is to create a transportation system which will provide services to international commercial services, in other words, transportation of oil and other bulk cargoes from Russia to western European countries.

8. The fact remains that even if the most optimistic view would be reality with regard to revision of relevant legislation, it is most probable that commercial activities require such instruments which are not realistically available in the near future in NSR.

Therefore, we would recommend parties who, acting in mutual interests, have a flexible approach and have multilateral, legally binding private contracts in order to establish a friendly businesslike environment with a fair, balanced and reasonable split of rights/obligations, rights/responsibilities and profits/losses. In those multilateral, legally binding agreements, a neutral choice of law and enforcement should be agreed between parties. With regard to civil law, this would be a preliminary solution to lift unpredicted uncertainties. Even if operations in NSR are maritime related activities, it goes without saying that the necessary infrastructure comprises a network of relevant legislation, i.e.

? ? contract law
? ? sales law
? ? corporate law
? ? banking law
? ? bankruptcy law
? ? international private law
? ? criminal law
? ? currency regulations

From experience we can tell that shipping activities may tangle all of the examples and more.

9. The problems which are related to insurance cover.

We would wish to mention some of the general problems involved:

A. The trading area is beyond the scope of customary insurance cover.
B. The customary period of insurance is restricted.
C. The underwriters lack experience, data and knowledge of NSR. According to the information available to us, the underwriters or any other companies involved in the project have not made a comprehensive risk analysis of the ARCDEV project.
D. The insurance companies lack a network of local correspondents.
E. In Russia the legislation with regard to insurance companies and their activities has not been westernised.
F. The Russian contracting parties to western oil and shipping companies lack sufficient insurance cover. Furthermore, their business partners and sub-contractors also have inadequate insurance cover.
G. The underwriters of western companies have considerable problems to arrange re-insurance contracts covering the risks of operations in NSR.
H. The western companies have considerable unpredicted risks, which might not be covered by their underwriters, due to the fact that under extreme circumstances with unconventional working methods involved. Under the underwriters statues and rules there might be incidents, which are beyond the scope of ordinary insurance cover.

In order to achieve satisfactory insurance arrangements with reasonable rates, the following improvements would be required:

? ? financial security arrangements by Russian partners
? ? financial security arrangements by involved governments and authorities

- tailor-made insurance arrangements
- to contribute in POLAR CODE project by IMO improving risk analysis and loss prevention
- an obligation for the Russian partners and their sub-contractors to arrange western style insurance arrangements
- natural limitations for operations, which would cause western operator's unreasonable, unpredictable, uninsurable risks (risk assessment)

10. Specific problem: "Lex Savannah"

The fact that nuclear powered ice-breakers are widely used in NSR creates a specific problem related to insurance cover. In the western world, nuclear powered vessels are not used commercially due to "*Lex Savannah*". When nuclear powered vessels were suggested to be used commercially, the coastal countries passed laws which prohibited nuclear powered vessels to trade with the respective countries. The marine insurance underwriters adjusted their coverage accordingly and excluded insurance coverage for any kind of consequences of damages from radiation of nuclear materials. To our knowledge, the Russian nuclear powered ice-breaker operators do not have any liability insurance which would cover for any kind of consequence of nuclear related incidents, which in turn are today not easily insurable risks for the western operators. As we have mentioned, this problem constitutes a troublesome equation to solve. The ship owners are provided services which deprive their insurance cover and they expose themselves for risks which are not accountable. Primarily this would be a problem of operating ice-breakers which have problems to fit in westerns type of trading.

3.3. Recommendations for the future

Russian economy is in transition. The state owned industries are under process of privatisation. An extensive revision of legislation is carried out to meet the requirements of market economy. The process is rapid but for those who are making strategic investments in Russia it is still painfully slow. With regard to existing industries, the transition is extremely difficult for a variety of reasons. However, the projects of developing the northern part of Russia might be an opportunity to proceed in a way which is not feasible in other parts of Russia. As we have described in our report that the cargo volumes which are carried in NSR are negligent with regard to potentials. Starting from scratch is an opportunity which might open up avenues to experiment with a western way of doing business.

The present legislation in Russia is merely a platform to proceed with experimental voyages. The European Union might accelerate the development by negotiating bilateral agreements with Russia for harmonising the procedures. The oil and gas is primarily intended to be used in Western Europe by ultimate users. That is why it would be in mutual interests both for Russia and the European Union to develop NSR towards full-scale commercial application.

4. ICE CONDITIONS

4.1. Objectives

The objective of WP 3 was to create basic material on ice conditions for the other Work Packages and to demonstrate the methods used for determining the ice conditions. The conditions are to be described both locally in much detail and more globally along the route. The local description were done from the vessel on her way. The objective of this report is to summarise the work that has been done during the ARCDEV project and to present conclusions and potential improvements in ice research with respect to vessel traffic in the Arctic.

4.2. Research methods

Work Package 3 contained various different ice research teams, who did their specified part of the research work. Each team made a separate report of their own activities during the project. Some of the research was on the go 24 hours a day (e.g. ice watch), some research was occasional during the voyage (e.g. satellite image analysis, ice reconnaissance flights) and some research was done only during the times, when the convoy was stopped for research (e.g. field research on ridges).
Following ice observations and measurements were conducted or acquired during the ARCDEV project.

1. Remote sensing
   - METEOR, OKEAN and NOAA satellite images were used to determine general ice situation in the sea area more globally (AARI, HSVA).
   - RADARSAT and ERS-2 satellite images were used to determine ice situation and the dynamics of the ice cover along the route and also more globally (NERSC, AARI).
   - Laser profilemeter flights were made to determine ridge height and ridge density (HUT).
   - Electro-Magnetic (EM) measurements were made to measure the apparent ice thickness along the route from the ship (HSVA / AWI)
   - Visual observations were made from the bridge of the vessel to determine different ice parameters along the route, two groups (HSVA, MTW / AARI, KSRI).
2. Ridge property measurements
   - Thermal drill measurements were made to determine ridge thickness and the inner structure of the ridge (KMY).
   - Sonar scanning was made to determine the underwater geometry of the ridge (HSVA).
3. Level ice property measurements
   - EM-measurements from ice were made to measure the level ice thickness (HSVA / AWI).
   - Motor auger was used in drilling to determine the level ice thickness (KMY).
   - In situ cantilever beam tests to determine the flexural strength of ice (AARI).
   - Ice temperature measurements from core samples (KMY)
   - Ice density measurements (KMY)
   - Ice salinity measurements (KMY)
   - Flexural strength tests from disc samples (AARI)
   - Flexural strength from salinity / temperature samples (KMY)
   - Uniaxial compressive ice tests (KMY, AARI)
   - Drop ball tests (KSRI)
4. Snow property measurements
   - Snow thickness measurements (KMY, HSVA, AARI)
   - Snow density measurements (KMY)

Data was acquired during and prior the from various different sources. From time to time the convoy was stopped to enable ice teams to do field ice research. In total 6 sites were studied along the convoy route, from which one was at the loading point in Sabeta.

4.3. Operation experiences

This section does not contain detailed information of the ice research results, because the data amount is so vast and the results are presented in the separate deliverables in D5 (see Appendix A). The intention of this section is to give operation experiences from the ARCDEV project and also to have a general description of the success of different ice research tasks in Arcdev project.

4.3.1 Satellite data

Satellite information can be made available on board real-time or near real-time. Remote sensing from satellite is essential for proper ice navigation and the availability of satellite based information is good. Images from weather satellites are relatively easy and cheap to receive, but western SAR images (ERS-2, RADARSAT) are relatively expensive and their availability has to be ensured beforehand. If only one vessel is using and paying for the SAR images and their analysis, then the price of the service is high, but if the same SAR images can be used to help convoy(s) with several vessels, and the price per vessel is reduced then the service is worth the price.
Due to their large image area and poorer resolution weather satellite data was mainly used in strategic navigation, where the route selection time window was more than one day. SAR images were used mainly in navigation, where the time window was generally less than two days. This is because their image area is smaller and image resolution is better.

4.3.2 EM measurements from the ship

Ice thickness measurements from ship did not go according the plans, since the EM-device could not be installed on the leading icebreaker. The system was not far enough away to enable to profile the undisturbed ice next to the channel broken by the leading icebreaker Rossia. Thus, almost all measurements were performed over the highly broken and disturbed ice at the boundary between the channel and the original ice floes
However, the measurements from IB Dranitsyn showed that even when following the leading icebreaker relatively good results can be achieved. The results from the EM thickness measurements correlate fairly well with the ship speed, although the measurements were not made from the leading icebreaker. The difference between measurements from the leading icebreaker and a ship, which follows behind in the channel, is not known.
Due to technical reasons the thickness measurments are averages over a larger area. This means, that absolutely correct results are derived only over undisturbed, level ice. As soon as the ice is rough or disturbed, only average thicknesses are derived. In the case of fragmented ice floes like at the edges of the icebreaker channel, the water (ice thickness = 0) aside the floe fragments always contributes to the average thickness as well. Therefore, the measured thickness will always underestimate the true thickness. Therefore the given ice thicknesses should only be taken as 'apparent ice thicknesses'.

4.3.3 Laser profilemeter measurements from helicopter

The quality of the ridge data is good, and e.g. in the Kara Gate showed average ridge heights up to 3-times higher than in the Baltic Sea. One problem was that the helicopter did not have GPS onboard during the measurements and therefore the georeferencing accuracy of the data is very poor. Therefore no comparison can be made to visually observed ridge heights and ridge spacing distribution.. Also the comparison to ship performance is impossible.

4.3.4 Visual ice observations from IB Kapitan Dranitsyn

All the visual ice observations in WP 3 were made from IB Kapitan Dranitsyn. There were two observation groups: one western group and one Russian group. Since the observations were done by two different groups, there was a good opporturnity to compare the results of the two groups. This comparison showed significant differencies between the two groups. E.g. the Russian observation group divided the whole voyage to 704 separate sections, while the westerm group divided the whole voyage to 194 separate sections. This can be partly due to the fact that the first group had more ice parameters under observation than the other. The interpretation of an ice parameter can change between observers and the effect of the ice parameter on the convoy speed can also change from time to time. E.g. the overall ice concentration is generally relatively easy to determine, but when one thinks of the ice concentration that the ship “sees” or meets, the result may be totally different, when the vessel is making it’s way along a lead or a polynya.
Overall the differencies between the two groups were remarkable and this raises the question about the goodness of visual observations in general. The observed ice situation changes with the observer

and obviously also with e.g. the lighting conditions and with the vigor of the observer. This leads to a situation, where two different ice observations are not directly comparable with each other, if accurate comparisons are needed. Therefore new methods, which are not sensitive to the above mentioned facts, should be developed.

4.3.5 Thermal drill measurements of ridge thickness and inner structure

Minor technical problems slowed the thermal drill research at the first site North of Novaya Zemlya. After the first site field work in general went smoothly, but ridge studies are so time consuming that only one big ridge can be studied in 4 to 6 hours.

Since ridge and level ice geometrical and structural properties can vary a lot even in the same sea-area, it would be important to have frequent research opportunities and have different size ridges studied. It generally reguires more than 20 ridges in the same sea area to enable statistical analysis of the acquired measurement results.

During the voyage there was a chance to do research only on one site per sea-area. This means that the results — especially average and minimum values — can be biased, since the ice group usually tries to find the largest ice feature in the area. Statistical analysis of scarce data is useless and can give misleading results.

4.3.6 Sonar scanning of ridge underwater geometry

Sonar scanning had also technical problems in the beginning. This was mainly due to a new sonarscanner that was tested in the project and required some fine adjustments.

Sonar scanning is also time consuming and therefore no statistical analysis of the results is meaningful. The same that was said about the amount of data for the thermal drilling applies in this case with sonar scanning.

The observed maximum ridge keel depths from sonar scanning are higher than from thermal drill measurements. This phenomenon has a simple explanation. The thermal drilling was done at distinct points, which were 2.5 m—5.0 m apart. Therefore it is very probable that none of the selected points are not at the very deepest point of the keel. Sonar scanning on the contrary measures a grid that is dense and therefore it is probable that the values are higher than with thermal drilling. When comparing the results, the maximum values from the sonar were approximately 2 m higher than with the thermal drill at hole distance 2.5 m—5.0 m.

4.3.7 Level ice thickness measurements from ice with EM-device and with motor auger

EM-measurements and auger drilling from ice are easy to arrange and are not very time consuming. The results of the level ice thickness measurements showed good correlation to level ice thickness measurements from auger holes. On the average the EM-measurements showed slightly higher values than drilled results. The difference increased, when the ice was rafted and there were voids in the ice. Voids and ice rafting make the analysis of the EM signal more difficult.

4.3.8 Ice property measurements

As a whole the project got ample ice and snow property measurements. The results of these measurements were in line with previous studies from the same sea areas. The only drawback was that cantilever beam tests, could be arranged only at the last site, where there was enough time to perform these measurements. At the loading place, where there was ample time to do measurements, the ice was too thick (2 m) for cantilever beam tests with the equipment onboard.

4.4. Conclusions and recommendations for future work

Key element in succesfull operation in the Arctic is to know the ice conditions and to have good enough an estimation of how these conditions will change in the near future. This information is needed both in route planning and in loading terminal operations.

Problem with ice research is that ice conditions vary with the weather and therefore an ice situation at one location at a certain time is not likely to last very long. When planning continuous winter operations, one has to keep in mind that ice conditions are prone to change with external influence (e.g. frequent ship traffic). This is especially the case in shallow and narrow places — such as harbours, offshore loading points and rivers.

Occasional measurements give only information of what the situation is at the moment of the measurement, and possible annual and interannual variation is left to educated guessing. Thus, to get a picture of the probable ice conditions at a specific location, systematic ice observations and measurements are needed.

Data gathering is to be made during several consecutive years, which comprise both hard and mild winters. Measurements should be carried out with different methods to check for inconsistency and to backup the results.

Due to the time consuming nature of field ice studies, comprehensive ice measurements cannot be done over a large sea area, but the investigations should be concentrated to specific, limited areas. The am ount of data gathered should be large enough to enable statistical analyses. This is especially needed for the ridges.

However, there is also a great need to understand the general ice condition to be able to handle transportation tasks and to better understand the development of the local conditions. It is recommended that the development of ice conditions throughout a winter in a smaller area is needed to better understand also lighter conditions and the ice movement.

Large scale ice conditions (satellite imaging and air reconnaissance flights) should be studied simultaneously to be able to provide calibration data for remote sensing measurements.

Based on the data gathered during the field work, an Ice Forecast Model should be developed to enable planning and operation of large scale transportation in the Arctic Sea. The model should also have a connection between ice state and the transportation logistics planning.

It is difficult to do basic ice property data gathering during a voyage with commercial interests. On the other hand measurements and observations, which are directly related to ship transit and do not delay the convoy speed are relatively easy to arrange. A continuous automatic ice state follow-up / measurement systems, which can operate during commercial voyages should be developed and implemented on ships operating in the Arctic.

It should be carefully thought beforehand, which kind of research is suitable to be performed from a commercial convoy with tight schedules to follow. Valuable statistical results can be obtained from commercial convoys, and these kind of opporturnities should be arranged more often. In the end this would benefit both the commercial and the scientific aspect.

Pre-planning and scheduling of in situ ice measurements during the ARCDEV voyage was difficult for one reason or the other. However, during in situ measurements the co-operation between different groups worked well and despite of various difficulties the field work was successful.

One thing that arise during the ARCDEV project was that there is usually a general agreement of how the basic ice property measurements should be done and analysed (beam tests, compression tests, density measurements etc.) and that the results of different groups are or should be comparable.

There are, however, several ice research methods, which are relatively new or at a development stage, and from which there is no general conception. Common about these methods is that there is no commonly agreed procedure of how the measurements should be analysed and how their results compare with the results from old methods. Generally these methods deal with larger scale ice properties and remote sensing, but there are also methods, which handle basic ice properties. Another common thing is that the results of these new methods differ from the results of the old methods in one of the following way:

- The new methods basically measure the same thing as the old methods, but the approach is such that the results differ (e.g. laser profiling vs. visual observations of ridge height or 3D measurement of ice surface vs. laser profiling)
- New methods can be some kind of combination of parameters measured with old methods (e.g. EM-measurements from ship vs. visual observations of level ice thickness and ridge height)

New methods can of course bring out totally new ice parameters. There can also be semantic differences in the results, i.e. same word(ing) can mean different things. E.g. 3D-measurement result of ridge density would generally be ridges per km², while laser profilemeter flight result is ridges per km along a relatively straight line. On the other hand visual observations or measurements from a ship give ridges per km along the ship track.

It is important to be aware of the differencies of the new methods vs. the old methods and co-operation between different research institutions should be done to minimize misunderstandings in this respect. A critical eye is needed in the development and introduction of new ice research methods and care should be taken that the research does not scatter too much. Value for the ice research work does not come from changing the research method as often as possible, but from a systematic and continuous follow-up.

In the following chapters the main conclusions of different tasks in WP 3 are concluded and recommendations for possible future projects are presented.

4.4.1 Satellite data

Satellite data is the most important component of ice navigation support and played a leading role in the route planning in the ARCDEV expedition. Different kinds of satellite data is needed to cover both local and global ice conditions.

Even if satellite data is good, some of the ice parameters cannot be determined remotely. Some ice conditions cannot be identified reliably with SAR instruments and therefore some form of backup data is needed. SAR data availability is also still insufficient to cover constantly large sea areas in the Arctic. The cost level of the western SAR data is also still too high for commercial shipping, if only one vessel is buying the product. Satellite data analysis could further be improved by using multi-spectral analysis methods. The first steps could be e.g. to combine visual and IR light sensor data with SAR data.

The ice chart plotted from the RADARSAT image at EOS -UK and transmitted to the icebreaker via INMARSAT contained in the opinion of ice experts a significant number of interpretation errors. A part of this error probably due to the fact that the images were not received through Norway, and the calibration of the automatic system was for the Norwegian system. The automatic interpretation needs still development, since there are some ambiguities for certain ice conditions.

Conclusions of SAR usage in the ARCDEV project

1. Satellite Synthetic Aperture Radar (SAR) images provides ice information useful for determination of several types of ice conditions of relevance for operational, strategic and tactical ice navigation.
2. The availability and frequency of SAR data coverage are still insufficient to meet the operational requirements at an acceptable cost level.
3. The interpretation of ice information content of SAR images includes ambiguities for certain ice and ocean conditions.
4. Different SAR sensor systems have different ice imaging capabilities and these needs to be taken into account in the image interpretation.
5. The information content in a SAR image is too complex and detailed to be classified to a traditional type of ice map, hence direct on board use of the images are relevant for operational navigation use under certain ice conditions and applications.

Recommendations for future SAR development projects:

1. Further research and development of the classification routines used on SAR and other EO data for determination of sea ice conditions, including muti-sensor satellite data strategies and use of auxiliary information sources. Prepare the state-of-the-art classification routines to take advantage of the technical improvements in future spaceborne radar systems.
2. Impose the space agencies in the requirements to and design of future earth observation missions related to sea ice monitoring.
3. Analyse and use the huge amount of SAR data available since 1991 for the Arctic regions to improve the knowledge of ice conditions, their annual and inter-annual variability of relevance to ship navigation, design criteria for ice going vessels and for the identification of potential loading sites in the region.
4. Investigation of use of SAR technology for determination of wind conditions in open leads is of importance for prediction of the wind conditions over ice. This information is further essential for improvement of prediction models for both meteorological and ice dynamic predictions.
5. Develop models for predictions of ice conditions included techniques for data assimilation of EO based information in the prediction models.

The deficiency of ERS information is a narrow swath width and significant ambiguity (this is also typical of the RADARSAT data) in interpreting the ice cover parameters.

The METEOR and NOAA imagery is not perfect either and the ice cover survey through clouds is impossible. From experience, the period of the absence of sufficient information on the ice cover state in the Kara Sea can be as long as a week under unfavorable cloud conditions. This deficiency is compensated to a great extent by the possibility of obtaining up to five Meteor images a day for one and the same region selecting separate cloud-free zones.

The cost of Meteor data (the information itself is free of charge and money is needed only for data receiving and processing) is incomparable with the high cost of RADARSAT data (around 4000 $ for a 500 ? 500 km fragment). The latter necessitates a careful approach to selecting the survey regions and the amount of information requested. The most optimal way for providing ice navigation support is a reasonable combination of satellite data at different spectral ranges. The expensive RADARSAT data should be primarily used in the areas of low mobile ice and in the most difficult ice navigation areas.

Further im provement of the satellite block in the system of hydrometeorological support for ice navigation should be accompanied by the development of automated technologies for a combined decoding of different spectral range data based on the automated procedures and all available hydrometeorological information including the regime and model calculation data.

Continuous ice cover monitoring is particularly important for a successful functioning of such a system allowing to follow the temporal and spatial changes of its state and improve the quality of interpreting current satellite images that are used for supporting ice navigation.

4.4.2 Laser profilemeter flights

Laser profilemeter data gives valuable information of the ridge height and density. The drawback of the sys tem is that if only one or few flights are made in the research area, the 2D data does not necessarily give enough information of the ridging in the area. E.g. if the ridges have a prevailing direction there is a great difference in the results, if the flight direction is parallel or perpendicular to the dominant ridging direction.

To get proper idea of the ice surface shape a dense flight grid should be used. This would take a lot of flying time with a 2D measurement system and the cost of this kind of investigation would be high. To overcome the problem, existing 3D measurement systems should be developed to suit to ridge and lead detection, floe size analysis etc. Because there is a large amount of data from 2D laser profilemeter flights, a calibration system between 2D and 3D data should be developed.

4.4.3 Electro-Magnetic (EM) measurements

Problem with the EM-measurements was that it was not done from the leading icebreaker. In future measurements it should be emphasized that the EM measurements are always to be performed from the leading ship, otherwise the results are inaccurate.

No comparison of the ARCDEV data can be made to previously measured data, since they were done from a disturbed ice field. Despite of that, the ARCDEV project has shown that ship-based measurements of ice thickness are well suited to explain a great deal of the performance of a convoy. Other similar measurement occasions should be arranged to confirm the relationship between EM-measurements and ship performance.

Since the convoy speed reacted to the same things as the EM-measurements reacted, EM-measurements with real-time or near real-time analysis could effectively be used as an ice reconnaissance tool from a helicopter or an unmanned aerial vehicle to help to select the optimum navigation route through ice.

4.4.4 Visual observations

Visual ice observations give a general idea of the ice conditions in an sea area, but the ARCDEV project has shown that between two independent groups the observed results can differ a great deal. This difference is due to several reasons, which cannot be eliminated. Education and training can reduce the tolerance in the observations, but the fact remains that even such obvious causes as lighting conditions can change the opinnion of an observer of the ice conditions. If only a general idea of the iceconditions is needed, visual observations work well, but if one wants to compare the results in detail, more reproducible measurement systems are needed. New technologies should be tested to replace the human observer.

4.4.5 Ridge property measurements

Sonar scanning and thermal drill measurements of ridge properties require much time since one big ridge can be properly studied in 6—8 hours. The tight schedule during the ARCDEV project lead to a situation, where only one ice station per sea area could be arranged. When examining the results, one should keep in mind that the variation of the ridge properties is great even in smaal areas. The data acquired during the ARCDEV project does enable any conclusions to be made about the size of the variation.

To get the most out of future projects, data gathering should be made during several consecutive years, which comprise both hard and mild winters.intensive long time reasearch. Investigations should be concentrated to specific, limited areas, which are probable offshore terminal sites. The amount of data gathered should be large enough to enable statistical analyses.

4.4.6 Level ice property measurements

Although level ice property measurements are the kind of measurements, which have been practiced the longest time, there sill is some development in the area. EM-technique is relatively new in the field, when compared to e.g. level ice thickness measurements with auger. Drob ball testing is common practice in Russia, but western ice society is still having discussion of the theoretical background of the testing and therfore it has not become general in the western countries.

When the calibration is right, EM measurements have a good correlation with the auger measurements of the level ice thickness. If there are large voids in the ice or the ice is rafted, the measurement results differed, since the interpretation of the EM-signal becomes more difficult.

Basic ice property measurements showed results that were in line to previous measurement from the same sea areas. Some overlapping of work did occur, which should be avoided in the future expeditions.

Some ice property measurements do not require long stops, because the ice specimens can be taken relatively fast and they can then be tested onboard. The most reliable flexural strength test, which is cantilever beam test requires quite a lot of time especially in thick ice. Non destructive testing methods for flexural strength should therefore be studied to enable flexural strength testing even during normal commercial voyages

5. SHIPS NAVIGATION TECHNICAL AND OPERATIONAL ASPECTS

Subject of navigating in Arctic areas was studied in the Arcdev project in three separate work packages. During the voyage the vessel related technical data were recorded all the time in order to faciliate it to other related work packages and future development of trafficability models. Arctic navigation demands different ways of passing through ice fields than normal seafarers are used to. This includes several aspects like route finding, icebreaker assistance, tactical manoeuvring of the vessel, whether and ice forecasting and operation with Russian administration.

The work packages decscribed in this chapter include:

1. Ship Performance
   Acquisition of experimental data how the different ice conditions in the Arctic will influence ship performance and will give recommendations on how this should be considered in trafficability models.
   On all vessels involved in the demonstration and exploratory voyage navigational, machinery, and propulsion data will be continuously acquired in high frequency.
   These data will be processed and validated and facilitate also other work packages for conduction of their specific tasks.

2. Ice Routing
   Creates of basic data for verification of different methods for ice routing.
   The demonstration and exploratory voyage also serves as a test case for development activities of methods for route forecasting and optimisation in the Arctic for a related EU project called Ice Routes.

3. Navigation and Operation
   Determination of manoeuvring and operation times and techniques during the voyage of the tanker both alone and with icebreaker assistance as basis for proposals how to reduce the transport time.
   These investigation also includes the flow of information between tanker, icebreaker and the Russian administration.

5.1. Acquisition of experimental data

The basic objectives of WP 4 was stated in the Technical Annex: “To create experimental data on how the different ice conditions in the Arctic will influence the ship performance and to give recommendations on how this should be considered in trafficability models.”
To achieve this goal the following measurements and observations were conducted during the voyage:

1. Position, speed and direction of the ships (MT Uikku, IB Kapitan Dranitsyn)
2. Machinery m easurements
   MT Uikku: Power, propeller rpm, Azipod angle
   IB Kapitan Dranitsyn: Shaft power, propeller rpm
   NIB Rossiya 4 hour average power logging
3. Ice data from WP 3
   Visual observations from the bridge
   EM ice thickness measurements
   Ice property measurements at selected sites.
   Laser profilemeter flights

Convoy performance in different ice conditions along the route is evaluated and the measured machinery parameters and logged navigation information are combined with the observed and measured ice parameters to make theoretical predictions of the convoy and vessel speed. The theoretical predictions are then compared against the actual speed to be able to evaluate the goodness of different methods and to improve the used theoretical methods and models.

5.2. Machinery data

This section describes the nature of the measurements and how they were made onboard MT Uikku and IB KAPITAN DRANITSYN during the ARCDEV voyage. A brief description of the succession of the measurements is also given.

PRIMARY SOURCES OF THE MACHINERY DATA

MT Uikku

Machinery data from MT Uikku was recorded with a computer and with a digital tape recorder (DAT recorder1). The computer was used to calculate 20 minute statistics of the measured signals and the DAT recorder was used to store the measured signals. The measured signals are presented in **Error! Reference source not found.** on page 36. The original sampling frequency of the system was 600 Hz. This high frequency was used because the same system was used in the hull load measurements, which required high frequencies. The 5 Hz signal was obtained from the high frequency signal by calculating 30-point moving averages for the original signal. Figure 2 shows a schematic view of how the measurements were carried out during the ARCDEV voyage.

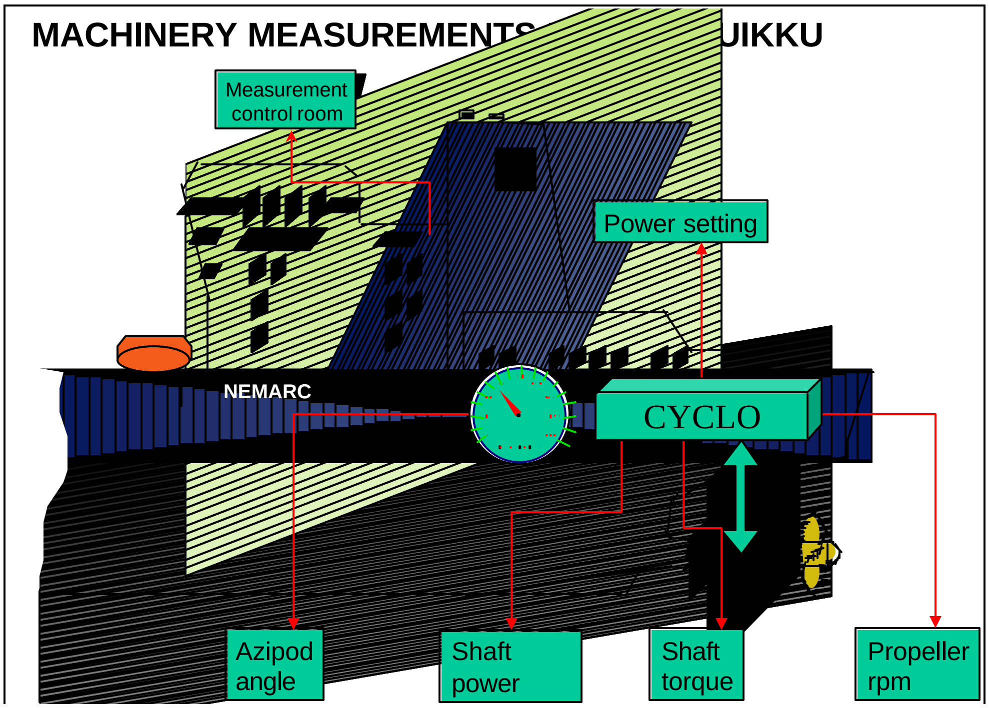


Figure 2. Machinery measurements onboard MT Uikku.

Succession of the measurements

Basically the measurement system worked very well. One problem was discovered in the analysis phase, while converting the measured signal from the digital instrument recorder to computer:
The error correction system of the DAT instrument recorder got sometimes stuck in correcting the measured signal. This lead to some data losses. The time with no data was 10:13:09 on the way from Murmansk to Sabeta and 06:51:45 on the return trip. Total time of recording onboard MT Uikku was 232.6 hours.

1 Racal-Heim DATaRec A160, 32 channel, DAT- digital instrument recorder

IB Kapitan Dranitsyn

Machinery data from IB Kapitan Dranitsyn was recorded with a computer through an A/D measurement board. The computer measured automatically 20 minute data files, which it saved to the computer hard disk. Measurement frequency was 5 Hz for all the five channels that were measured.

In case the day of the month was less than 10, the day was presented with a single digit. The whole dataset is in 1153 files. During the time the ship was stopped for research work, 346 files were recorded. Data from these 346 files was not analyzed, thus, the total amount of analyzed files is 807. Pauses between the files lasted in general 10—12 seconds, which was the time it took to save the signals to the computer hard disk. Backup procedure, which occurred once per day, took some 20—40 minutes each time.

5.2.1 Installed systems for data logging

MT Uikku

All of the measurements were made from the ship's own instrumentation. Preparations for the measurements consisted of:

1. Designing and planning of the measurements.
2. Installation of the measurement cables from the machinery room to the pilot cabin, which acted as the measurement centre.
3. Testing of the cables.
4. Installation and checking of the measuring computers, DAT recorders and the ancillary equipment.
5. Connection of the cables to the signal sources and to the measuring system.
6. Checking and calibration of the whole system.

No additional transducers were installed. This means that e.g. the propulsion motor torque is calculated from the electric properties of the Azipod propeller unit. The measured machinery parameters and their signal sources are presented Table 8. General signal cabling arrangements are presented in Figure 3.

Table 8 Measured machinery parameters and signal sources, MT Uikku.

Quantity	Signal source
Azipod angle	Azipod angle indicator
Propeller rpm	Cyclo converter output
Power setting	Cyclo converter output
Propulsion motor power	Cyclo converter output
Propulsion motor torque	Cyclo converter output

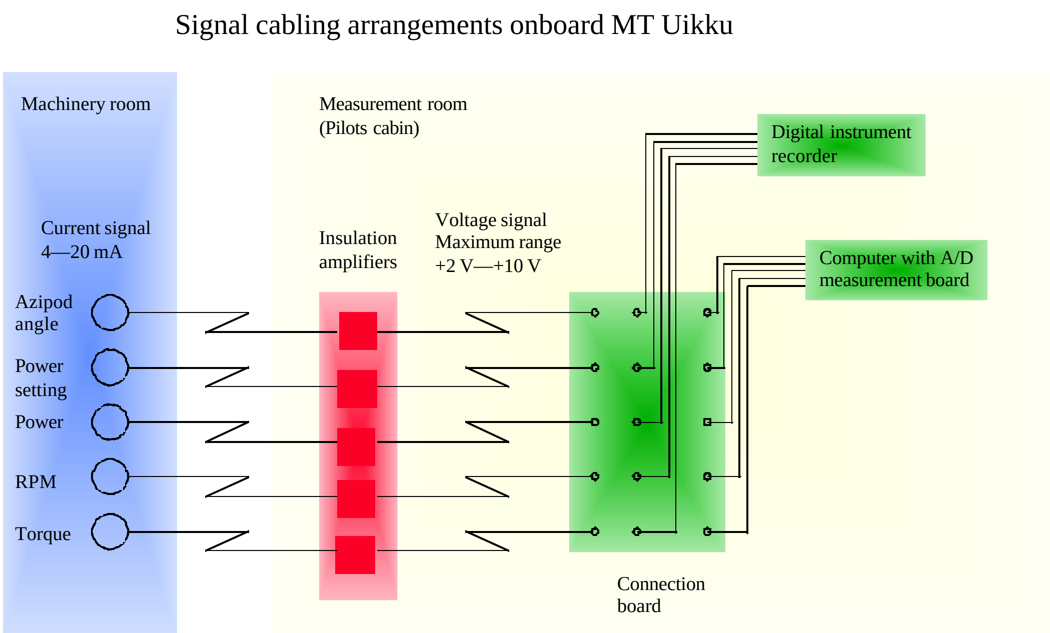


Figure 3: Signal cabling arrangements onboard MT Uikku.

The signal from the machinery room to the pilots cabin was analogue electric current signal (4—20 mA). Current signal was used to minimize signal distortion. The signal was transduced to voltage signal (+2 V—+10 V) with insulation amplifiers, which were located in the measurement room. From the insulation amplifiers the signal was led to a connection box, which distributed the signal to the computer and the digital instrument recorder.

IB Kapitan Dranitsyn

All of the measurements were made from the basic instrumentation of the ship. Preparations for the measurements consisted of:

1. Designing and planning of the measurements.
2. Installation and checking of the measuring computers and ancillary equipment in the machinery control room, which acted as the measurement center.
3. Installation and connection of the measurement cables to the signal sources.
4. Connection of the cables to the measuring system.
5. Checking and calibration of the whole system.

No additional transducers were installed on the ship. Before the voyage there was practically no information of the levels of the signals that were to be measured. Therefore there was problems with the RPM signals that were measured. The rpm signals required additional electric resistors, because the voltage level (-50 V…+50 V) had to be lowered for the measurement purposes.
The RPM signal level was between -50 V and +50 V. The signal level had to be reduced to allow the measurements with the insulation amplifiers, which could handle signals from 0 to 10 volts. Onboard Kapitan Dranitsyn there was not enough electric equipment (=suitable resistors) to allow to reduce the signal on all three shafts. Thus, only SB and BB side propeller revolutions were measured.
Another problem was that the insulation amplifiers could not handle negative signals. This caused the signal to show value 0, when the propellers were reversing.
The measured parameters and their sources are presented in Table 9. General signal cabling arrangements are presented in Figure 4.

Table 9 Measured machinery parameters and signal sources, IB Kapitan Dranitsyn.

Quantity	Signal source
MID shaft power	Machinery control room gauge
SB shaft power	Machinery control room gauge
BB shaft power	Machinery control room gauge
SB shaft rpm	Machinery control room gauge
BB shaft rpm	Machinery control room gauge

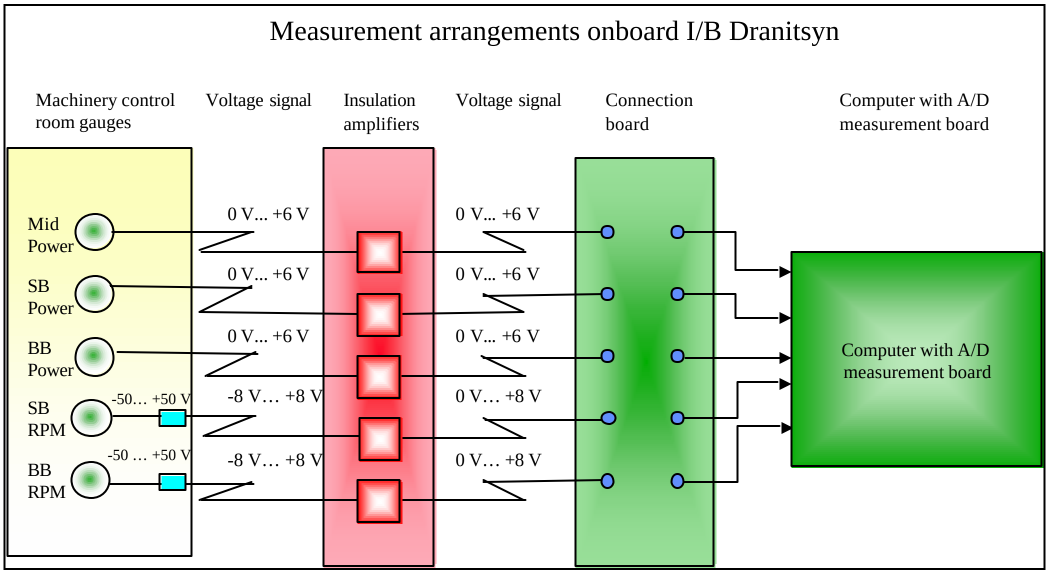


Figure 4 : Signal cabling arrangements onboard IB Kapitan Dranitsyn.

5.3. Navigation data

5.3.1 GPS data

In general all GPS data was received using the NMEA 0183 standard. The NMEA 0183 Standard for Interfacing Marine Electronics Devices is a voluntary industry standard, first released in March of 1983. The NMEA 0183 Standard defines electrical signal requirements, data transmission protocol, timing and specific sentence formats for a 4800 baud serial data bus (8 bits, no parity).

The following Internet page shows more detailed information of the NMEA 0183 usage: http://www.marinesoft.com/Navigation/Technical/index.htm

MT Uikku

Navigation data onboard MT Uikku was logged with a computer from two different sources. The primary source was directly from the ships own GPS system and it contained the following information:

1. Date
2. Time
3. Position
4. Speed
5. Direction of the movement

This signal was updated every two seconds (0.5 Hz). This dataset contains 260 files in total and the total size is 74.5 Mbytes.

Due to computer malfunction there is a 71 hour gap in the primary data (30.4.1998 12:01:52—3.5.1998 10:53:46). In the analysis the secondary data is used for this period.

The secondary data (114.6 Mbytes in 335 files) was received from the navigation instruments of the ship (vector data). This dataset contained the following information:

1. Time
2. Position

3. Speed
4. Direction of the movement
5. Heading of the ship
6. True wind velocity and direction
7. Relative wind velocity and direction

This signal was updated every 8 seconds (0.125 Hz). As can be seen from the information list , no date signal was included in the vector data. Therefore the date has to be concluded from the file date, which corresponds to the UTC time.

Installation of the logging system

The data was measured with two computers (primary data and secondary data), which were connected to the ships navigation system via a RS-232 cable. To prevent disturbances to the navigation system, a NMEA buffer was installed between the logging computers and the navigation system of the ship. The layout for navigation data logging onboard MT Uikku is presented in Figure 5.

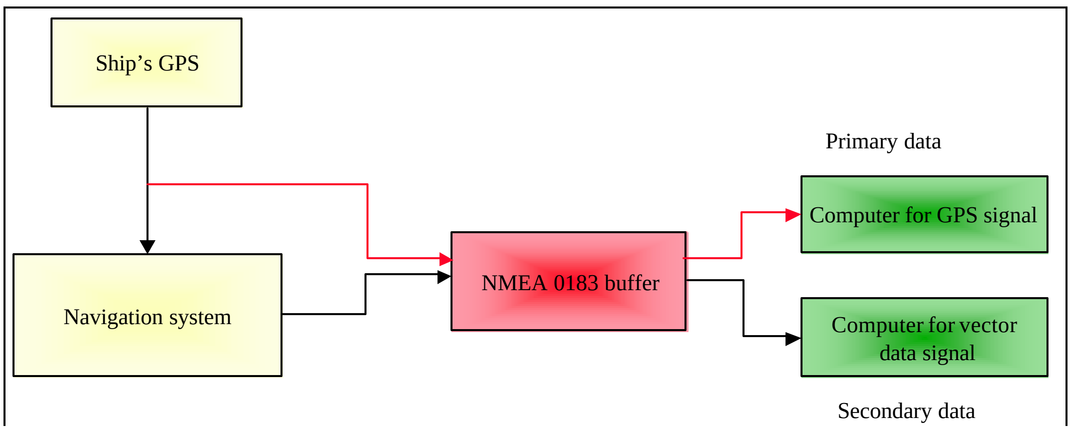


Figure 5: Navigation data logging onboard MT Uikku.

IB Kapitan Dranitsyn

There were two separate navigation data logging systems onboard IB Kapitan Dranitsyn. They acted independently from each other and independently from the navigation system onboard.
The two systems used different satellites for position measurements:

1. GLONASS system (arranged by HSVA)
2. GPS system (arranged by KMY)

Both systems had their separate antennas attached to the railing on the 5th bridge deck on the BB side of the ship. The location of the antennas is presented in Figure 6. The antenna cables were located outside of the superstructure of the vessel, and the cables were lead inside through cabin windows. The actual data logging occurred in cabins, which belonged to the measuring personnel.

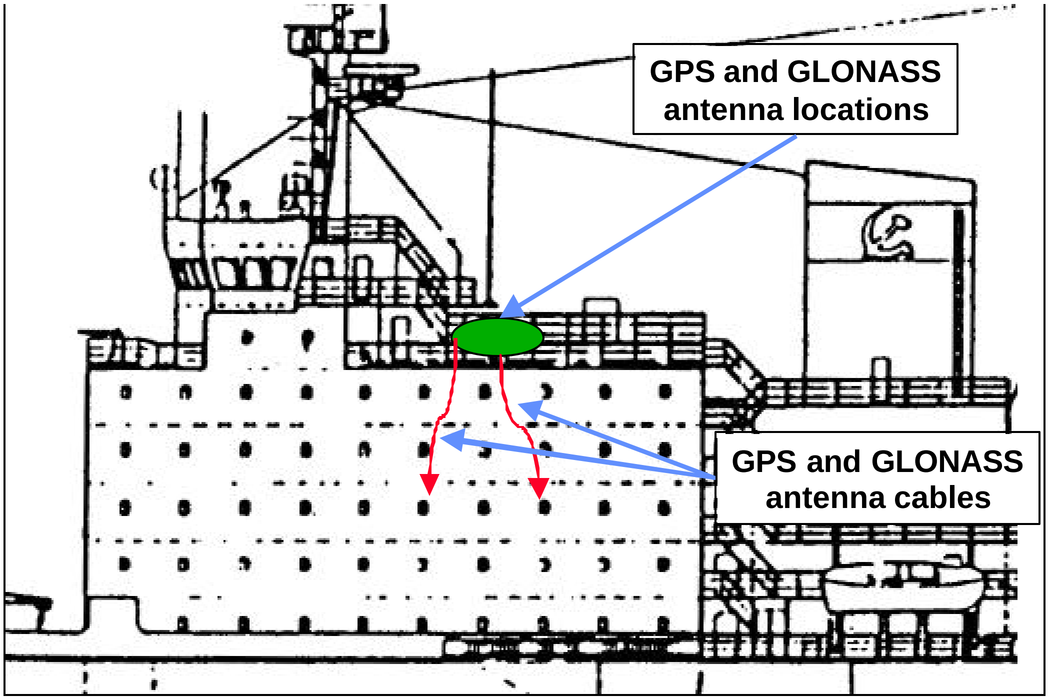


Figure 6: Antenna locations for GPS and GLONASS systems.

The most comprehensive and accurate dataset is the GLONASS data, which is recommended to be used in analysis. The GLONASS system is managed for the Russian Federation Government by the Russian Space Forces[2] and it is more accurate than the distorted GPS signal.
In practice the dataset is continuous since the start of the logging 27.4.1998 till the end of the logging 13.5.1998. There are two considerable gaps in the GPS dataset. Russian authorities denied the usage of the GPS for continuous data logging in the Russian territorial waters. This happened twice: in the Gulf of Ob and in the Kara Gate.
The layout for navigation data logging onboard IB Kapitan Dranitsyn is presented in Figure 7.
The GLONASS dataset contains following information.
1. Time
2. Position
3. Speed
4. Direction of movement
5. Data of the goodness of the location and speed signals

The GPS dataset contains following information.
1. Time
2. Position
3. Speed
4. Direction of movement

2 http://www.rssi.ru

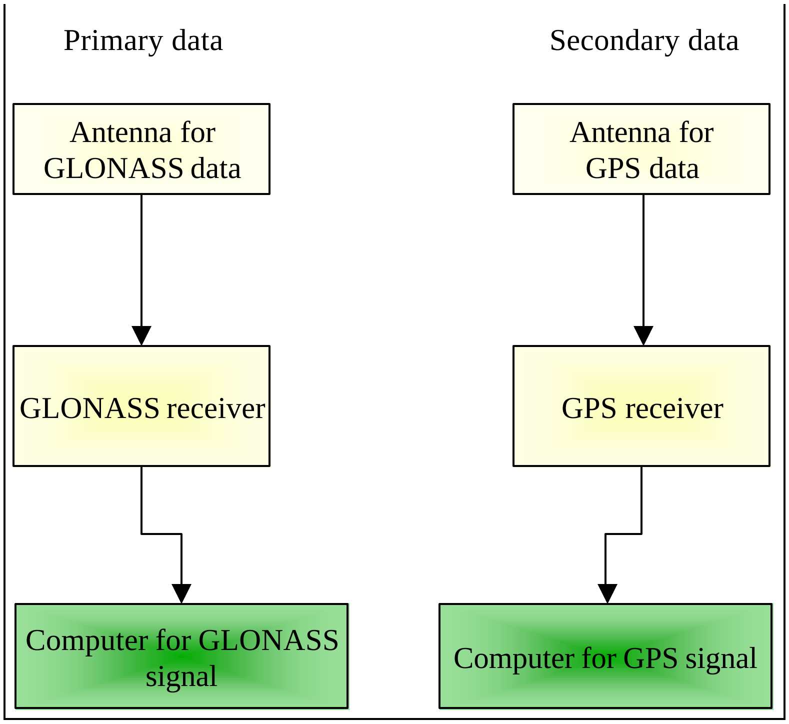


Figure 7: Navigation data logging onboard IB Kapitan Dranitsyn.

5.3.2 Visual observations

Objective of the visual observations onboard IB "Kapitan Dranitsyn" during ARCDEV voyage was obtaining that information about ice conditions and navigation data that are required for analysis of peculiarities of ship motion in ice, mainly, for evaluation of ship speed. Methodology of such observations was traditionally applied by specialists from AARI. This was expedient due to necessity of the comparative analysis of ice and operational data recorded during the ARCDEV voyage with the data, received previously.

Ice observations were aimed at assessment of ice parameters both in navigation area within a visibility range and along the ship route within a corridor that about 6 times wider than ship hull. Linear dimensions during ice observations were estimated with the help of GPS and ship-borne locators.

List of fixed area specific parameters of ice included:

? ? total ice concentration;
? ? partial concentration of ice of each stage of development (age);
? ? prevailing plan dimensions of floes of each age;
? ? ice ridge coverage;
? ? rafted ice coverage;
? ? orientation (in respect to ship direction of motion) of leads and wide cracks.

List of fixed route specific parameters of ice included:

? ? total ice concentration;
? ? partial concentration of ice of each stage of development (age);
? ? prevailing plan dimensions of floes of each age;
? ? range of variation of ice thickness of ice of each age;
? ? ice ridge coverage;
? ? rafted ice coverage;
? ? snow thickness;
? ? ice pressure.

In addition to this typical list of parameters a number of the following additional characteristics of ice were recorded during the voyage:

- ? ? Ice ridges:
  average height of ridge sails
  maximum height of ridge sails
- ? ? Leads and cracks:
  average width of lead or crack
  duration of ship motion along lead or crack with width that approximately equal to ship breadth or exceed it.
- ? ? Total ship route in ice was subdivided into 678 zones with homogeneous conditions. Within each zone the following navigational parameters were fixed:
- ? ? Time and coordinates of the beginning and end of each zone;
- ? ? Convoy order;
- ? ? Distances between the ships in convoy;
- ? ? Motion mode (continuos motion, ramming, etc.)
- ? ? Duration of ramming;
- ? ? Number of rams;
- ? ? Duration of event when a ship get stuck;
- ? ? Power usage (from bridge indicators).
- ? ? Ice and navigation observations were accompanied with conventional meteorological observations that included measurements of air temperature, wind speed and direction, air pressure, visibility. These measurements were performed each 4 hours (visibility was assessed within each zone with homogeneous ice conditions).

As far as the demands of trafficability methods are concerned the information about vessel's position was important, since it determines the characteristics of ice cover. The averaged speeds of vessel for the selected time interval were also determined using this information.

The ship's satellite navigation system and, in particular, GPS portable stations allow the position of the vessel to be registered practically over any interval of time. From the point of view of ice cover condition it is enough to have the data on position of a vessel at the beginning of each ship watch or even at the beginning of each day, i.e. to use the data of the ship log.
The observers from the KSRI institute were able to register the position of the icebreaker "Kapitan Dranitsyn" only. Concerning co-ordinates of the tanker "Uikku" it is necessary to bear in mind that practically during all the voyage the tanker followed the icebreaker at an average distance of 5-7 cable lengths, i.e. came at the registered point of the icebreaker position in 3-5 minutes. Therefore for the purposes of the present research it is quite permissible to consider the co-ordinates of the icebreaker as the co-ordinates of the caravan, including the tanker "Uikku".

Ship logs are not suitable for the purposes of any scientific research due to their low accuracy.
The satellite navigation system also provides data on a vector of speed (course and instantaneous value of speed in this direction). The stations GPS allow to receive and to remember this information practically through any intervals of time. However this data package is of interest only if the synchronically recorded data packages on other parameters of vessel operation are available. If there are no such packages, in particular, on ice conditions, the expediency of using the instantaneous values of speed is insignificant.
By using rather simple methods for processing the records of GPS station it is possible to obtain values of the average speeds calculated as a distance between two observed points for the selected value of time interval. In our case the hour-long interval allows us to receive interesting data for the observed volume of information.

5.4. Ship performance reached

It is a many-sided task to make an assessment of the performance of the different ships and the convoy in general. In this section the aspects of the performance criteria is been considered in means of average speed and power concumption. The detailed information on subjects is given in respect with the whole convoy and individual vessels during the Arcdev route.

5.4.1 Ice conditions at the start of the expedition

South-eastern Barents Sea

The drifting ice edge passed slightly westward of its multiyear position. Grey and grey-white ice with a thickness of 15-30 cm predominated from the ice edge to the meridian of Kolguyev Island. East of the meridian of Kolguyev Island, thin and medium first-year ice 50 to 70 cm thick in level ice zones prevailed. In the central Pechora Sea an ice massif was located with dominating medium and thin first-year ice floes (up to 70-80%). Strongly hummocked ice was observed at the approaches to Kara Gate Strait. As a result of easterly winds a large polynya formed along the western coast of Novaya Zemlya Island (Figure 8). The ice conditions at the start of the expedition were estimated as moderate trending to severe.

Western Kara Sea

The western Kara Sea was practically completely (80-90 %) occupied by thick and medium first-year ice with a thickness in level ice zone between 100 to 140 cm. The landfast ice was developed within its average boundaries. The landfast ice thickness from data of polar stations comprised 145-160 cm in the region of Ob' Bay and around 140-150 cm off the Yamal coast. During the winter there was repeated development of extensive flaw polynyas along the Yamal and Amderma coasts, as well as along the eastern coast of Novaya Zemlya. In early April the Yamal polynya was observed to develop from Cape Kharasavey to Bely Island (Figure 8). The ice conditions in the western Kara Sea at the start of the expedition were estimated as moderate trending to severe.

Ob' Bay

In autumn 1997 a positive air temperature anomaly at the arctic coast and the mouth regions of the Kara Sea rivers lead to a late onset of ice formation. The ice formation in Ob' Bay began 9 days later compared to mean multiyear dates. During the subsequent period the ice growth and snow accumulation were more intense than usually. In early April the ice cover thickness in Ob' Bay was 10-15 cm greater than the mean multiyear value and the snow thickness was 5-10 cm greater than the norm. The ice thickness in the region of Novy Port at the end of the first 10-days of April was 146 cm at the norm of 130 cm with the snow depth comprising 30-39 cm at the norm of 30 cm. The ice conditions in Ob' Bay were estimated as more severe than the average multiyear conditions.

Resume: the ice situation at the start of the expedition was characterized by the:

- greater ice cover extent in the Barents Sea,
- stable existence of the western Novozemelsky polynya governed by the prevailing eastern air transports,
- weak development of polynyas in the southwestern Kara Sea identifying a significant thickness and low mobility of the Novozemelsky ice massif,
- presence of a dynamic boundary separating the northeastern part from the southwestern Kara Sea manifested in the zone of increased ice fragmentation recorded on the charts as discontinuities in the ice cover oriented from Cape Zhelaniya to Bely and Sverdrup Islands.

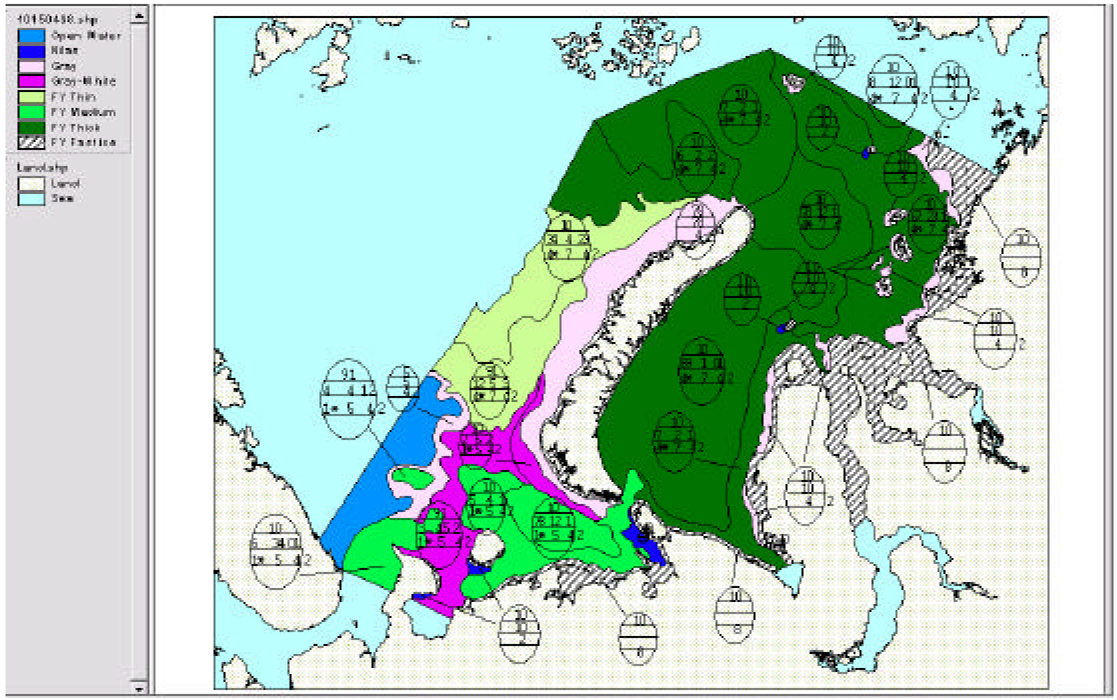


Figure 8 Ice conditions in the region at the start of the e xpedition Sailing routes during the 1998 winter navigation season

Different sailing variants were used during the 1998 winter navigation period. In January-February the central variant was the main which used the shortest route along the line Kara Gate Strait-Bely Island-Dikson Island. In mid-March sailing was performed in the extensive polynya along the eastern coast of Novaya Zemlya Island crossing the ice massif along latitude 74?N. In late March-early April, the Cape Zhelaniya - Dikson Island variant was used.

5.4.2 Average speed of the convoy on the whole route

In practice the speed of IB Kapitan Dranitsyn has been selected as the speed of the convoy. The cases, where MT Uikku and IB Dranitsyn were separated are considered to be negligible.
The speed of the convoy is presented in two ways:

1. Average speed for great circle sailing
2. Average speed along the actual route

Great circle sailing means that we take the shortest possible route to the destination. Average speed for great circle sailing is calculated through Kara Gate, which is the shortest possible route.
Figure 9 shows roughly the great circle sailing route and the actual route that was used during ARCDEV. The average speed is obtained by dividing the great circle route distance by the voyage time. Average speed along the route is obtained by dividing the route length by the voyage time. The voyage time does not include time that was spent on research. except at Site 1. At Site 1 the actual cause for stopping was that IB Kapitan Dranitsyn could not penetrate a ridge and ice research was started while waiting for NIB Rossiya.

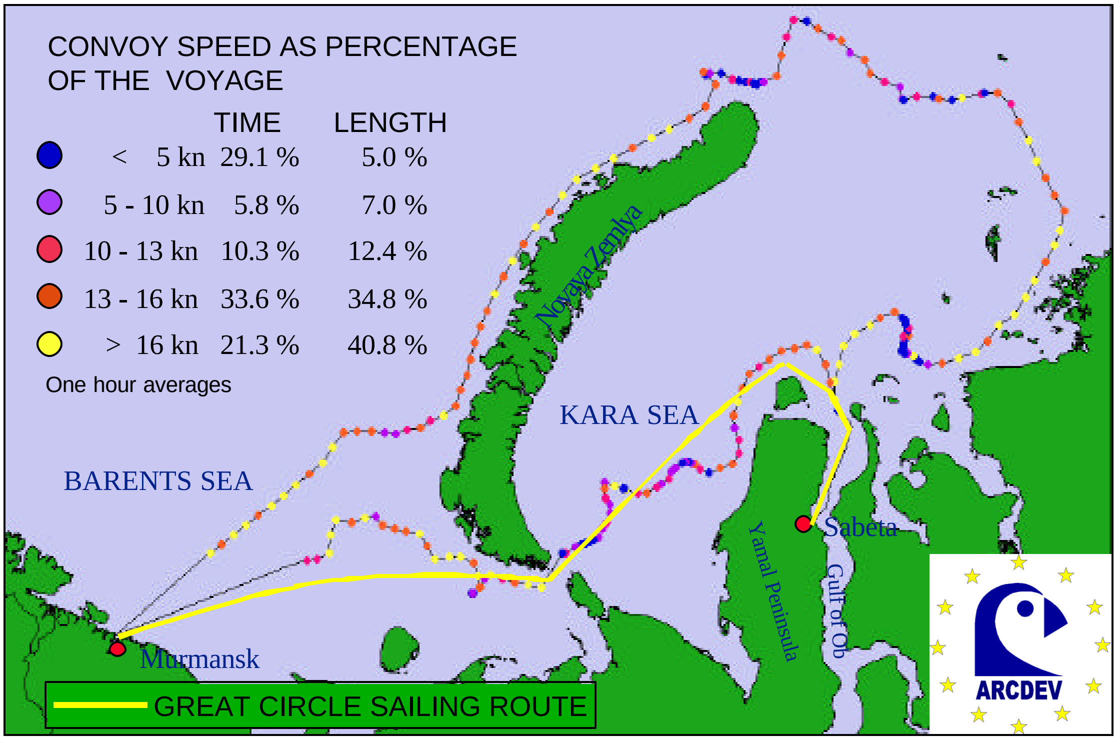


Figure 9: Convoy speed along the route as percentage of the voyage time and length.

Speed histogram for MT Uikku on the ARCDEV route is presented in Figure 10. The speed for IB Kapitan Dranitsyn is practically the same, and therefore it is not presented here. The histogram bars include also the time that was spent for research.

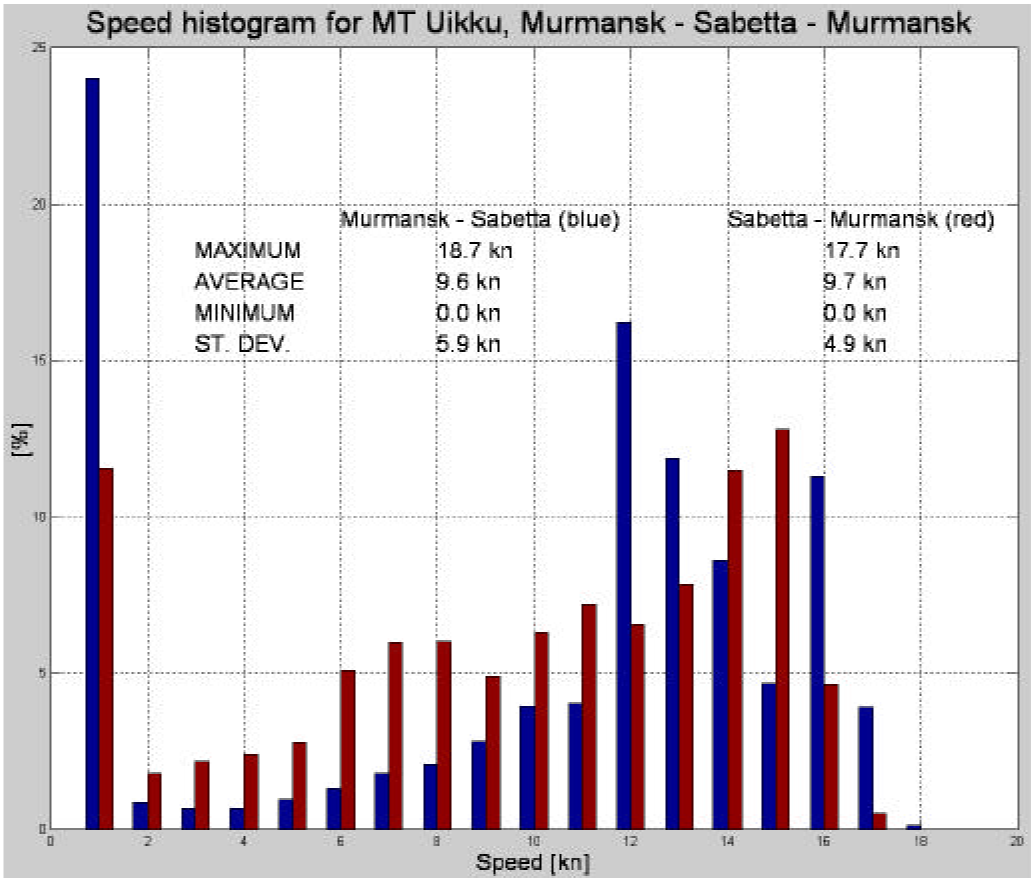


Figure 10: On route speed histogram during ARCDEV voyage for MT Uikku.

5.4.3 Average speed of the convoy on different legs

The route was divided into 9 legs, which are shown in Figure 11. Waypoints for the legs and the corresponding UTC times are given in Table 5-10. Leg lengths and the corresponding average speeds along great circle sailing and along the actual route are presented in Table 5-10.. The selected legs include only the part of the voyage, where machinery measurements and visual ice observations were performed. Table 5-11 shows the waypoint locations and times. Table 5-12 shows the reasons and times that are not included in the average speed calculations.

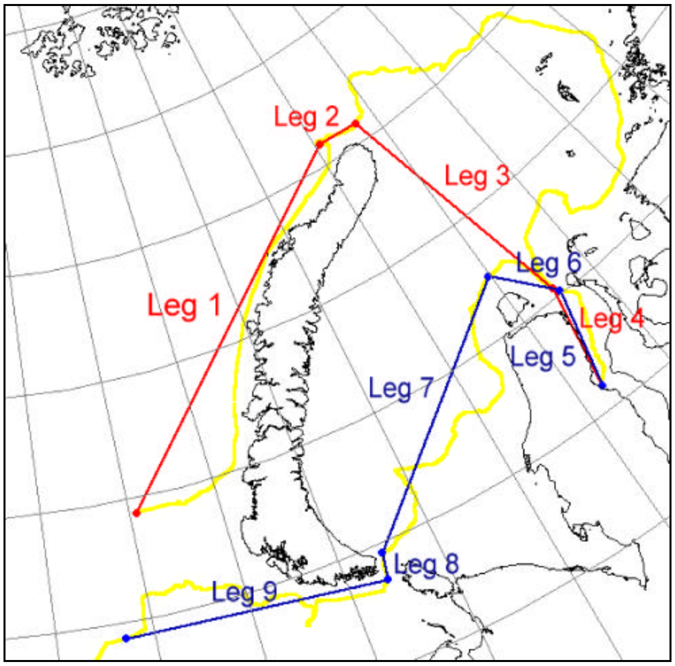


Figure 11: Chart of the leg numbers and the voyage route.

Description of the different legs

1. Ice edge — northwestern corner of Novaya Zemlya
   The point, where the polynya west of Novaya Zemlya ended
2. Northwestern corner of Novaya Zemlya—The point north of Novaya Zemlya, where NIB Rossiya came to assist the convoy.
3. North of Novaya Zemlya—Point where NIB Rossiya left the convoy in the Gulf of
4. Gulf of Ob— Sabeta
5. Sabeta—Gulf of Ob
6. Gulf of Ob—North of Bely Island
7. North of Bely Island—Eastern end of Kara Gate
8. Crossing of Kara Gate
9. Western point of Kara Gate—End of recording

Table 5-10: Average speeds on different legs.

Leg #	WP start	WP end	Length of the leg [nm]	Duration (time for research not included)	Average speed (great circle sailing) kn	Average speed on route kn
1	1	2	413	31:31	13.1	14.6
2	2	3	43	25:54	1.7	2.8
3	3	4	257	68:49	3.7	10.7
4	4	5	112	15:02	7.5	8.6
5	6	7	108	19:41	5.5	6.3
6	7	8	71	6:21	11.2	13.6
7	8	9	297	42:21	7.0	9.7
8	9	10	29	3:51	7.5	7.7
9	10	11	271	22:35	12.0	14.9

Table 5-11: Waypoint times and locations.

WP #	Time	Latitude	Longitude
1	27.4.1998 21:38	46° 07.1658' N	72° 40.8114' E
2	29.4.1998 05:10	66° 06.3798' N	77° 16.4064' E
3	30.4.1998 10:35	69° 18.1530' N	77° 14.0040' E
4	3.5.1998 10:00	73° 14.1900' N	73° 05.4672' E
5	4.5.1998 06:35	72° 08.7468' N	71° 18.5214' E
6	8.5.1998 08:07	72° 09.3918' N	71° 19.5366' E
7	9.5.1998 03:48	73° 29.7222' N	73° 00.0468' E
8	9.5.1998 10:10	70° 36.5178' N	73° 54.3864' E
9	11.5.1998 13:16	57° 57.9384' N	70° 46.7040' E
10	11.5.1998 17:07	57° 41.8854' N	70° 19.5246' E
11	13.5.1998 05:55	44° 14.3376' N	70° 39.5976' E

Table 5-12: Times that are not included in the average speed calculations.

Description	Start	Stop	Duration
People to visit MT Uikku	29.04.1998 11:30	29.04.1998 12:30	01:00
People back from MT Uikku	29.04.1998 19:56	29.04.1998 20:14	00:18
Ice station 2	01.05.1998 03:24	01.05.1998 06:00	02:36
EU-representatives onboard	03.05.1998 12:21	03.05.1998 12:53	00:32
Ice station 3	03.05.1998 14:45	03.05.1998 19:14	04:29
EU-representatives left the ship	04.05.1998 04:44	04.05.1998 05:16	00:32
Ice station 5	10.05.1998 12:53	10.05.1998 21:38	08:45
Ice station 6	11.05.1998 22:30	12.05.1998 12:42	14:12

5.4.4 Average power of the ships in the convoy

Total power usage has been analyzed for all ships that took part in the voyage. For NIB Rossiya the power is only for the time it assisted the convoy i.e. 30.—3.5.1998 and 9.—11.5.1998. For IB Kapitan Dranitsyn and MT Uikku the power average is for period 27.4.—4.5.1998 and 8.—13.5.1998. Average total power during the voyage was:

- NIB Rossiya 35.6 MW
- IB Dranitsyn 10.1 MW
- MT Uikku 4.5 MW

Average power and energy consumption of IB Kapitan Dranitsyn and MT Uikku

Total average power and energy consumption per nautical mile on different legs for IB Kapitan Dranitsyn and MT Uikku is shown in Table 5-13. Great circle sailing distance between leg waypoints has been used in distance calculations. Detailed analysis for NIB Rossiya cannot be performed because the power usage was based on logging 4 hour average energy consumption an estimate of the results that this analysis provides is given in the table below.

As a reference it can be said that in open water the energy consumption for MT Uikku at 15 knots is about 0.4 MWh/nm.

Table 5-13: Total average power and energy consumption per nautical mile on different legs.

Leg #	Average power [MW]			Energy per nautical mile [MWh/nm]		
	IB Dranitsyn	MT Uikku	NIB Rossiya	IB Dranitsyn	MT Uikku	NIB Rossiya
1	8.7	7.1	-	0.6	0.5	-
2	10.1	0.9	-	6.3	0.6	-
3	10.9	5.0	28.7	2.9	1.3	7.6
4	13.0	5.2	-	1.7	0.7	-
5	14.9	5.0	-	2.7	0.9	-
6	9.2	7.2	-	0.8	0.6	-
7	9.2	5.5	40.7	1.3	0.8	5.8
8	7.8	4.8	43.1	1	0.6	5.5
9	12.3	7.5	-	1	0.6	-

If we divide the whole voyage to legs according to the ice observations made by AARI, we can get the energy consumption per mile with unchangeable ice conditions along the actual convoy route. Histogram analysis for the energy consumption is made i.e. the result has been sorted to sections, where energy consumption per nautical mile is same and their proportion of the whole voyage length has been calculated.

We can see that over 10 MW energy consumption per nautical mile was observed at 14 % and 10 % of the whole voyage length on voyages to and from Sabeta, respectively. Over 50 % of the voyage the energy consumption was less than 1 MWh/nm and 1.6 MWh/nm on route Murmansk—Sabeta—Murmansk, respectively. The maximum energy consumption per nautical mile for IB Kapitan Dranitsyn was 79.6 MWh/nm. This situation occurred in the compressive ice field near the Gulf of Yenisey at 73°43.623'N 77°49.239'. On the return voyage the maximum encountered value was 22.0 MWh/nm. This situation occurred on a 0.4 nm long section in the Gulf of OB (71°54.041'N 72°59.518'E), where the water depth is less than 15 m.

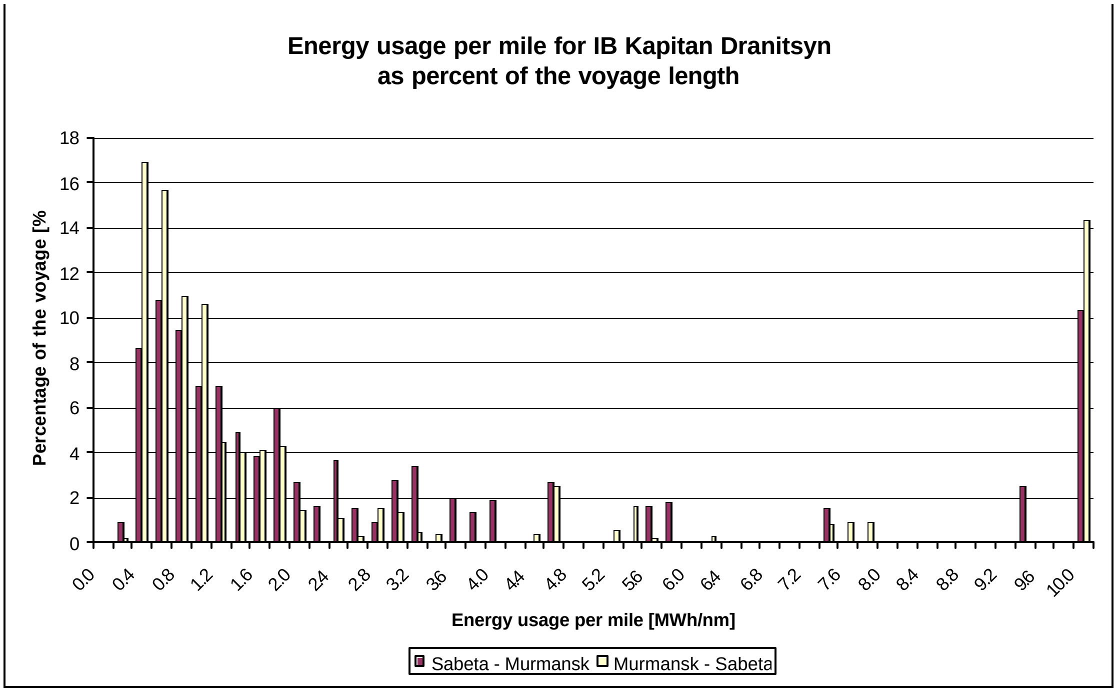


Figure 12. Energy usage per mile for IB Kapitan Dranitsyn as percent of the voyage length.

5.5. Ice routing

This section gives a brief factual description of events related to the provision of automatically generated ice charts for the ARCDEV project. An important EU-sponsored project Ice Routes was in co-operation with ARCDEV program.

The ARCDEV expedition and the simultaneous cruise of Sovietskiy Soyus under Ice Routes represented the first “live” test of the automatic ice charting and vessel routing capabilities developed under the Ice Routes project. An important goal of the exercise was to deliver and evaluate near real-time navigational information to the vessels involved in the campaign. This was not achieved, for various reasons. However, in the weeks following the campaign, steps were taken which prove that substantial progress has been made towards this objective, and the prospects for achieving operational support to vessels operating in icy waters are quite good. A detailed description with several satellite images are found in Ice Routes, Transport Research publication.

The ARCDEV expedition was also the first occasion when Radarsat data was available together with in-situ data from ice-breakers for winter ice conditions in the Kara Sea. It provided important information which was used to enhance and develop the automatic ice classification capability.

The currently available capability for automatic generation of ice charts gives an impressive level of detail, not available with conventional classification systems. However it does not yet offer high enough accuracy to be offered directly to navigators. The best strategy for exploiting the current version of the Ice Routes charting system is to provide ice interpreters with a tool for amending the chart when the system fails to produce a reasonable result.

The currently available capability for automatic generation of vessel routes shows impressive performance, and indicates that with further development, and provision of more precise input from improved ice charts, this service could become a standard feature of high latitude navigation. The following identifies some of the major issues which it is felt should be addressed since they are important and stand a good chance of success:

(a) Maintain and develop long-term working contacts with user groups who have expressed interest and can assist with development of strategy and refinement of operational requirements

(b) Further develop the use of contextual information as an element of ice charting methods using artificial intelligence techniques, with emphasis on small scale features such as ridges and leads

(c) Address methods of handling multiple satellite data sources and ensure calibration issues between systems and ground stations are incorporated

(d) Establish robust ship route modelling algorithms which combine the effects of multiple ice conditions (e.g. floe size, ice concentration and ice type) on vessel operations, in order to predict transit speed, fuel consumption and risk

Ensure that technical advances in ice charting and ship route modelling take due account of the anticipated International Polar Code of Navigation in order to develop consistent and appropriate strategies and methods.

5.6. Preliminary selection and assessment of the optimal sailing variant

At the stage of the strategic choice of the sailing route three possible navigation variants were analyzed:

1. Murmansk – western Novozemelsky polynya – Cape Zhelaniya – Ob’ Bay,
2. Murmansk – Kara Gate Strait – Bely Island – Ob’ Bay (central variant),
3. Murmansk – Kara Gate Strait – Yamal polynya – Ob’ Bay (southern variant).

Given the scenario of the ice process development and synoptic forecasting for the first expedition stage, the following ice cover characteristics for the proposed sailing variants were used as a preliminary quantitative assessment of the optimal navigation variant (Table 14 to Table 16).
As a result of calculations, the transit time for the convoy (nuclear icebreaker of the "Arktika" type and the "Uikku" tanker) comprised 5.5 days along the route Murmansk – Cape Zhelaniya - Ob' Bay mouth (Variant 1) and 6 (Variant 2) and 7 days (Variant 3) along the route Murmansk – Kara Gate Strait-Ob' Bay mouth. Thus, at the planning stage of the expedition the variant of sailing north of Cape Zhelaniya was recognized as the optimal variant for sailing to the Ob' Bay mouth

Table 14 Initial ice data on the ice conditions for Route Variant 1

Length of segment, miles	Ice conditions
240	Open water
20	? = 7-8, FY thin (50cm) and G (15cm), medium and small floes
120	?=10, FY medium (100cm) and thin (50cm) – 3, big and medium floes; G/W (25cm) – 5, small floes; G (15cm) and Nilas (5cm) – 2, small floes; hummocks – 6
405	?=9-10, G/W (25cm) – 4, medium floes; G (15cm) and Nilas (5cm) – 5-6, small floes
50	?=10, FY thick (130cm) and medium (100cm) – 4, big and medium floes; FY thin (60cm) and G/W (25cm) – 3-4, medium and small floes; G (15cm) and Nilas (5cm) – 2, small floes; hummocks – 7-8
45	?=10, FY thick (150cm) and medium (110cm) – 7-8, big and medium floes; FY thin (60cm) and G/W (25cm) – 1-2, medium and small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 7-8
150	?=10, FY thick (150cm) and medium (110cm) – 7-8, big floes and medium floes; FY thin (60cm) and G/W (25cm) – 2, medium and small floes; G (15cm) and Nilas (5cm) – 0-1, small floes; hummocks – 5
80	? =10, FY thick (150cm) and medium (110cm) – 6, big floes and medium floes; FY thin (60cm) and G/W (25cm) – 3, medium and small floes; G (15cm) and Nilas (5cm) – 1, small floes

Table 15 Initial ice data on the ice conditions for Route Variant 2

Length of segment, miles	Ice conditions
195	Open water
15	? = 7-8, FY thin (50cm) and G (15cm), medium and small floes
110	?=10, FY medium (100 cm) and thin (50cm) – 3, big and medium floes; G/W (25cm) – 5, small floes; G (15cm) and Nilas (5cm) – 2, small floes; hummocks – 2
200	?=10, FY medium (100cm) and thin (50cm) – 5, big and medium floes; G/W (25cm) – 4, small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 2
40	?=10, FY medium (100cm) and thin (50cm) – 5, big and medium floes; G/W (25cm) – 4, small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 6
30	?=10, FY thick (150cm) and medium (100cm) – 7-8, big and medium floes; FY thin (60cm) and G/W (25cm) – 2, medium and small floes; G (15cm) and Nilas (5cm) – 1-2, small floes; hummocks – 8
165	?=10, FY thick (150cm) and medium (100cm) – 8-9, big and medium floes; FY thin (60cm) and G/W (25cm) – 1, medium and small floes; G (15cm) and Nilas (5cm) – 0-1, small floes; hummocks – 7-8
30	?=10, FY thick (150cm) and medium (100cm) – 7, big and medium floes; FY thin (60cm) and G/W (25cm) – 2, medium and small floes; G (15cm) and Nilas (5cm) –1, small floes; hummocks – 8
20	?=8-9, FY thick (150cm) and medium (100cm) – 1-2, big and medium floes; FY thin (60cm) and G/W (25cm) – 6, medium and small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 2
95	?=10, FY thick (150cm) and medium (110cm) – 6 big and medium floes; FY thin (60cm)

	and G/W (25cm) – 3, medium and small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 3

Table 16 Initial ice data on the ice conditions for Route Variant 3

Length of segment, miles	Ice conditions
195	Open water
15	? = 7-8, FY thin (50cm) and G (15cm), medium and small floes
110	?=10, FY medium (100cm) and thin (50cm) – 3, big and medium floes; G/W (25cm) – 5, small floes; G (15cm) and Nilas (5cm) – 2, small floes; hummocks – 2
200	?=10, FY medium (100cm) and thin (50cm) – 5, big and medium floes; G/W (25cm) – 4, small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 2
40	?=10, FY medium (100cm) and thin (50cm) – 5, big and medium floes; G/W (25cm) – 4, small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 6
130	?=10, FY thick (150cm) and medium (100cm) – 7-8, big and medium floes; FY thin (60cm) and G/W (25cm) – 2, medium and small floes; G (15cm) and Nilas (5cm) – 1-2, small floes; hummocks – 8
65	?=10, FY thick (150cm) and medium (100cm) – 8-9, big and medium floes; FY thin (60cm) and G/W (25cm) – 1, medium and small floes; G (15cm) and Nilas (5cm) – 0-1, small floes; hummocks – 7-8
90	?=10, FY thick (150cm) and medium (100cm) – 7, big and medium floes; FY thin (60cm) and G/W (25cm) – 2, medium and small floes; G (15cm) and Nilas (5cm) –1, small floes; hummocks – 8
125	?=8-9, FY thick (150cm) and medium (100cm) – 1-2 big and medium floes; FY thin (60cm) and G/W (25cm) – 6, medium and small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 2
95	?=10, FY thick (150cm) and medium (110cm) – 6 big and medium floes; FY thin (60cm) and G/W (25cm) – 3, medium and small floes; G (15cm) and Nilas (5cm) – 1, small floes; hummocks – 3

For return to Murmansk the central sailing variant along the route Bely Island – Kara Gate Strait was proposed. A review of the hydrometeorological conditions, a synoptic forecast, the scenario of the development of ice processes and a preliminary convoy sailing variant were presented to the administration of the expedition, Murmansk Shipping Company (MSCO) and the interested organizations 10 days in advance of the expedition.

The implementation of sea operation revealed that the strategic choice of the optimal motion route made at the preparation stage of the expedition was completely justified.

5.7. Tactical procedures and methods of the tanker escorting by icebreakers

In the course of the experimental voyage of tanker *Uikku* scientists of CNIIMF were observing process of the escorting of the tanker through ice as well as gathering information on the tanker/icebreaker interaction. The voyage was supported by three icebreakers: *Kapitan Dranitsyn*, *Rossia* and *Vaigach*. The first one provided the icebreaker assistance during the entire voyage, the second one headed the escorting in the Kara Sea and the third one made a channel in the Ob Gulf prior to the approach of the convoy. Mode of escorting and route of the convoy were selected in accordance with recommendations of the Headquarters of Marine Operations and in dependence on ice conditions and specific situations in the order. The escorting was mainly carried out by leading by one or two icebreakers having been changed twice for towing. During the voyage several tactical procedures of the tanker escorting in ice were implemented: icebreaker route reconnaissance after prior making a channel, leading, breaking out of the stuck ship, towing.

5.7.1 Methods of escorting and duration of its implementation

For a substantial period of time (amounting to about 24 % of the voyage duration) tanker *Uikku* sailed independently: from Murmansk to the ice edge and on the way back from the Kara Strait to the ice edge and further on to Murmansk. It took 2.7 days for this; for 2.03 days out of this time the ship proceeded in open water and for 0.67 days - through young ice of the Barents Sea. For the rest of time the tanker was escorted by icebreakers *Kapitan Dranitsyn* and *Rossia* the escorting having been made either by one of them or by both icebreakers simultaneously. In the latter case, tanker *Uikku*, as a rule, was bringing up the rear of the convoy or immediately followed a leading icebreaker under heavier conditions. Durations of each of the escorting alternatives including towing are presented in Table 17 and in Figure 13.

The distribution obtained is not a typical one because the escorting of one ship was carried out by two icebreakers. For a customary commercial voyage in the presence of a nuclear icebreaker in the convoy, icebreaker *Kapitan Dranitsyn* would be superfluous. Principal task of a diesel icebreaker in the present voyage was to provide for the fulfilment of the scientific programme. Under conditions of routine operations in the Western area of the Arctic in winter all the works related to the navigation of tankers in ice are performed by linear icebreakers of *Rossia* or *Taimyr* types. Under the most severe navigational conditions the icebreaker escorting takes up some 70-80 % of the total voyage duration.

Table 17 Steaming time distribution of tanker Uikku *according to modes of escorting*

Mode of escorting	Murmansk – Sabeta		Sabeta – Murmansk		Murmansk – Sabeta – Murmansk	
	Hours	%	Hours	%	Hours	%
Independently	28.0	18.1	36.8	32.2	64.8	24.1
Escorting by leading						
i/b *Kapitan Dranitsyn*	62.2	40.2	19.9	17.4	82.1	30.5
n/i *Rossia* and i/b *Kapitan Dranitsyn*	43.6	28.2	46.1	40.4	89.7	33.4
n/i *Rossia*	3.6	2.3	11.4	10.0	15.0	5.6
In tow behind n/I *Rossia*	17.2	11.1	0	0	17.2	6.4
Total	154.6	100	114.2	100	268.8	100

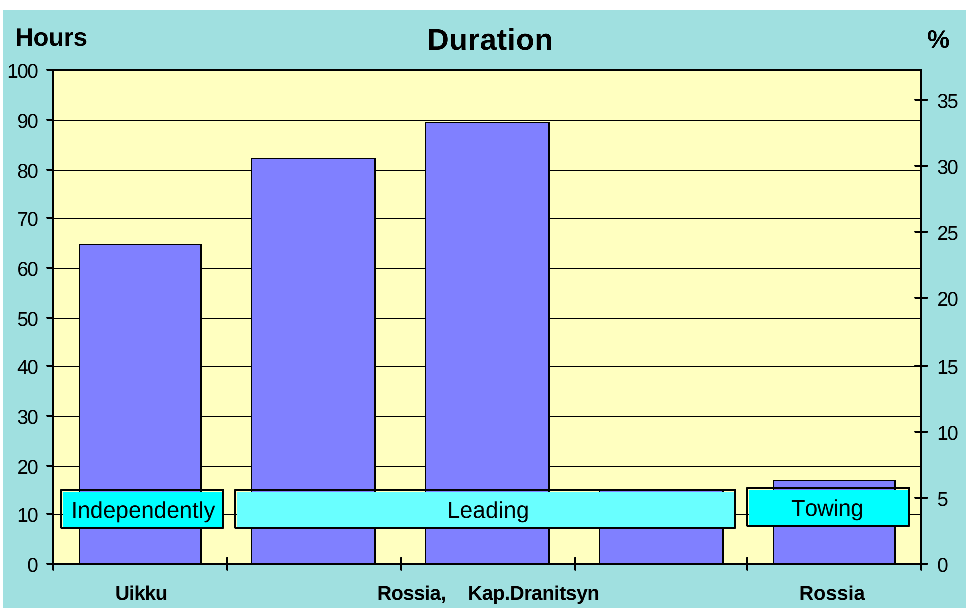


Figure 13 Versions of the escorting of tanker Uikku and duration of their realization in the experimental voyage

5.7.2 Tanker escorting in tow

During the first half of the voyage, icebreaker *Rossia* twice used the towing of tanker in the Kara Sea at the approach to the Ob Gulf (Figure 14). Prerequisites for taking such decision were difficulties of the encounter of convoy with a massif consisting mainly of debris and vast floes of the first-year thick ice. The ice situation became even more complicated by hummocking of 3 - 4 and compacting of 1 - 2. As a rule, under conditions of heavy compacting a ship cannot move and icebreaker has to take it in tow.

Figure 14 Towing of tanker Uikku *by icebreaker* Rossia *in the Kara Sea*

The first towing lasted for 5.8 h., the second one - for 10.3 h. and finished at the entrance to the channel made by icebreaker *Vaigach* in the fast ice of the Ob Gulf. During the interval between towings (3.7 h.) caused by the breakage of the towing rope, icebreaker *Rossia* was carrying out the escorting by leading. Not only the breakage of the towing rope but also two other factors are indicative of the seriousness of ice conditions. In the first case the convoy *icebreaker-tanker* could resume movement only after the ice has been broken near it by icebreaker *Kapitan Dranitsyn.* In the second case, icebreaker *Kapitan Dranitsyn* after one of maneuvers could not enter the channel and had to make its way for 150 miles independently arriving to the fast ice of the Ob Gulf 3.5 hours later than tanker towed by the nuclear icebreaker.

A towing rope from icebreaker *Rossia* was thrown twice onto tanker *Uikku*. In the first case, the whole complex of necessary measures on maneuvering, docking, securing and pulling of the towrope was accomplished for 43 minutes, in the second - for 24 minutes. Considerable time difference is due to the fact that as a result of the first contact, optimum adjustment of the icebreaker stern cut-out and the tanker forebody by trimming was achieved as well as technological procedures of the transfer and fastening of the towing rope were perfected. Duration of the repeated taking of tanker in tow complies in full with the Russian practice of towing in the Arctic according to which the whole operation from the approach of ships to the beginning of movement takes up not more than 25-30 minutes. Casting off of the towing rope on the completion of escorting is carried out during several minutes.

5.7.3 Breaking out of ships for the resumption of movement of the convoy

In the course of the voyage, to resume movement of participants of the convoy a tactical escorting procedure - breaking out of ships - was used several times. This maneuver was performed mainly by icebreaker *Rossia* releasing tanker *Uikku* and icebreaker *Kapitan Dranitsyn* (Figure 15). The latter resorted to this method only in the absence of the nuclear icebreaker or at the moment when it was towing the tanker. Principal reasons conducing to the loss of the speed of ships are sinuosity of the channel made through cracks and fractures, heavy hummocking isthmuses as well as compacting caused by the shearing of ice fields.

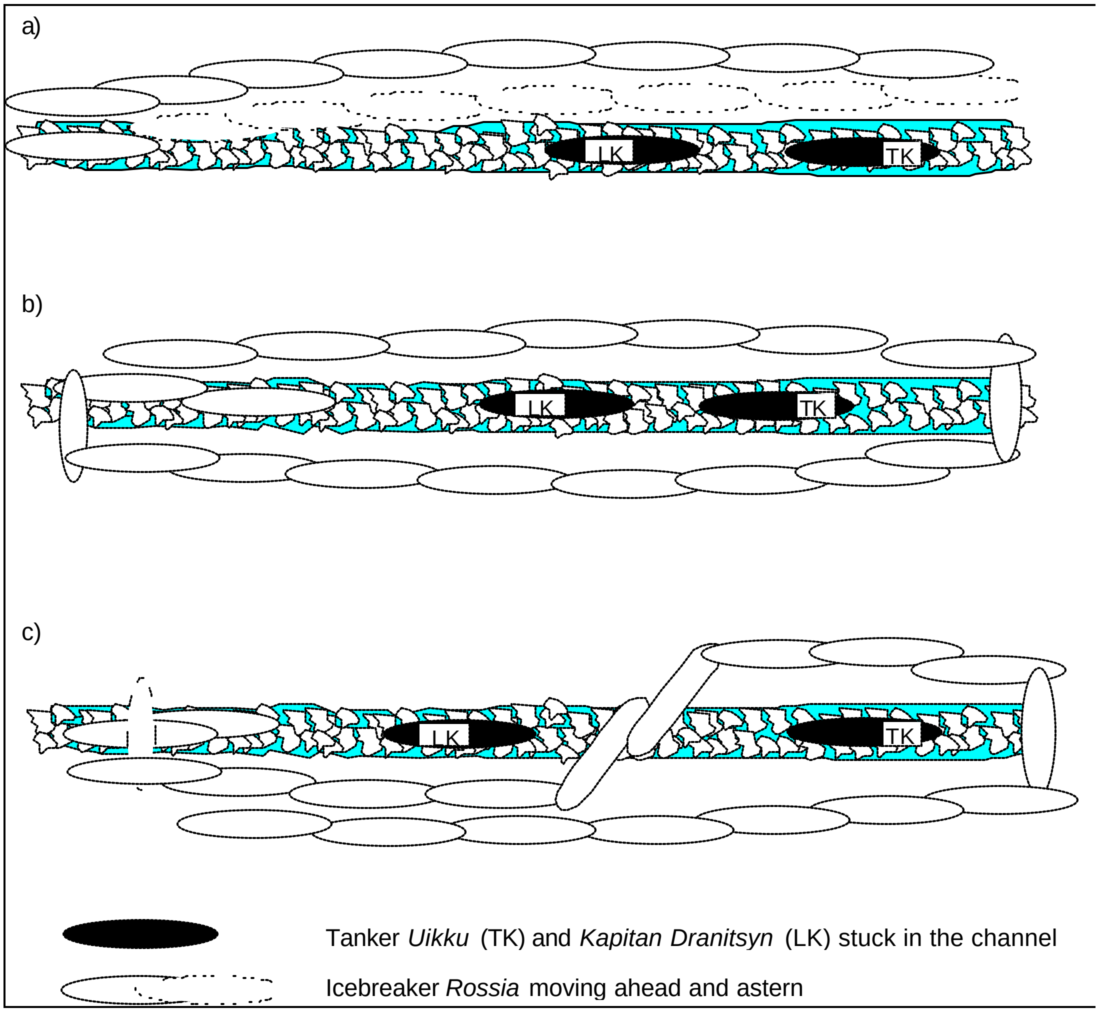


Figure 15 Maneuvers of icebreaker Rossia *in the breaking out of icebreaker* Kapitan Dranitsyn *and tanker* Uikku

Breaking out of ships was carried out by icebreaker in the movement astern (Figure 15.a) or, if the ice situation required, in the movement ahead (Figure 15.b and c). The icebreaker passed in the immediate vicinity (at a distance of 50-150 m) of ships which were dead in the water and after they resumed moving was again at the head of the convoy. During the voyage the above procedure was used 16 times because of the sticking of one or two ships (Figure 16).

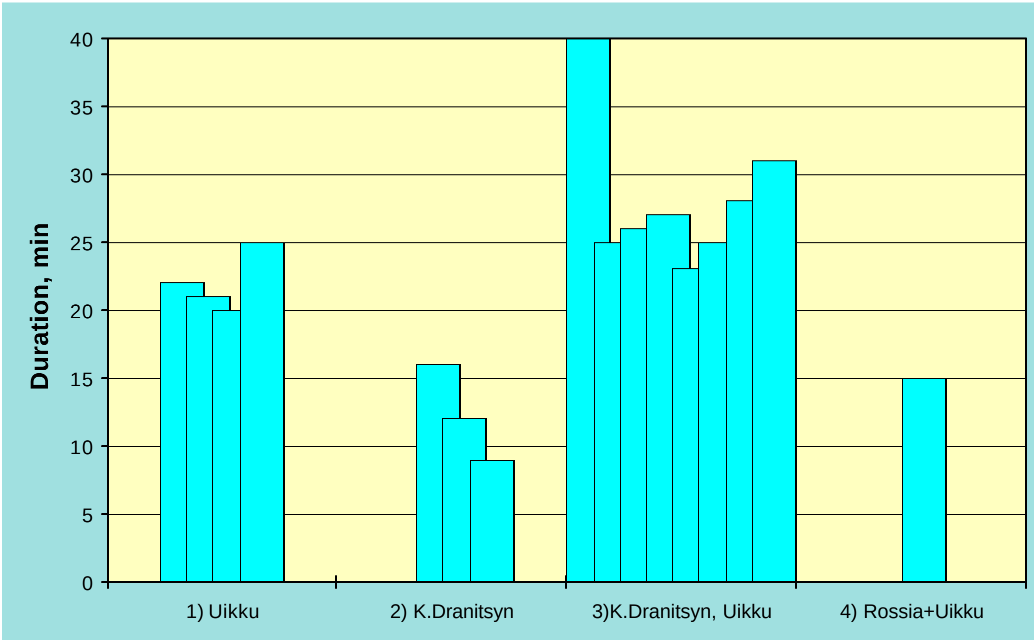


Figure 16 Time consumption of icebreakers Rossia *(1, 2, 3) and* Kapitan Dranitsyn *(4) for the breaking out of stuck participants of the escorting*

Breaking out operations were most frequent in the passage from the Yamal Peninsula towards the Kara Strait. The convoy spent about 36 hours of steaming time for this passage. Icebreaker *Rossia* ten times stopped the escorting spending more than 4 hours (about 11 %) for the release of stuck ships. As a whole, average duration of one operation was about 23 minutes and total time consumption - about 6 hours.

5.7.4 Breaking through heavy stretches by ramming

Maintaining fairly high speed of movement of the convoy on the route, icebreakers were breaking through separate heavy stretches by ramming. In the Kara Sea, icebreaker *Rossia* bore the principal load and in the Ob Gulf, icebreaker *Kapitan Dranitsyn* did. This procedure was most frequently used by the diesel icebreaker because, as to icebreaking potentials, it ranks much below the nuclear icebreaker. Over the voyage period the first of icebreakers made 19 ramming impacts and the second - 165 (actual number of impacts was greater as the above number was recorded only by one group of scientists being either on the diesel icebreaker or aboard the nuclear icebreaker). Total time consumption for forcing heavy ice stretches was 1.4 and 12.5 hours. To make one impact cycle including reversing, retreat, reversing, acceleration, impact proper and moving until the full stop[3], icebreakers spent approximately the same time the average value of which being about 4.4 min. (Figure 17).

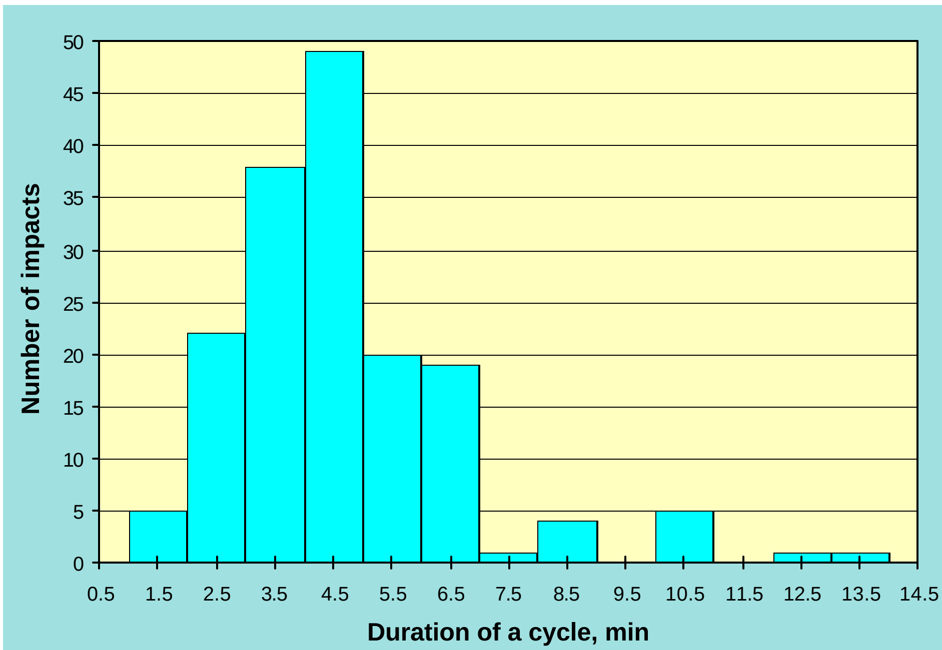


Figure 17 Differential distribution of the time consumption of icebreaker Kapitan Dranitsyn *during the work by ramming*

At the same time, while working by ramming there is a risk of jamming of icebreaker with a full loss of the possibilities to move and maneuver. It was 8 times the case with icebreaker Kapitan Dranitsyn*: 3 times in the Kara Sea, 4 times at the approach of tanker to the loading place and in the preparation of an ice berth and once while going out of the Ob Gulf along the old channel (Figure 18 and*

Table 18). The last jamming was the longest one. It lasted for about 50 minutes. They managed to resume movement only after the switching on of heeling and trimming systems. There were no jammings with nuclear icebreaker *Rossia* during the entire period of the voyage.

3 Disregarding jamming

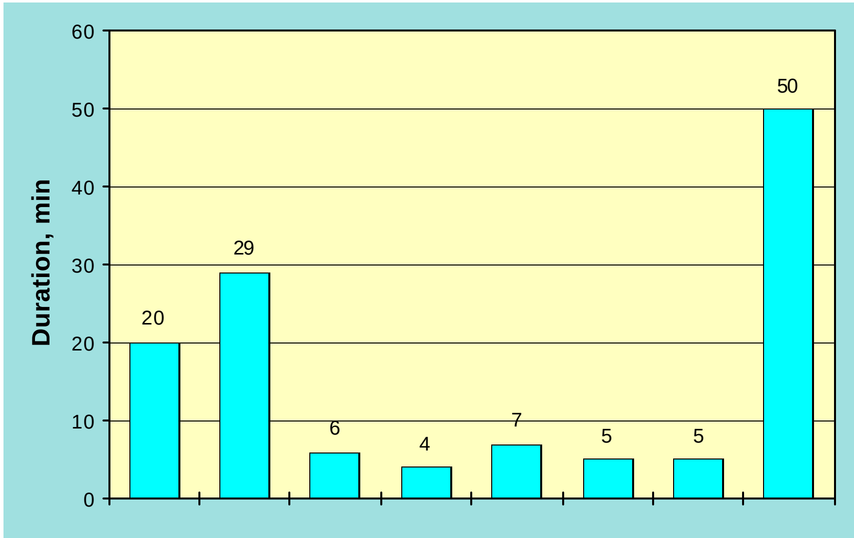


Figure 18 Duration of jammings of icebreaker Kapitan Dranitsyn

Table 18 Jammings of icebreaker Kapitan Dranitsyn

No.	Date	Moscow time	Duration, min	Coordinates
1	April 30	00:56 - 01:16	20	77?13N / 69?17E
2		01:33 - 02:02	29	77?13N / 69?17E
3	May 3	02:37 - 02:43	6	74?13N / 77?07E
4	May 4	11:10 - 11.14	4	Preparation
5		11:39 - 11.46	7	of the ice
6		12:10 - 12:15	5	Berthing
7		12:19 - 12:24	5	at Sabeta
8	May 8	17:25 - 18:15	50	71?40N / 72?50E

During the entire voyage, navigators had at their disposal practically exhaustive information on the ice cover over the route of sailing. Aside from ice charts obtained from artificial earth satellites, the tracking was made by the results of helicopter reconnaissance flights regularly performed by hydrologists of both icebreakers. In this connection, tactical procedure *icebreaker route reconnaissance* was used only once in the Barents Sea at the approach to the cape Zhelania when icebreaker *Kapitan Dranitsyn* having left tanker adrift was searching ways under complicated ice conditions. The icebreaker spent 1.6 hours for this maneuver.

One should especially note the high professional skill of hydrologist N.G. Babich, Superintendent of the Headquarters of Marine Operations of the Western area of the Arctic in the selection of a rational track for the convoy to proceed through ice.

5.8. Conclusions and recommendations

This section summarises the major findings from each of the component areas described in this chapter. It suggests a number of ways members of the consortium or others could capitalise on the advances made.

5.8.1 Major conclusions

The following are the primary conclusions:

1. The cooperation between the ARCDEV collaboration and Ice Routes for validation of the classification and routing work was successful.
2. The consortium achieved a **positive response from a broad spectrum of potential customers** to the ideas developed during the project. Several volunteered to participate in more detailed analyses. The lack of consensus reflects the diversity of potential uses for ice and ship route information.
3. An **operational need exists for high-resolution ice information** to complement existing methods of ice reconnaissance. Some form of automated classification is necessary to avoid the use of SAR imagery on-board ships; there are ambiguities in this unclassified data which makes accurate discrimination of ice and water problematic for the non-expert.
4. Artificial intelligence techniques have demonstrated that the **combination of data sources gives ice information at a level of detail not attainable by humans**. Expert systems and neural networks cope well with the integration of diverse sources such as SAR, SSM/I and contextual information and are suitable tools to fuse other information in order to achieve higher charting accuracies.
5. For the immediate future, a **hybrid** of automatically generated charts with screening/editing of results by ice interpreters appears to be the way forward.
6. Several **unique validation datasets** have been collected which allow quantitative assessment of the accuracy of ice charting methods through closely coincident satellite and surface observations over a range of ice conditions.
7. The **basis for a ship routing model has been clearly demonstrated** using either efficient or more sophisticated concepts. Future development should now concentrate primarily on accurate speed loss calculations.
8. The joint use of **ice charting and routing tools will play roles in bridge navigation display and ice navigation training**. The business opportunity for this will grow in step with the economic development of the Russian arctic and with the adoption of international standards relating to polar navigation.
9. **Power levels used in M/T Uikku were exeptionally low**, incicating that more effective tactical navigation could be done to improve convoy performance.
10. **Energy per nautical mile** was low in Uikku showing the capability of icebreakers to clear the channel for convoy.
11. **EM ice measurements corresponded** well with measused performance on convoy.

5.8.2 Recommendations

Given the broad scope of the Ice Routes WP, a great variety of recommendations may be developed as a guide to others working in the area. The following identifies some of the major issues which it is felt should be addressed since they are important and stand a good chance of success:

- Maintain and develop **long-term working contacts with user groups** who have expressed **interest** and can assist with development of strategy and refinement of operational requirements
- **Further** develop the use of contextual information as an element of ice charting methods using artificial intelligence techniques, with emphasis on small scale features such as ridges and leads
- Address methods of handling multiple satellite data sources and ensure calibration issues between systems and ground stations are incorporated
- The advantages of the existing route selection algorithms can be combined in modeling the arctic marine transportation system operation based on GIS-technologies.

- ? ? Establish robust ship route modelling algorithms which combine the effects of multiple ice conditions (e.g. floe size, ice concentration and ice type) on vessel operations, in order to predict transit speed, fuel consumption and risk
- ? ? Ensure that technical advances in ice charting and ship route modelling take due account of the anticipated International Polar Code of Navigation in order to develop consistent and appropriate strategies and methods.
- ? ? For optimal route selection in addition to the actual and prognostic hydrometeorological information it is also necessary to take into account information on the location of the icebreaking fleet and its plans.

On the basis of the conclusions, findings and recommendations listed above, the Ice Routes consortium has addressed and made significant advances against all of its primary objectives. The project has enhanced the level of European expertise in several of the component areas, advancing the capabilities of the groups involved and developing the awareness and interest of a broader community. These successes provide important stepping stones towards safer, more efficient and more capable navigation in the European and Russian arctic waters, which will be advantageous to all the nations involved.

6. ICE NAVIGATION MODELS

6.1. Navigation simulation

Today there are navigation simulators used for training ship personnel to handle their vessels under various problematic situations eg. approaches, narrow waterways, channels etc. All these only have programs for open water operations. As ice navigation increases, the need for a training simulator for ice conditions also increases. These ice navigation simulators are under development today in several countries and the state of development varies considerably. This report gives an overview of the present state of simulation of navigation in ice, and the methods and data to be used. When using a ship's simulator for education and post graduate training, it is not only the existence of a suitable mathematical model that plays a major role. The operations to be carried out with this simulator are also important. Once one knows what is to be simulated, conclusions can be made regarding the requirements of a mathematical model, its precision and realism. A short overview of typical and important operations in ice is given and various examples outline the direct comparisons made to actual driven manoeuvres during the ARCDEV demonstration and expedition.

When using a ship's simulator for education and post graduate training, the information required for planning a ship's voyage also plays a role. This information is not needed for the actual development of a simulator and the exercise carried out in a simulator does not just consist of direct use of the simulator itself. Usually it consists of a complete scenario, including preparation, execution of the exercise and the following evaluation. Some attention will be paid to ice routing, facilities for locating ice and ice observation.

The task was to record the data measured during the ARCDEV expedition, looking firstly at the quality of the available data and then making comparisons to establish what data is relevant for carrying out simulation and what is missing and likely to be required. The use of ice simulators in ice operation training enhances the aim to reach the training objectives in ice operation courses as no classroom training can adequately replace practical training. Various scenarios which should be created in the simulator are outlined. Because of the very complex system of operating a ship in ice, many influences must be taken into account for simulation. A number of these influences are listed. The simulator itself is very important for realising the simulation of navigation in ice as it is able to simulate realistic and different ice conditions. This report outlines suggestions for further development and consequent expansion of suitable mathematical models which are necessary to describe the interaction between ship and ice. In principle, operating in ice has hidden dangers compared to navigating in open water. Faults can have serious consequences for the safety of crew, ship and cargo when operating in ice-covered areas. Further danger can be caused to the environment considering the increase of traffic with tankers in arctic waters. If there is a greater need to navigate in ice and simulators are required for training to operate in ice, more resources must be provided for the development of such a system. Developing a suitable mathematical model is a very complex task and the efforts required to do so should not be underestimated.

Considering the traffic in the eastern Baltic Sea during the winter and the damage that occurs every year due to inexperience, it would be extremely advantageous to provide special training for captains and navigators by using simulators for training to navigate in ice. There is a great interest in Canada, Sweden, Finland, Russia, Germany and Norway in developing the simulation of navigation in ice. The development is looking towards an increase in traffic in ice. Captains and navigators of different origins already have to prove their ability to navigate in ice. This, the sea accident statistics in ice, the unusual features of operating in ice, as well as a number of other conditions, prove that we seriously need to start developing the simulation of navigation in ice.

6.2. Conclusion

In principle, operating in ice has hidden dangers compared to navigating in open water. Faults can have serious consequences for the safety of crew, ship and cargo when operating in ice-covered areas. Further danger can be caused to the environment not only considering the increase of traffic with tankers in arctic waters. If there is a greater need to navigate in ice and simulators are required for training to operate in ice, more resources must be provided for the development of such a system. Developing a suitable mathematical model is a very complex task and the efforts required to do so should not be underestimated. Considering the traffic in the northern and eastern Baltic Sea during the winter and the damage that occurs every year due to inexperience, it would be extremely advantageous to provide special training for captains and navigators by using simulators for training to navigate in ice. There is a great interest in Canada, Sweden, Finland, Russia, Germany and Norway in developing the simulation of navigation in ice. The development is looking towards an increase in traffic in ice. Captains and navigators of different origins already have to prove their ability to navigate in ice. This, the sea accident statistics in ice, the unusual features of operating in ice as well as a number of other conditions prove that we seriously need to start developing the simulation of navigation in ice.

6.3. Trafficability models

From the ice observation data for each leg an equivalent level ice thickness is calculated based on parameters such as:

? ? level ice thickness
? ? ice concentration
? ? ice floe size
? ? ridge or hummock occurrence
? ? ice pressure

Correction functions are used for each of the above mentioned ice conditions to calculate the equivalent ice thickness. The correction functions influence the ice thickness so that the resistance under the above ice conditions causes the same ship resistance in an equivalent level ice thickness. Therefore the correction functions are specific for each ship.

With this equivalent ice thickness the resistance is calculated according to G. Lindqvist, “A straightforward method for calculation of ice resistance of ships”, POAC 1989. This method has been improved by HSVA.

The open water resistance is calculated according Holtrop/Mennen and added to the ice resistance (Holtrop, J.; Mennen, G.; An approximate power prediction method; ISP 1982).

The delivered power and thrust are calculated with the help of empirical formulae. Both can be adapted to the actual vessel if model or full scale prediction data are available.

The program delivers the following results for each leg:

- distance and course for the leg (great circle calculation between start and end of the geographic position of the leg)
- average speed
- case 1: Operating with maximum power and/or maximum allowable speed

Results: speed and propulsion power for the leg

- case 2: ARCDEV voyage, using the average measured power of icebreaker KD

Result: speed and the time required for the leg.

The difference between the time measured for a leg during the ARCDEV voyage and the calculated time for the same leg is an indicator for the reliability of the calculations.

6.4. Results of trafficability studies

The results of the trafficability calculations based on ice observation and on predicted ice charts are listed in the Tables 5.1 to 5.3. Two program versions were used. The program version 1 was available at the voyage, the version 2 is the improved and calibrated version. This version was calibrated without the leg “Kara Strait” where the ice observation is wrong. No changes in the program or of the calibration of the program were carried out when calculating the different cases.

Table 19 Results for the voyage from the edge to the Ob estuary and from the Ob estuary to the ice edge on the way back to Murmansk

Ice data	No. of legs (-)	Real Time (minutes)	Calculated Time (minutes)	Difference Calc.-real (minutes)	Error (%)	Remarks
Observed	174	10660	12224	1564	14.67	Without calibration and improvements Version 1
Observed	173	10600	11519	919	8.67	* - " -
Observed	174	10660	11201	541	5.08	Improved and calibrated program (Version 2)
Observed	173	10600	10736	136	1.28	* - " -
Observed	29	10660	10004	-656	-6.15	Version 2
Predicted NOAA with observed ridges & hummocks	29	10660	10007	-653	-6.13	Version 2
Predicted NOAA	29	10660	9280	-1380	-12.95	Version 2

* *excluded the leg in the Kara Strait*

Table 20 Voyage from the ice edge to the Ob estuary

Ice data	No. of legs (-)	Real Time (minutes)	Calculated Time (minutes)	Difference Calc.-real (minutes)	Error (%)	Remarks
Observed	93	6861	7276	415	6.05	Without calibration and improvements
Observed	93	6861	7088	227	3.31	Improved and calibrated program
Observed	20	6861	6638	-223	-3.25	Improved and calibrated program
Predicted NOAA with observed ridges & hummocks	20	6861	6032	-829	-12.08	Improved and calibrated program
Predicted NOAA	20	6861	6049	-812	-11.84	Improved and calibrated program

Table 21 Voyage from the Ob estuary to the ice edge through the Kara Strait on the way back to Murmansk

Ice data	No. of legs (-)	Real Time (minutes)	Calculated Time (minutes)	Difference Calc.-real (minutes)	Error (%)	Remarks
Observed	81	3799	4948	1149	30.24	Without calibration and improvements
	80	3739	4243	504	13.48	* Without calibration and improvements
Observed	81	3799	4113	314	8.27	Improved and calibrated program
	80	3739	3648	-91	-2.43	* Improved and calibrated program
Observed	9	3799	3366	-433	-11.40	Improved and calibrated program
predicted NOAA with observed ridges & hummocks	9	3799	3975	176	4.63	Improved and calibrated program
predicted NOAA	9	3799	3231	-568	-14.85	Improved and calibrated program

** excluded the leg in the Kara Strait*

(-) calculated time for the voyage shorter than the measured time

6.5. Conclusions

The calculation of voyage time showed that it is possible to reduce the time error from about 15.3 hours through calibration and improving the program to a minimum of 2.3 hours for the part of the route from the ice edge to the Ob estuary and back to the ice edge on the way to Murmansk. This voyage was divided in legs of about one hour.

The distribution scatters in a wide range from -100% to 100% and above. This indicates that the ice observation and/or the program for calculating the time and speed have shortcomings.

Improvements are necessary in ice observation and in the calculation of the ship´s speed.

Reducing the number of legs by adding single legs to one larger leg the error distribution was improved. Using only some legs the error can be reduced close to zero. Through the calibration of the program and adding single short legs to a larger leg the errors of the short legs neutralize one another, but this does not solve the problem.

Comparison of continuous EM ice thickness profiling and observed ice data with the ship performance data showed that the EM data have a smaller error distribution. It could be shown that the ice thickness measured with the EM is more reliable than the observed ice data. Using the EM ice thickness profiles as input data a new program with shorter time legs should be investigated to calculate continually the resistance and speed of the vessel.

Using the actual ice charts of the "National Ice Center" (USA) as input data for ARCDEV the error distribution scatter in a wider range. One reason is that the difficult hummocked and ridged ice is not identified in the "egg-code". But hummocks and ridges do effect the ship´s speed, significantly. Nevertheless these charts are a good basis for pre-calculating the duration of a voyage. It would improve the speed prediction, if the ice thickness would be noted in 0.1 m steps.

It would be useful to have better information about the ice conditions along a proposed route. It would then be possible to calculate more accurately the expected time of arrival (ETA). With improved ice information also the computer program for speed calculation of the icebreaking ship could be further improved. But during each voyage in Arctic waters some new surprises can occur. It is the target for the future to minimize this unknown Arctic surprises.

7. REMOTE COMMUNICATIONS

Remote Service and Maintenance workpackage of Arcdev, tested how latest communications and IT-technology could be used to assist the crew of a ship when sailing in Arctic conditions. For this purpose a satellite communications system was installed onboard M/T Uikku when it was being docked for preparation of the Arcdev voyage. During the voyage itself one researcher from the Arcdev project used the equipment to send information about the voyage to the project members on land and made a series of tests with the crew using the remote maintenance programs of the system.

Modern vessels have in their propulsion and navigation systems a lot of highly developed technology. On the other hand the transportation economics require smaller crews with less specialised personnel. On vessels operating in remote areas with no supporting infrastructure this creates problems with service and maintenance of the high-tech systems. Today's telecommunication systems offer possibilities to handle the diagnostic and service functions without having the specialists onboard the vessels. The capabilities of these systems were tested during the voyage.

7.1. Remote Service and maintenance background

Remote service and maintenance is the management, control, operations support, repair and corrective activities based on communication services, which will ensure that optimum levels of availability and overall performance of operations are achieved, in order to meet business objectives. The service and maintenance operations are part of an equipment manufacturers after-sales activity and operating organisations operations function. (See Figure 19)

In the ARCDEV project the activities were mainly focused on the technical side of remote Service and Maintenance. (See Figure 20). The processes were evaluated when the demonstration situations and setups were created. Some training sessions with the crew were also done but otherwise most of the activities were made in the information and technology side.

All the activities in workpackage 10 of ARCDEV were done in order to achieve these goals. The goals are rather abstract and there are not very good means to measure how much this system has improved these things. However they are kept in mind through the whole project and the results in the end of this document have been evaluated against these goals.

?

Competitive advantages to manufactured or supplied products through value-added services. Better means through communications for supporting users in all areas with latest information and best competence available. Improved economy and quality of operations, through better reliability and availability of operations. Improved quality and response time of operations support. Better grounds for planning and scheduling of operations and prediction of output. Schemes for improving reliability and predictability. Utilization in product design and operations support of information and knowledge captured through maintenance and operations reporting.

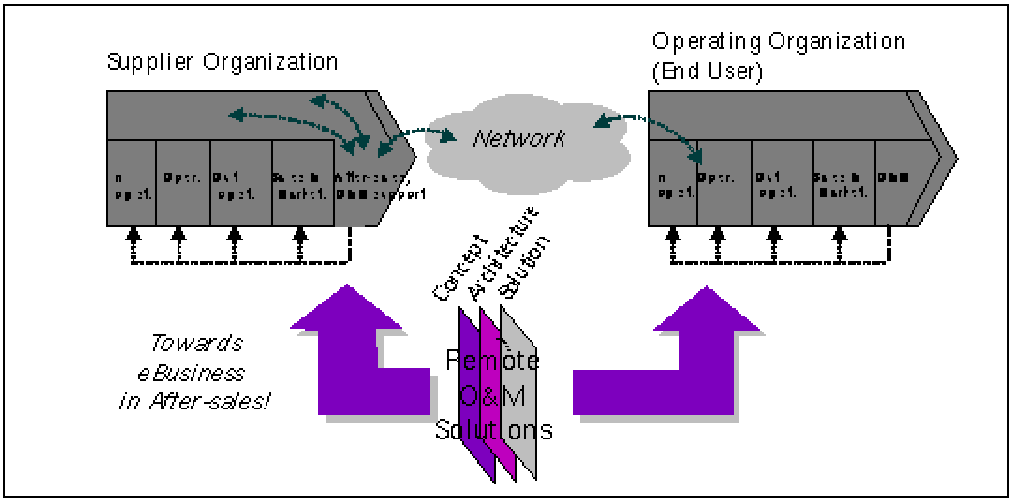


Figure 19 Remote O&M supprt role in value chains

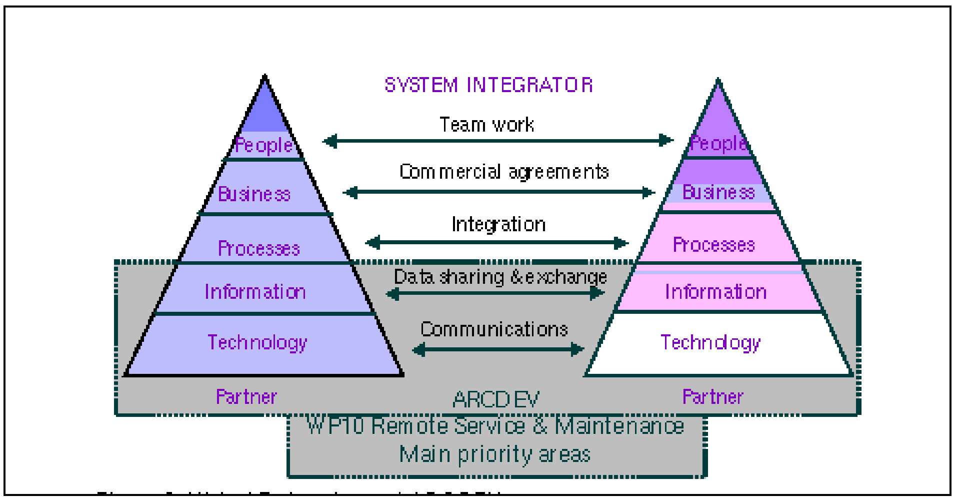


Figure 20 Virtual Enterprise and ARCDEV

7.2. Overview of the system used during the ARCDEV voyage

Virtual reality assisted tele-existence system for remote maintenance

The communications and remote maintenance system used onboard M/T Uikku during the ARCDEV voyage was based on the Remote Video system from Remtec Systems, Ltd. The system is a complete multimedia satellite communications system with ability to transfer video, audio and data information on both ways between the ship and shore. The system as such can directly be used for example for remotely helping the maintenance personnel onboard to carry out a special maintenance task or to give medical aid. In this project the functionality of the system was extended in two ways. The first way is to add a local mobile base station and a lightweight PC with a cordless connection to the base station. This way the person with the communications unit could move around and use all the system capabilities with a portable device. The second way was to add a virtual reality display to help in the maintenance work of a complex machine. In the Figure 21 there is a diagram of the basic communications system. The 64 kbit/s digital signal was sent through the Inmarsat-B satellite system to the closest land-earth station and the forwarded to the recipient through ISDN telephone network. The system is compatible with standard H.320 ISDN videoconference units.

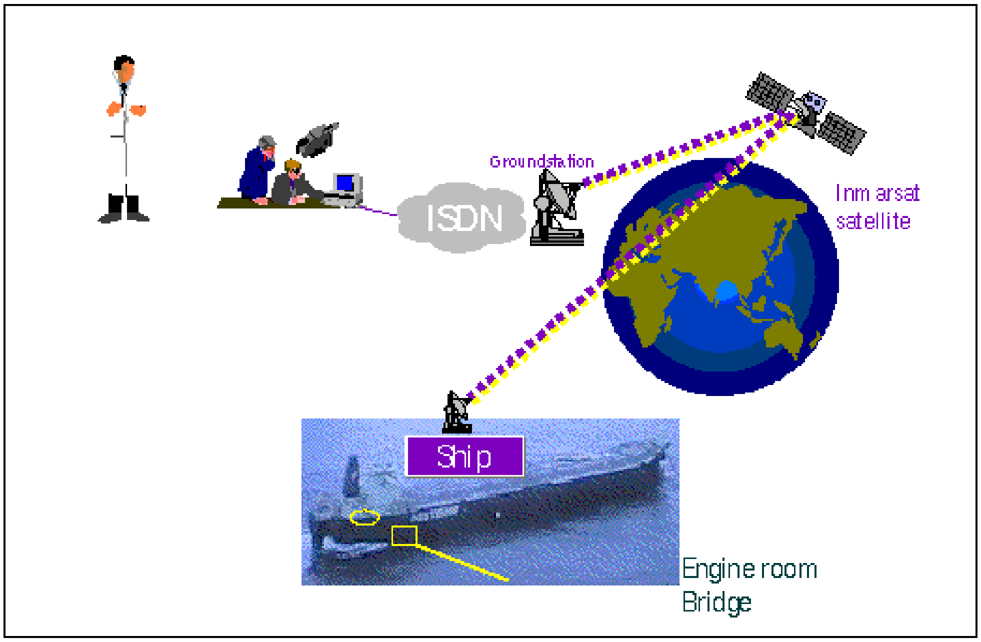


Figure 21 The principle of the ARCDEV communications system

The virtual reality assisted remote maintenance and diagnostics system demonstration is part of the ARCDEV project's work packages WP4 and WP10. The purpose is to demonstrate the use of virtual reality techniques in conjunction with video conferencing systems for maintenance and remote assistance. The system users are an expert in his office and a person located on the sea going vessel, in this case on M/T Uikku. The expert views the target with a vision system. 3D-virtual information is augmented on the live video sequences in the form of virtual images, CAD-drawings, process measurements, component data etc. The expert can point objects on the ship with a laser-pointing device, that he can control using a mouse or a joystick. The expert sends instructions to the maintenance crew by voice communications, laser pointing, work sequence video and animation transmissions, and by sharing "white boards" and other application programs.

The system consists of a remote station and an expert station. The remote station comprises of communications unit, a camera/laser pointer unit, and the operators portable communications unit. The expert station comprises of a head-mounted display, remote camera controls, a 3D virtual model viewing and generation software with graphics-video overlay capabilities, a telecommunications computer with videoconferencing software, and LAN connections to expert databases.

Virtual images will be overlaid on top of the real-time video. The virtual images are structural images of the system under surveillance. Animated images of measured variables will also be overlaid on the video sequences. The overlay video pictures can be viewed at the expert station and still images can be transmitted back to the vessel.

In work packages WP4 and WP10 we used existing videoconference system by RemtecSystems, Ltd, which was enhanced with the additional virtual reality and telepresence features described above. The additional features have been developed by Helsinki University of Technology Automation Technology Laboratory in co-operation with VTT-Automation (Automation section of the Finnish State Research Center).

7.3. Public and private demos

The system functionality was demonstrated to a wider audience 8 times. The demos were done for different organizations and their contents were planned accordingly. The demos documented in this chapter are mainly for companies involved with arctic shipping or other arctic activities.

7.3.1 Wartsila NSD demo

The Wartsila NSD demonstration showed the basic functionality of the system to the Wartsila people situated in their premises in Vaasa. They were using their standard video communication system (Remote Video by Remtec Ltd.). The system had no capabilities in showing the virtual objects. The movement of our standard camera pan-tilt unit could not be controlled from Vaasa. However, we had a standard videoconferencing camera with pan-tilt possibilities. That was controlled from the Wartsila NSD office. The purpose of this demonstration was mainly to demonstrate to the Wartsila NSD company the video communication system over satellite connection, the use of multiple cameras in various different locations (the bridge, outside of the bridge, and in cargo control room) and the use of the laser-pointing device. No actual or invented maintenance tasks were carried out during the demonstration.

7.3.2 Neste demo

The Neste demonstration idea was to demonstrate the use of the system in a fire drill situation. The idea being of course that all kinds of emergency situations lend a good opportunity for using this kind of remote video communication system in following and in aiding and in directing the rescue operations.

The pan-tilt camera head was located in the electrical cabinet room of the engine room. Supposedly smoke was pouring in to the room from some of the cabinets. A fire fighter with smoke-diving equipment was crawling into the room after a general alarm had been given on the vessel. In this experiment the camera movements and the laser pointing device where controlled from the telecommunications center of the vessel. The people at Neste's headquarters could communicate with the person sitting in the communications cabinet and at the same time with the person who was situated in the fire fighting area. In our demo the fire fighter did not wear the belt compute with the associated head-mounted-display, but that could also be done.

7.3.3 Etälä project demo

The ETÄLÄ project demonstration had the telecommunications connection between Helsinki University of Technology, Automation technology laboratory and motor tanker Uikku. In this demonstration the use of virtual reality and the augmented reality techniques were demonstrated. The camera with the pan-tilt unit was situated in the middle of the ship bridge. A virtual model of the ship bridge had been constructed. (The model can be seen and manipulated at the project webpage:
http://www.automation.hut.fi/~pharmo/Public/UikunSilta.html.
Below is a still image of the virtual model of the bridge.

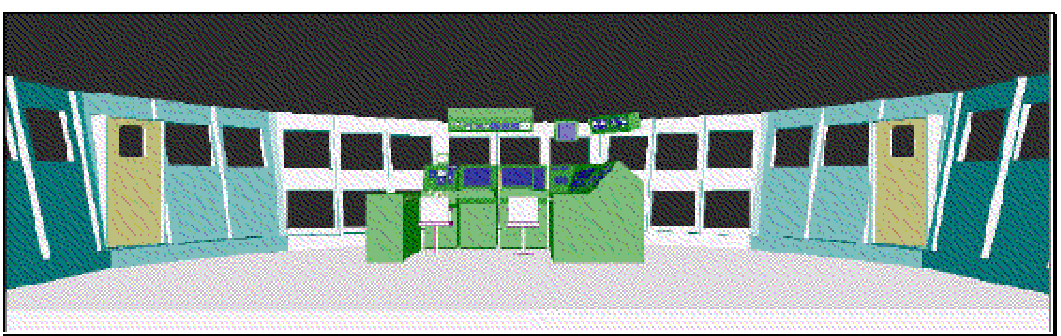


Figure 22 The virtual model of the bridge of M/T Uikku.

7.3.4 Demo for ABB Marine, the maintenance of the ships Azipod propulsion system

The electronic propulsion system maintenance possibilities were demonstrated to the provider of the system ABB Marine. In the demo the virtual model of the propulsion control unit was used together with the laser pointer to show the possibilities for remote maintenance and tele operation.

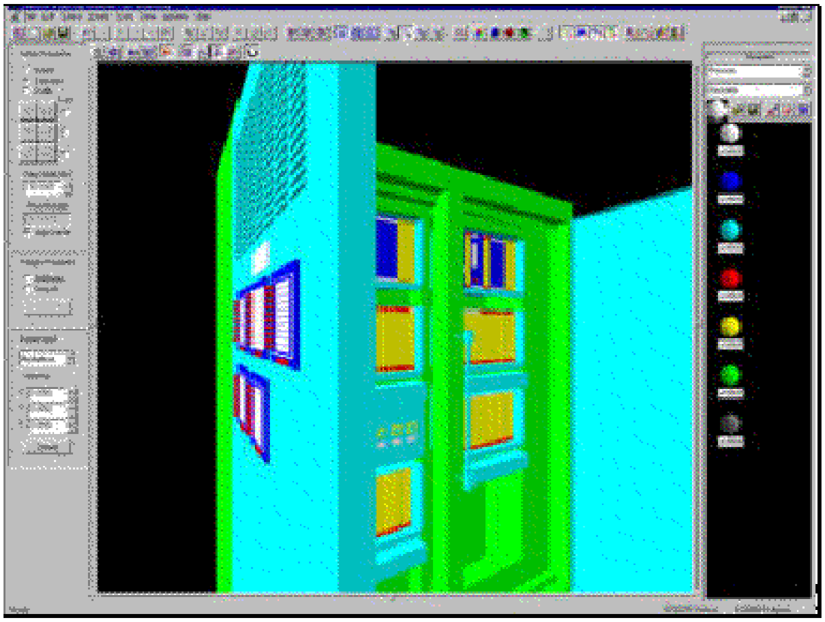


Figure 23 The virtual model of the Propulsion control unit.

7.4. Results and experience collected in ARCDEV

Technology and applications are feasible and more or less ready to use as they exist today. Usability is at an acceptable level today, but could be improved. New state-of-the-art technology will further improve the possibilities from both a service and usability point of view. The sys tems and applications should be operated by the ordinary crew and not by specific experts and researchers, which are available only part of the time. Ship personnel should be widely trained and be aware of the possibilities. More integration and broader us e of the existing facilities and services would bring even more benefits. Uncovered areas where e.g. spare part information, more process data integration, reporting processes etc.

Problems in starting the telecommunications connection to the expert stations in Finland

Technology and devices operated normally even in the harsh arctic conditions. Success rate of communication seemed adequate (90% success). Would have been even higher, had the satcom terminal installation not been done as an add-on later. If possible advanced communication matters should be taken into account at an early planning stage, otherwise the services might be non-operational part of the time or proper training etc can't be arranged. On board Uikku the late add-on installation of the satellite antenna caused a line-of-sight problem, as the chimney was part of the time in the way. The system had some problems that could not be solved prior to the ARCDEV voyage. One was that the videoconferencing session had to be started from the ship. Calling the ships High Speed Data channel number did not function properly, and thus the video conferencing session could not be initiated this way.

Approximately 50% of the connection trials did not lead to a connection and starting of the video conferencing session. The main reason was that the systems antenna did not see the satellite that was situated quite low over the horizon. The ship chimney was in the way. Soon it was discovered that if the ship was moving north or northeast, that the satellite connection could not be initiated. The antenna is not placed to the best spot on the top of the mast. This is due to the fact that the ship had an other Inmarsat satellite terminal also installed. However, the satellite connection could always be initiated during the trip by turning the ship. This was done on two occasions when the ships were stopped in ice during ice research sessions.

Problems in maintaining the communications

After the connection was initiated and successfully started there were only minor problems with it. Approximately 20 of the videoconferencing sessions were interrupted and the connection broken. All the reasons for this were not recovered, but we can name some of the probable causes: the ships chimney or other structure hindered direct line of sight to the satellite while the ship was being maneuvered, data transmission errors in the ship, in the satellite connection, or in the ISDN connection to the satellite base station, or within the expert station computer caused the videoconferencing session to be aborted. Since all data traffic was also handled by the videoconferencing system, data traffic was also aborted.

Problems in accessing various Internet services such as mail and WWW-servers

At some occasions the various services were unavailable while trying to reach them from the ship. This was mainly caused by the land-based server being locked up because of communications errors. This was especially annoying when the ship was furthest east and the time difference between the ship and Finland caused that the land-based server was not operated by a research team member at the time when it was being used by the ship.

TCP/IP networking

The connections does not support fully the normal services of the TCP/IP networking, such as FTP, UDP. This was because the communications channel of the video codec that was used did support only TCP-connections with so called socket forwarding. This enables a TCP/IP-program to connect to the local server and the data to be transmitted to another computer on the other end of the videoconference to the TCP/IP port of the receiving computer. While this was not a full TCP/IP connection it still provided communications channel to any TCP-based program. This enabled all the services needed like file transfer and Web browsing.

Placement of the satellite antenna

The low altitude of the satellite over the horizon and the placement of the satellite antenna caused connection problems. This is a normal problem in arctic waters and cannot be eliminated when using geostationary satellite systems. Future low-orbit satellite systems should provide more reliable and stable communications.

8. LOADING SYSTEMS

8.1. Introduction

The demonstration of the possibility and economical viability of developing and maintaining continuous year-round navigation routes along the Northern Sea Route must necessarily include the verification of the feasibility, accessibility and operability of offshore terminals, where trading vessels can moor safely to load or unload the cargo.
Moreover, the huge amount of recoverable oil and gas reserves discovered in the Russian Arctic leads to the consideration that the development of infrastructures for mooring and loading of the tankers in remote and environmentally hostile areas will have a great demand in the next decades.
The potential locations of interest for such terminals are spread in a quite large geographical area, but, in most cases, this area is characterized by limited depth, severe ice conditions and exposure to strong northern winds. Sometim es, as it is the case of the large Siberian river estuaries, the scenario includes high river currents and large tidal excursions.
Consequently, from the technological point of view, the design, installation and operation of systems in such areas still represent a challenging task.
Studies on Arctic loading terminals are not new and in the recent years, mainly in the eighties, considerable funds have been devoted by Oil Companies, Marine Operators and Governmental Institutions to develop research dedicated to this subject. However, in most cases, the content of such studies has not been divulged. The same applies to the documentation relevant to operational experience, which has been achieved, mainly with reference to the Canadian part of the Arctic.
Therefore, still today, primary objectives of investigation remain:

- the acquisition of knowledge on the environment,
- the identification of suitable configurations of terminals for ice scenarios,
- the definition of design methodologies for their development,
- the acquisition of practice on how to operate these systems.

Based on the above, the research activity within the Work Package 7 has been focussed on:

- the observation of the general ice and meteoceanographical conditions at the sites of interest for installation of offshore loading systems, dedicated to the export of hydrocarbons from the fields discovered in the Ob and Yenisey Estuaries areas, East Barents and Kara Seas;
- the evaluation of the potential of alternative systems and the feasibility of year-round operations. Among the identified alternative systems, a version of the SBAM (Sea Bed Anchor Mooring), a single point mooring system developed by Tecnomare, has also been considered. Such version presents specific features with make it attractive for application in Arctic and sub-Arctic areas;
- the provision of recommendations for the development and operation of the future systems and for future research work.

In order to evaluate the potential of each system, a number of aspects has been identified for discussing and ranking the various identified alternatives, taking into account published literature, engineering judgement, available data and observations made during the voyage.
ANNEX 1 provides a summary of results of the observations made, for WP-7, during the voyage.

8.2. Description of arctic tanker loading systems

In the Arctic, the presence of ice precludes the use of the conventional loading systems utilised for open waters, such as SPMs with surface buoys and floating hoses, and it is necessary to develop systems suitable for both open water and ice conditions. Depending on the location and water depth, the sizing criteria are dictated by the wave or the ice conditions.
At present, no year-round loading operations of tankers are maintained in the Arctic at exposed locations, although the large number of studies carried out in the latest 20 years and the accumulated operating experience indicate that the year-round loading is feasible on a regular basis.

The permanent systems for tanker loading in the Arctic can be grouped into three main types:
- the conventional fixed jetty
- the gravity type loading system
- the single point mooring.

The berthless loading, similar to the one adopted for the loading operation at Sabetta, is not considered as a proper system, as the method can be utilised only for a limited period of the year and it is not suitable for transfer of industrial quantities of hydrocarbons.

8.3. Information collected during the voyage

8.3.1 Location of the Loading System

Sabetta is a geological research centre situated on the Yamal Peninsula and on the West bank of the Ob River. The centre was founded in 1977 with accommodation originally designed for a total workforce of 1200 personnel. Today, the workforce is reduced to approx. 150 personnel. The community is served by an air service, which brings provisions and supplies once per month. Crew changes are effected at the same time.

The geological work carried out has included the search for hydrocarbons and the community produce gas condensate. The condensate provides them with fuel for the vehicles and for the generators. The balance of the condensate is stored in a tank farm and exported once per year, in volumes of approx. 14,000 m^3. The revenue from the export provides the finance to continue with the research work.

The condensate is produced from three wells, and the gas produced is flared off.

8.3.2 The Loading Facilities

The gas condensate is delivered from the production field to a tank farm, located on the riverside of Ob, at a distance of several km from Sabetta. At the tank farm the condensate is accumulated in vertical, cylindrical tanks, of about 2,000 m^3 capacity each. The total capacity of the storage tanks is about 14,000 m^3.

There are a number of designs and types of tanks, no doubt added over a period of time as production in the field increased. There are no bund walls in the tanks, although bunds had been created by digging out the snow to gain access to the valves and lines. There was no fire fighting capability in the area.

To deliver gas condensate aboard the tanker, a pipeline consisting of two pipe runs was laid over the river ice prior to the arrival of the vessel, from the tank farm to a position 2 miles offshore, where the water depth is about 10-12 m. The diameter of one pipe is 146 mm (6"); the diameter of the other pipe is 114 mm (4"). Figure 24 shows the gas condensate pipeline laid over the ice near Sabetta and the winter road along the pipeline. On the horizon line, Sabetta settlement can be seen. The length of the pipeline is 4,100 m.

The pipeline was assembled by using 25 m pipes used for drilling wells and welded together to form lines of about 150 m long, joined by means of flanges. A winter road destined for movement of tractors, trucks, buses, tank truck, crawler-type cross-country vehicle, truck crane was laid along the pipeline. At the shore end of the pipes, there was a crossover valve between the lines.

Two diesel-driven pumps installed, in individual sheds, at the tank farm deliver the gas condensate.

The pump characteristics are as follows:
- one pump is of reciprocating type, with a capacity of 150 m^3/h at 20 kg/cm^2. It is powered by belt drive from two diesel motors.
- the second pump is of axial type, with a capacity of 90 m^3/h at 10 kg/m^2, powered directly by a third diesel motor.

The pumps were connected to the discharge lines by flexible hoses. When not required the pumps can readily be disconnected from the tank farm piping system, and removed from the area.

The pipeline end (PLEM) is fitted with shut-off valves, connecting flanges and reducers placed over a drip tray.

The tank, installed on a pad, adjacent to the drip tray, has a diameter of about 3.2 m, a length of about 6 m and a capacity of about 50 m^3.

The tank is intended to blow the residues out of the pipeline and to collect leaks from the drip tray.

The drip tray, to collect leaks developed during hose connection, loading and other operations, is placed under the pipeline ends (valves, connecting flanges and reducers). It has approximately the following dimensions: 2 m x 4 m x 0.6 m, for a capacity of about 4.8 m^3. A tank car with a pump is used to collect the condensate from the drip tray and the tank.

There is no jetty or permanent loading facility. The basin in the ice in the way of the pipeline end was made by the KAPITAN DRANITSYN. The manoeuvre was initially to form a lead past the PLEM, to the point it was assumed the UIKKU bow would be when in position for connecting the loading hoses. After this, the ice was cleared to the left and right of the lead, in order to allow the DRANITSYN to put the bow towards the shoreline, and then slowly to break the ice in a line parallel to the shoreline and adjacent to the pipeline end. The manoeuvre took 5 hrs. The UIKKU was then able to approach the berth and moor with her bows in the ice, and vessel parallel to the shore, at a distance of about 15 mm from the pipeline ends. No mooring lines were used, and the vessel stayed in position due to the pressure of the surrounding ice, which froze as the loading, progressed.
The DRANITSYN berthed astern of the UIKKU. The size of the basin created was approx. 500 metres long and 150 metres wide.
Figure 25 shows the tanker UIKKU in the ice berth.
To load the cargo, two flexible hoses with a length of about 25 m, joined by flanges, were delivered from the ship's side by the shipboard crane. The hoses were reinforced by steel wire, were of about 150 mm in diameter and designed to withstand a pressure up to 10 bar. The hoses were freely placed on the ice since they had an extra length, which prevented them from breakage due to possible movements of the tanker.
There was no fiscalisation of the cargo from the shore. There were no meters, and it was not known if the tanks were calibrated. The bill of loading figures were those provided by the vessel.
The loading arrangement was fit for purpose, although such a system can only used for one month per year. This is in the spring, when the ice is not too hard for navigation yet is hard enough to support the vehicles, loading lines and to provide a berth for the vessel.

Figure 24 Winter road along the gas condensate pipeline laid over the ice

Figure 25 M/T UIKKU at Sabeta loading berth

8.3.3 The Loading Operations

To avoid freezing, during the voyage from Murmansk to the Tambey loading point, in the Ob Bay, the water ballast was maintained at a temperature of +6 °C. Heating was applied throughout the ballast voyage.

For heating of the ballast water, glycol was used, circulating inside coils fitted to the ballast tanks and heated by steam.

- The vessel during the passage encountered no problems.
- The ballast was discharged concurrent with loading but such that the vessel's displacem ent was never less than the arrival displacement.
- During the homeward passage, 60 tonne of water ballast were retained in a ballast tank in engine room, while all water ballast was discharged from the main ballast tanks and forepeak tanks.

8.3.4 Preparation of the Berth

The sequence of preparation of the berthing area was as follows (ship time is used, equal to Moscow time, +4 h w.r.t. UTC):

- the research IB arrived at the Tambey area (co-ordinates: lat. 71°19'N, long. 72°08'E) at 10:37 of the 4th May 1998, by following the channel created five days before by the nuclear icebreaker VAYGACH. The tanker, which was following the K. DRANYTSYN, stopped some miles behind, waiting for the preparation of the berth;
- by ramming on the fast ice, having thickness of about 1.8 m and snow cover of about 0.5 m, the i/b created a channel, perpendicular to the orientation of the incoming pipelines. Such channel was completed in about 1h 15 min;
- by ramming, the final part of the channel was widened, to permit manoeuvring of the tanker. The final evolution basin, having a length of about 500 m and a width of about 150 m, was completed at 14:15;
- the K. DRANITSYN proceeded backwards along the channel and, at about 1 n. mile from the pipeline end, created and entered a lateral channel, where it stopped, with its bow oriented to the

main channel, in order to allow the passage of the tanker. The icebreaker left the channel at 15:30;

- the tanker stemmed along the main channel and reached its final location, where it was berthed at 16:45. Its bow penetrated further in the unbroken ice, to provide stable positioning without use of mooring lines. This operation was completed after 6 hours from the arrival of the K. DRANITSYN at the Tambey area.

So speedy and successful berthing may be attributed to functioning of the propulsion system "Azipod" and bow thruster of the tanker.

The UIKKU remained alongside the broken ice edge, with its midship manifold oriented towards the pipelines end valves and flanges. The icebreaker remained at a safety distance from the tanker.

Although the vessel is equipped with 3 fixed winches at each end, the brake holding power being 25 tonnes, no fixed winches were used during mooring/demooring operations.

No problems were encountered during berthing on this occasion. The vessel was heading into the river stream. Only very strong winds with reduced visibility may have affected the berthing. This by delaying until the wind speed had reduced to such an extent that the vessel could manoeuvre with the bow thrust and azipod. In the event of an 'offshore' wind, the vessel would have put out moorings to 'piles' placed in the ice.

No mooring lines and bollards were used for station keeping at Sabetta.

8.3.5 Cargo Handling Operations

The operation of connection of the ship's hoses to the cargo manifold and pipeline laid on the ice took place from 16:45 to 18:45.

Regarding the contingency measures and safety procedures both onshore and on board, the vessel had its own contingency plan, and completed ISGOTT safety checklist. Communication with shore maintained throughout by VHF.

For hose connection, use was made of the 10 t shipboard crane for supporting the hoses, of the truck crane for hoisting the pipeline when aligning the pipeline and hose flanges (in view of the fact that the pipeline end lay on the drip tray), and of a tractor or crawler-type cross-country vehicle when placing the hoses on the ice.

Two members of the crew participated in the hose connection operations on board the tanker and 6 persons - on the ice. A valve on one of the pipes failed to be opened. Heating of the valve with exhaust gas from the crawler-type cross-country vehicle was of no effect.

The valve had to be disconnected from the pipeline. Use was made of the truck crane. The operation of the valve removal took 2 hrs. 45 min. Loading began at 21:30.

The initial loading rate was about 100 m^3/h and all the gas condensate loaded on the m/t was heated by steam through a heat exchanger as soon as it arrived from the tanker manifold. Successively, heating of the cargo was carried out only in the m/t tanks and the loading rate was increased: during the first 20 h, 3,892 m^3 of gas condensate have been loaded, at an average loading rate of about 195 m^3/h.

Deballasting of the ballast water started only 16 h after start of loading and proceeded in an intermittent way.

The gas condensate characteristics at the pumping station and at the tanker manifold were as follows:

Table 22 Gas condensate characteristics at the pumping station

	At the pumping station	At the tanker manifold
Pressure (bar)	8.0	3.5
Temperature (°C)	14	10

Loading of the gas condensate was carried out from 21:30 on 4th May till 08:00 on 8th May. The greatest loading rate was 250 m^3/h. The average loading rate on the 5th, 6th and 7th of May (till 19:00) was 190-235 m^3/h. The lowest rates were at the initial loading stage on the 4th of May and at the final stage on the 8th of May. On the 8th of May, coincidentally with loading, the storage tanks were stripped and cargo pipeline blown out. On the 6th of May the repaired valve was fitted and reconnection of hoses carried out. Along with that for collecting of condensate drained into the drip tray the tank track with a pump was used. The truck crane and tractor were involved in the operations.

The truck crane used in fitting the valve is visible in the background. Disconnection of hoses upon completion of loading was carried out on the 8th of May from 08:00 to 08:20. The documents were issued at the time of completion of loading. Unberthing of the tanker presented no special problems.

The icebreaker made one run along the tanker. The complete unberthing of the tanker took in total 1 hr.10 min.

8.3.6 Unberthing

Maneuvering of the tanker out of the channel and evolution (turning through 180^{o}) for proceeding in convoy were far more labour-intensive operations. These operations took place from 00:30 to 12:10 on the 8th of May. Then the ships began to proceed in the old channel in order to leave the Ob Bay, while the nuclear icebreaker ROSSIYA was waiting for the convoy.

8.3.7 Analysis of the Lay Time

At the time of stay 10,656 t of gas concentrate were loaded. The greatest loading rate amounted to 250 m^3/h. The net loading rate was 10,656 t/3.35 days = 3,180 t/day while the gross loading rate was 10,656 t/4.06 days = 2,625 t/day.

The Table 23 provides an analysis of the lay time at Sabetta. The operations can be broken down into:

- secondary operations (subdivided into “secondary ice operations” and “secondary loading operations”)
- tanker loading operations.

From this table it appears that the greatest portion of the lay time (82.5%) was taken by the proper cargo handling operations, while the remaining time (17.5%) was needed for the secondary operations. As a consequence, raising the loading rate will result in the most considerable reduction in the duration of stay. The average loading rate was 132 t/h, whereas the tanker was designed to load 2,800 t/h. To raise the loading rate, the capacity of the storage tanks, the diameter of the pipeline and the pumping rates of the supply pumps shall be increased.

In the secondary operations, the ice and hose connection loading operations comprised approximately equal proportions. In the ice operations, about 80% of the time was taken by the icebreaker operation to provide arrival and departure of the tanker, while in the hose connection loading secondary operations, the hose connection operations and the repair work on the shore pipeline took the longer time.

N°.	Description of the operation	Operation period	Time spent for the operation (hours)	Loaded cargo (m³)	Average loading rate (m³/h)
1	Proceeding of the IB K. Dranitsyn from the channel broken out by the IBN Vaygach to the loading point of the tanker, preparation of the ice berth	04/05/98 10:37-14:15	3.63		
2	The IB K. Dranitsyn leaving its own channel	04/05/98 14:15-15:30	1.25		
3	Proceeding of the tanker to the ice berth	04/05/98 15:30-16:00	0.50		
4	Tanker berthing	04/05/98 16:00-16:45	0.75		
5	Hose connection operations	04/05/98 16:45-18:45	2.00		
6	Removal of failed valve	04/05/98 18:45-21:30	2.75		
7	Loading 4/05/98	04/05/98 21:30-24:00	2.50	200	80.0
8	Loading 5/05/98	05/05/98 0:00-24:00	24.0	4,590	191.0
9	Loading 6/05/98	06/05/98 0:00-24:00	24.00	4,786	199.0
10	Installation of the valve and re-connection of hoses	06/05/98 9:00-11:00	2.00	4,483	235.0
11	Loading 7/05/98	07/05/98 0:00-19:00	19.00	33	1.7
12	Loading with the shore tanks being stripped and shore pipelines blown out	07/05/98 19:00-24:00 08/05/98 0:00-8:00	13.00		
13	Disconnection of hoses	08/05/98 8:00-8:20	033		
14	Issuance of documents	08/05/98	During other operations		
15	Unberthing and breaking down of ice by the icebreaker near the tanker	08/05/98 8:20-9:30	1.17		
16	Entering the channel with manoeuvring under the assistance of the icebreaker	08/05/98 9:30 -12:10	2.67		

Table 23 Lay-time analysis of loading

8.4. Recommendations and conclusions for arctic loading systems

The areas of interest for potential location of loading systems are those where the major known oil and gas fields belong. With the exception of Shtokmanovskoye Gas Field, located in the Central Barents Sea, in an area not covered regularly by ice, all these areas are located in the Pechora Sea, in the SouthWest part of the Kara Sea and in the Estuaries of the large Ob and Yenisey Siberian rivers.
Such regions are characterised by a quite large variability of environmental conditions, depending on the water depth, fetch, exposition to the North and distance from shore. Moreover, different plans of exploitation of the fields are envisaged, depending on the discovered volumes of the recoverable reserves and of the technological effort and investments needed to afford the risks associated with these activities. Therefore, it is apparent that recommendations on the optimum loading concepts can

be made only case by case, once the specific physical environment of the location under study and the related functional and operational requirements for export have been defined.
Thus, a proper design basis has to be established, where the following is defined:

Environmental data:

Such data, relevant to ice and wave, wind, current, water depth, tide and temperature, should be on a year-round basis, to define the seasonal scenarios, and should be the result of long term measurements, to allow to extrapolate design values with return periods corresponding at least to the 100-year conditions.
Regarding the ice, additional data regarding the location of the shear zone, the motion of the land fast ice and occurrence of grounded ice should be collected, preferably by field measurements. The selection of the shape and of the location of the terminal, the magnitude of the ice loads as well as the operativity of the system depend on all the above data and the leading criteria for sizing (wave, ice) are influenced, for a defined area, by the shape of the terminal.
Likelihood of formation of rubble fields should also be evaluated: massive structures are generally surrounded by ice rubbles, which create difficulties to the tankers for the access.
If the loading system is used as satellite export facility of a production and storage island or platform, the influence of the rubble fields caused by the presence of these islands or platforms should be avoided by properly selecting the relative distances.
In general, the availability of the following ice properties is needed for the calculation of the ice forces on the structure:

- formation (level ice, first-year ridge, rubble pile),
- thickness and extension of the area,
- compressive, flexural, tensile and shear strengths,
- temperature, age, salinity and crystal structure,
- strain rate
- elastic modulus
- chemical and physical impurities.

Due to its short duration, obviously the voyage did not allow the acquisition of all such type of information, although the observations and field measurements made are useful for comparison purposes, i.e.:

- to study the correlation between measured ice conditions and effects on the vessels, such as speed of advance or ice resistance. This is useful to establish a round trip duration in a simulation models of loading systems,
- to compare the predictions based on available long term data with the actual observed and measured data in the encountered season,
- to observe the difficulties encountered in carrying out operations with ice conditions corresponding to a defined return period according to long term statistics available from existing databases;

Data on the soil:

Geotechnical data on the soil are needed for the selection and design of the foundations of the terminal. The zone of transition between onshore and offshore permafrost (the shore crossing zone) may dictate the optimum pipeline crossing method (DeFranco et al., 1995). The knowledge of the dimensions and the frequency of scouring is also needed for selection of the burial depth of the pipelines;

Data on the product:

The type of product and its chemical physical properties (crude oil, gas, gas condensate) condition the selection of technical solutions for the fluid transfer system of the loading terminal and dictate requirements regarding the handling, storage and treatment of the product: the selection of the materials, of the operating pressures and temperatures and the need of insulation, compression, chilling equipment are influencing factors;

Operational data:

The configuration of the terminal depends also on the volume of exported product per year, on the required regularity for the system (therefore on the acceptable downtime) and on the round trip duration. The flowrates for the product transfer system, the storage capacity (onshore or offshore) and the maximum operational limits derive from the above requirements and the current technological solutions and state of art for some components (e.g. hoses, swivel units, valves) may pose limitations of feasibility.

The need to minimise the time needed for loading calls for the study of innovative high speed loading systems, but this aspect should be evaluated versus the opportunity of preferring the use of standard equipment to the maximum extent, to limit costs and for better reparability.
The operational data should also include the size and icebreaking capability of the export tankers, the type of mooring and loading arrangement and the achievable level of control in all stages of the operations.
Finally, the type of available icebreaking support and ice management capability at the terminal should be defined.
In section 5 of the report, alternative methods for loading tankers have been described, making reference to studies or experience of different Companies and Institutions relevant to the Russian Arctic or to regions of the Canadian Arctic having similar or more severe environmental conditions:

- the conventional fixed jetty
- the gravity type loading system (such as the Molikpaq type and the SSDC)
- the single point mooring (such as the monotower and the SBAM).

Advantages, disadvantages and limitations of the various alternatives have also been given to help the selection of the most suitable solutions for a specific application.
In section 6, a comparison based on specific assessment criteria has been made for the possible alternatives of loading system, considering also the berthless loading adopted for the operation at the terminal of Sabetta. Such comparison has revealed an appreciable advantage for the SBAM type, mainly due to its low development costs and high reliability.
The evaluation of the loading systems as a function of the annual exported volumes indicates that low volumes of export can justify the use of a berthless loading, in reason of its lowest costs for development, although it cannot ensure a year-round operation. For intermediate volumes of exportation, the SBAM is the preferred one, as it is cheapest system able to ensure a year-round operation. Highest volumes of export can justify the use of a jetty, where many large size lines can be used, provided that the local ice and wave conditions permit its use. If this is not possible, the SBAM and the gravity type structure have to be used, in association with an underwater pipeline.
These conclusions and recommendations can be obtained by taking as a reference scenario the export of hydrocarbons from the Ob Estuary area. To this regard, some considerations are made in the following.
The quantity of cargo loaded in Sabetta during the experimental voyage (about 14,300 m^3) corresponds to the capacity of the storage tanks available there, but not to the cargo-carrying capacity of the tanker, even though the water depths in way of the ice berth permits full utilization of the draft and cargo-carrying capacity of tankers with deadweight of about 16,200-17,500 m^3 (UIKKU or SAMOTLOR classes).
It follows that a first improvement in the performance could be obtained by increasing the total capacity of the storage tanks up to about 13,000-15,000 t, in view of the fact that the full utilization of the ship's cargo-carrying capacity makes the most significant impact on reduction of the transportation costs.
With the supposition of steadiness in the gas condensate exportation, which is associated with steady production and limited capacity of the storage tanks, the export schedule and tonnage requirements are defined by the voyage turn-around of ships in winter. Taking into account the results of the ARCDEV experimental voyage, it follows that in winter one tanker can make 2 voyages per month or 24 voyages per year.
Considering that the gas condensate can be exported from Sabetta by a tanker of about 16,200-17,500 m^3 carrying capacity at a draft of about 9 m, one tanker can transport within one year about 290,000-312,000 t of gas condensate (mass density of 0.74 t/m^3).
Under the conditions where the gas condensate is transported in quantity less than 150,000 t per year that is, where ships arrive at the loading point less than once per month, use may be made of temporary hoses to be placed on the ice in winter and afloat in summer.

To shorten the loading time, it would be necessary to raise the loading rates, to increase the size of tanks up to 20,000-28,000 m^3 and to fit a special tank stripping pump in order to have an opportunity to carry out stripping coincidentally with loading.
The hoses should be reinforced, have an internal diameter of about 180 mm, be designed to a pressure up to 15 ata. The condensate shall be loaded through two pipelines by means of pumps each of 250 m/hr in capacity at a head of 120 mm w.g.
With such equipment, loading will take about 40 hours and the whole stay 2 to 2.5 days.
With the exported volume of condensate being about 150,000 t per year, installation of such an equipment would be expedient since it will reduce significantly the condensate transportation costs, improve utilization of the ship's cargo-carrying capacity by 30%, reduce the lay time by one half and the voyage turnaround by 20%.
For the export of a larger annual volume of gas condensate, in the order of of 300-600 thousand tonnes per year, would require 1-2 tankers of the cargo carrying capacity of UIKKU or SAMOTLOR, making two-four calls at Sabetta settlement per month to accept the condensate for carriage. With such exported volumes the berthless loading would be inadequate and it would be expedient to lay an underwater pipeline and arrange a SBAM type single point mooring.
With the exported volumes of 1 million tonnes and more, as it follows from CNIIMF's studies, it would be expedient to locate the berth near the Kamenny Cape, in a more central area of the Ob Bay, where tankers of about 43,000 t dwt can have access. Carrying capacity of one such ship will be about 960,000 tonnes per year, assuming 2 voyages per month. To load these ships consideration may be given to a single point mooring of the SBAM or island type, associated with an underwater pipeline. As alternative, a fixed jetty associated with a pipeline laid on the scaffold bridge can be considered. Further studies should be made regarding the access to the terminal by the tanker, rubble ice formations, weathervaning capability of the tanker and possible damages to underwater pipelines to arrive at the selection of the preferred solution.
Therefore, the method adopted for loading in Sabetta settlement is very rudimentary and probably adequate for the current exportation volume. Some improvements in the existing loading system can enhance considerably the effectiveness of transportation but this method is not adequate for year-round operation and for high loading rates required by larger tankers and continuous operations. Better measures for environmental protection are also needed, such as, for example, a more effective fire fighting system in tank farm and bund walls around the tanks.
Regarding the SBAM system, the analysis of the hydrometeorological and ice conditions at the Sabetta loading site has shown that its use is feasible and effective.
It gives advantages in terms of:

- safety
- easy operability
- reliability
- cost effectiveness and significant reduction of running costs.

Depending on the storage requirements, it allows to be used as temporary mooring for shuttle tanker or for permanent mooring for a Floating Storage and Offloading unit.

9. ICE LOADS AND ICE CLASS

The purpose of WP8 work was to measure the ice loading on the hull and propulsion devices of MS Uikku during the voyage and then interpret the results so that knowledge about load level can be gained. The hull of M/T Uikku was instrumented so that ice induced loads and stresses on the shell plating could be studied on various locations both in longitudinal and in vertical direction along the ship hull. Longitudinal bending stresses at two locations on the hull and ship vertical accelerations were measured to study the global ship behaviour when hitting e.g. heavy ice ridges.
In addition to the measurements onboard M/T Uikku the Russian partners instrumented IB Dranitsin to measure strains and stresses in the ice belt grillage at the bow ship. Results of these measurements are presented on a separate report. IB Dranitsin acted as the other escort icebreaker during the voyage.
These results are to be used in the ARCDEV-project to asses the load level encountered in various ice conditions and operation modes navigating in the western part of NSR. Furth er, the loading level is to be applied in determining the required strength level. The results can also be applied in the work of harmonising the Polar ship rules of IACS and also gaining understanding and validation of the ice load calculation methods onwhich the rules are based.

9.1. The measuring system

The aim of the measurements is to study the ice induced loads on the ship hull and ship accelerations at bow when the ship navigated in various ice conditions. Time histories of almost all signals were recorded from the whole period in the ice. Maximum values of each signal were recorded on 20 minute periods. The period was kept short so that the maximum values could be later in the analysis related to the prevailing ice conditions. Also time history of measured signals was recorded during the voyage.
The measurements included following items onboard M/T Uikku:
Load on the shell transverse frame at bow area, at bow shoulder area, at midship area and at aftship area (measured by shear strain gauges).
Load on the shell longitudinal frames at midship area (measured by shear strain gauges).
Stresses on the shell plating and frames at waterline at bow area, at bow shoulder area, at midship area and at aftship area.
The longitudinal bending stresses on deck.
Vertical accelerations at the bow and stern of the ship and longitudinal acceleration at bow.
Steering angle of the azipod.
Power, torque and number of revolution of the propulsion motor.

9.2. Instrumentation

VTT Manufacturing Technology conducted the instrumentation as a sub contractor. Instrumentation was made according to Task WP 8 Detailed Plan except on midship area on where instrumentation was moved to the frames 63.5...66. The measuring system consists of 61 strain gages which were connected to 42 sensors. The abbreviations used in this section mean:
FFR load on the frame
FB bending stress on the frame
PL stress on the plating
HB bending stress of the hull

The ice loads were evaluated by measuring shear strains at roughly the neutral axis of the frame. Idea of the load measuring system is presented in Figure 26. Shear strain gauge pairs (marked with A and B) were connected so that load between gauges could be measured by using one recording channel. From each instrumented frame loads were measured separately from the upper, middle and lower part of the frame.

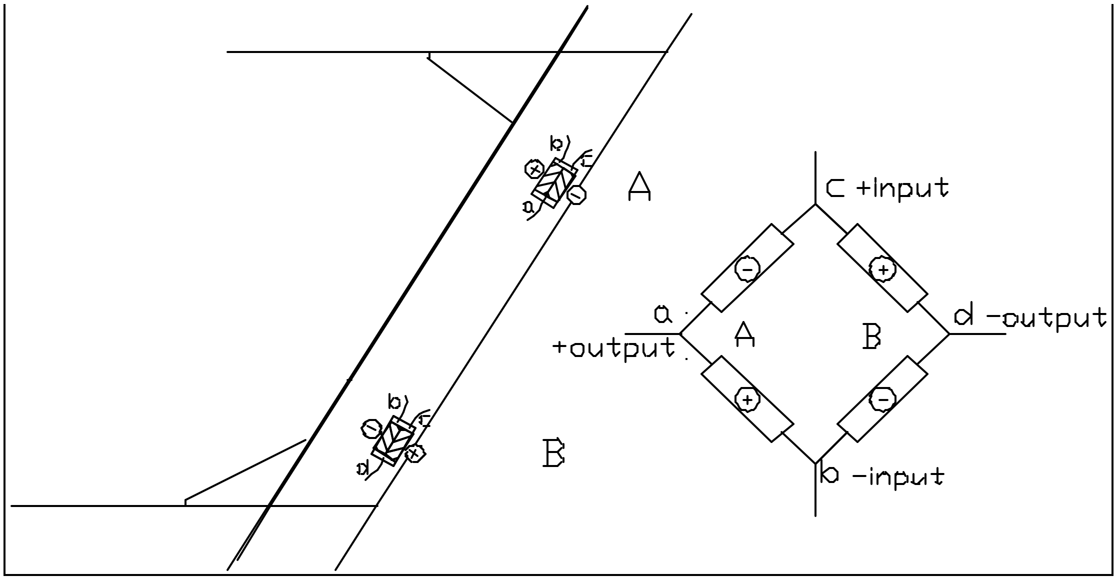


Figure 26 Arrangement to measure load from the frame (picture not in scale).

Accelerations at two points of the hull were also measured.
The signals from the sensors were amplified with DC-amplifiers. In addition low pass filters were used to filter high frequency noise from the measured signals.

9.3. Calibration of the load measuring system

The influence coefficients for the load-measuring (FFR) system are based on the assumption that all the ice load from plating goes through frames. So after shear stress distribution at the ends of the frames is determined load applied on the frame between these locations can be calculated. For each instrumented frame shear stress distribution was calculated analytically and by using the finite element models. Figure 27 presents finite element model used to calculate shear stress distribution on frame 196.5. Model includes besides part of the frame also 350 mm wide band of side plating and brackets on both ends of the frame. Model is made by using thin shell elements. Model has symmetric boundary conditions on both vertical edges of shell plate. Both ends of the frame are fully fixed. Used load is line load on mid span of the frame. Figure 28 presents the shear stress distribution on upper end of the frame.

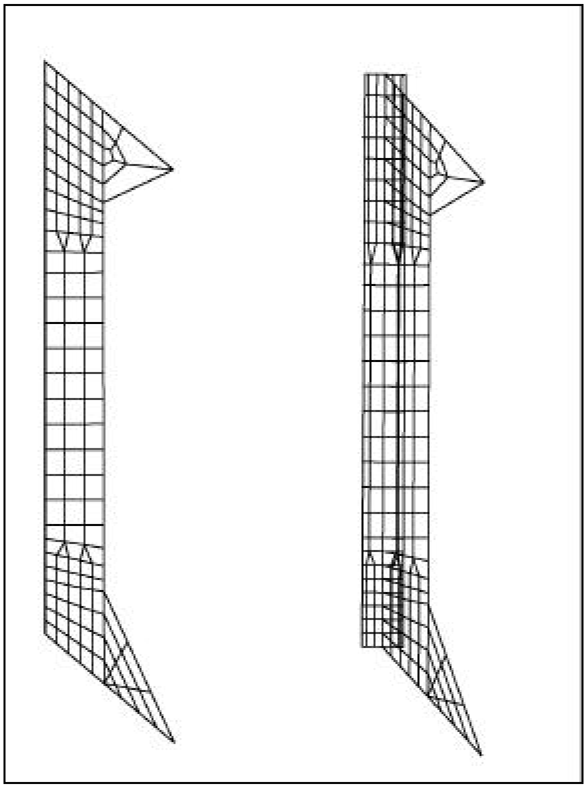


Figure 27: Finite element model of middle part (FFR2) of frame 196.5.

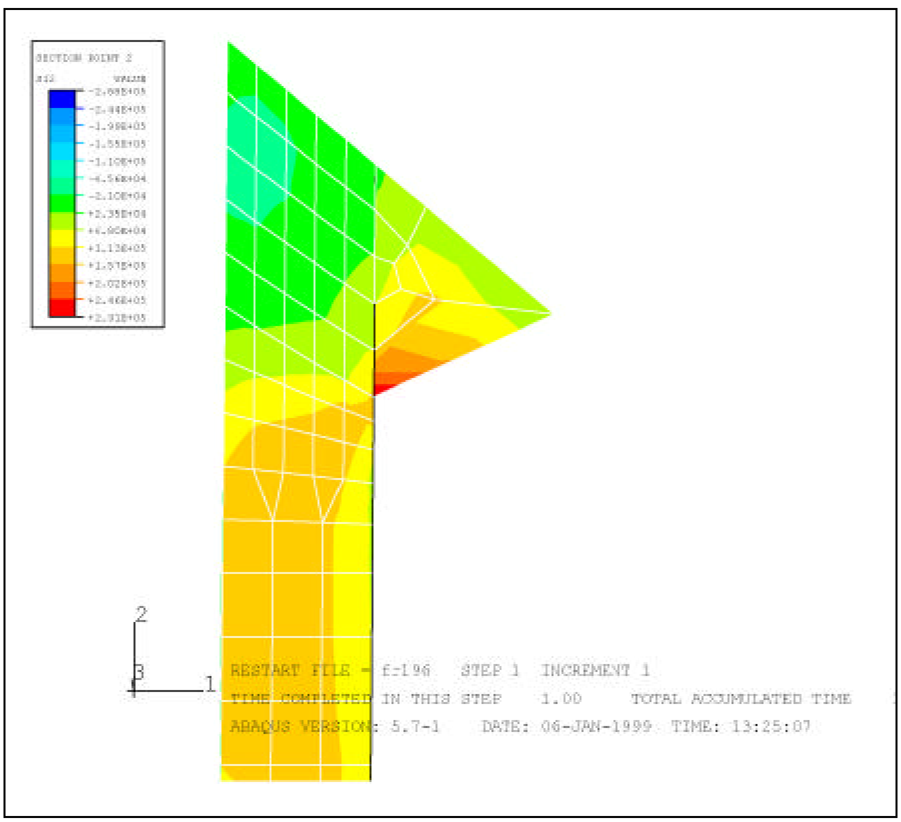


Figure 28: Shear stress distribution on area of gauge FFR2 A.

9.4. Measurements conducted during the voyage

Three parallel 32 channel recording systems were used. PC based recording system were used to collect maximum, minimum and average values from each 20 minutes periods. This system collected automatically extreme values during the voyage. An other PC based recording system was used to record time histories. This recording system started manually when it was found necessary. Duration of one recording period was 10 minutes. Digitizing frequency of 256 Hz/channel was used on both PC based recording systems.

Signals were also recorded continuously 24 hours/day with a digital 32 channel tape recorder. The digitizing frequency of 600 Hz/channel was used in the tape recorder.

Loads are presented by using kN/m, where the length used is the frame spacing for the vertical frames and length along the frame for the longitudinal ones. Time, which is used with extreme values, is the ending time of after 20 minute period.

Channels which were recorded were chosen based on draughts as the ship in cargo and ballast conditions. Recorded channels on both loading conditions are presented in Table 24.

Table 24. Recorded channels.

Symbol	Description	Recorded in ballast condition	Recorded in cargo condition
FFR 1	fr. 196.5, upper	-	+
FFR 2	fr. 196.5, middle	+	+
FFR 3	fr. 196.5, lower	+	-
FB 4	fr. 196.5, upper	-	+
PI 5	fr. 196.5, upper	-	-
FB 6	fr. 196.5, middle	+	-
PL 7	fr. 196.5, middle	+	+
FB 8	fr. 191.5, middle	+	-
FB 9	fr. 185.5, middle	+	-
FB 10	fr. 180.5, middle	+	-
FFR 11	fr. 175.5, upper	-	+
FFR 12	fr. 175.5, middle	+	+
FFR 13	fr. 175.5, lower	+	+
FB 14	fr. 175.5, upper	-	+
PL 15	fr. 175.5, upper	-	+
FB 16	fr. 175.5, middle	+	-
PL 17	fr. 175.5, middle	+	+
FFR 18	fr. 65-66.5, upper	-	+
FFR 19	fr. 65-66.5, upper	-	+
FFR 20	fr. 65-66.5, upper	-	+
FB 21	fr. 65-66.5, upper	-	+
PL 22	fr. 65-66.5, upper	-	+
FFR 23	fr. 65-66.5, midle	+	+
FFR 24	fr. 65-66.5, midle	+	-
FFR 25	fr. 65-66.5, midle	+	-
FB 26	fr. 65-66.5, midle	+	-
PL 27	fr. 65-66.5, midle	+	-
FFR 28	fr. 52.5, upper	-	+
FFR 29	fr. 52.5, middle	+	+
FFR 30	fr. 52.5, lower	+	+
FB 31	fr. 52.5, upper	-	+
PL 32	fr. 52.5, upper	-	+
FB 33	fr. 52.5, middle	+	-
PL 34	fr. 52.5, middle	+	-
FFR 35	fr. 38.5, upper	-	+
FFR 36	fr. 38.5, upper	-	+
FFR 37	fr. 38.5, middle	+	+
FFR 38	fr. 38.5, lower	+	+
FB 39	fr. 38.5, middle	+	-
PL 40	fr. 38.5, middle	+	-
HB 41	fr. 120 port	+	-
HB 42	fr. 120 starboard	+	-
ACV 43	Vertical acc. bow	+	+
ACV 44	Vertical acc. aft	-	-
ACL 45	Longit. acc. aft	-	-
AZA 46	Azipod angle	+	+
PSET 47	Power set value	+	+
PWR 48	Power measured	+	+
RPM 49	Rpm measured	+	+
TRQ 50	Torque	+	+
HBA 51	fr. 120 average	-	+

9.5. Time histories

In altogether there was 55 periods with the duration 10 minutes recorded on ballast condition and 58 on cargo condition. 27 of these were analysed more carefully. These sets are listed on Table 25. It has to be noticed that no zero point corrections are done on results of time history measurements presented here. Time history sets are also available in ascii and MATLAB format.

Table 25: Analysed time histories.

Ballast			**Cargo**		
Number	Date	Start	Number	Date	Start
6	29.4	13:49	3	8.5	8:08
11	29.4	18:02	8	8.5	14.27
16	30.4	10:46	9	8.5	14:47
20	30.4	13:04	11	9.5	9:32
22	30.4	15:38	13	9.5	15:18
23	30.4	19:05	22	10.5	9.32
26	1.5	7:25	24	10.5	13.58
30	1.5	9:38	25	10.5	14:13
37	2.5	12:29	31	11.5	7:19
40	2.5	13:35	35	11.5	10:25
45	2.5	14:42	42	11.5	14.56
49	2.5	19:25			
55	4.5	11:13			

9.6. Case example, measurement n:o 35

Measurement n:o 35 in cargo condition is presented on Figure 29 to Figure 34 as an example. During the measuring period n:o 35 M/T Uikku went through an ice ridge after the ship first got stuck in it.

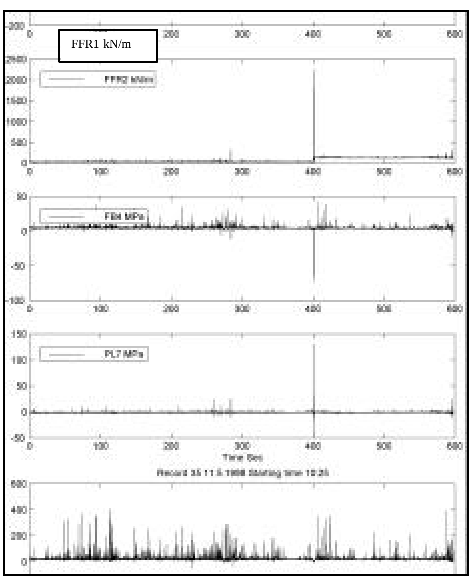


Figure 29: Signals form the bow area during measurement no. 35. Notice permanent deflection on sensor FFR2

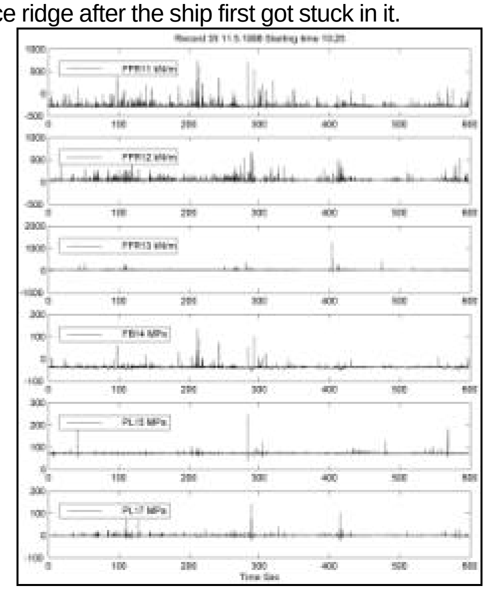


Figure 30: Signals from bow shoulder area during measurement no. 35.

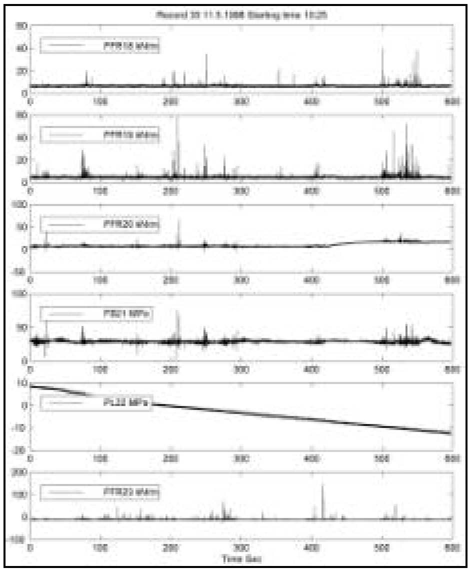


Figure 31: Signals from midship area during measurement no. 35.

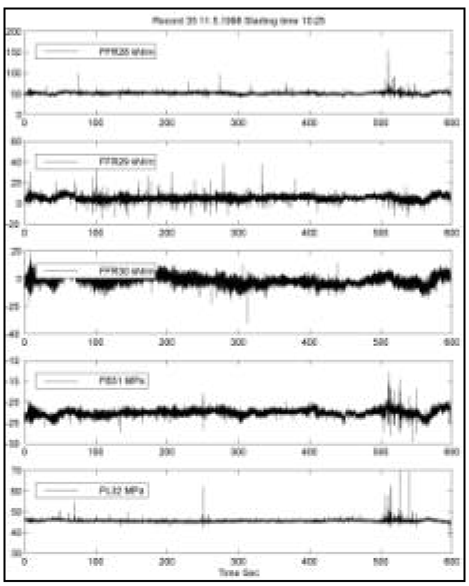


Figure 32: Signals from aft shoulder area during measurement no. 35.

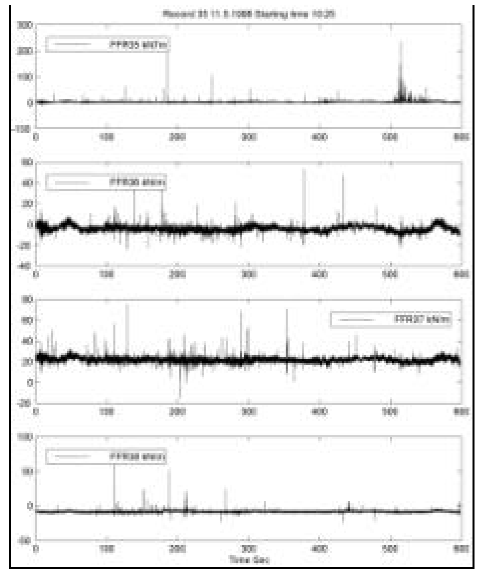


Figure 33: Signals from aft ship area during measurement no. 35.

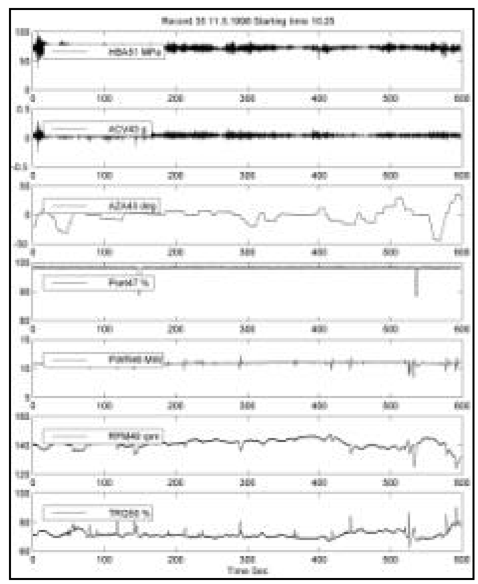


Figure 34: Machinery values during measurement no. 35

9.7. Permanent deflections

The observed ice induced load and stress level on the hull was fairly high. This is evidenced by some permanent deflections on various parts of the hull. Most of them were so small that sensors could be balanced after the event without any loss of the sensitivity of the sensor. Permanent strains found are presented on Table 26. Where remaining deflection was out side of the sensors measuring range values are marked with bold letters. In these cases the presented value of permanent deflection is the maximum value in the sensors measuring range**.** On the Figure 29 one of found permanent deflections is presented.

Table 26: Permanent deflections found

Date	Time (UTC)	Sensor	Frame	Offset		concentration %		Ice level cm (in tenths)					Ridges m (in tenths)						Dist. ship	snow cm	comments
				MPa	? m/m	ice fieled	channel	<10	10-30	30-70	70-120	>120	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	>2.5			
29.4	13:20	PL 7	Fr 196.5	29	281.55	95	100		1	4	4	1							>10		Rubble/ridge field
30.4	10:20	FFR 12	Fr 175.5	21.4	0.27	100	100				1					7	3		0.3	15	Rossiya started to assist
30.4	14:20	FFR 23	Fr 63.-65	57.6	721.80	100	100				1					7	3		0.3	15	14:15 Uikku did stuck
2.5	**15:40**	**FFR 25**	**Fr 63.-65**	**455**	**5701.75**	**100**			**5**	**2**	**3**					**5**	**5**		**0.3**	**30**	15:35 ramming
4.5	**0:40**	**FFR 24**	**Fr 63.-65**	**440**	**5513.78**	**100**	**100**			**10**										**10-15**	
4.5	0:40	FB 26	Fr 63.-65	47.5	230.58	100	100			10										10-15	
4.5	12:20	PL 34	FR 52.5	73.5	713.59	100	100					10									Attaching to the loading terminal
4.5	**12:20**	**FFR 37**	**FR 38.5**	**298**	**3734.34**	**100**	**100**					**10**									Attaching to the loading terminal
4.5	12:20	FFR 38	FR 38.5	78	977.44	100	100					10									Attaching to the loading terminal
4.5	12:20	FB 39	FR 38.5	-17.5	-84.95	100	100					10									Attaching to the loading terminal
4.5	12:20	PL 40	FR 38.5	120.5	1169.90	100	100					10									Attaching to the loading terminal
9.5	4:00	FB 21	Fr 63.-65	34.5	167.48	100	100			10										20-30	Rossiya started to assist
9.5	4:00	FFR 20	Fr 63.-65	307.8	3857.14	100	100			10										20-30	Rossiya started to assist
9.5	16:40	FFR 18	Fr 63.-65	93.6	1172.93	100	80		1	2	7			2	5	2	1				Rubble field
9.5	16:40	PL 22	Fr 63.-65	65.5	635.92	100	80		1	2	7			2	5	2	1				Rubble field
9.5	17:00	FFR 18	Fr 63.-65	222	2781.95	100	80		1	2	7			2	5	2	1				Rubble field
9.5	17:00	PL 22	Fr 63.-65	155.5	1509.71	100	80		1	2	7			2	5	2	1				Rubble field
11.5	4:00	FFR 19	Fr 63.-65	210	2631.58	100	100				10				10					7	
11.5	10:40	FFR 2	Fr 196.5	109	1058.25	100	100			4	5	1			5	5			1-2		

9.8. Maximum loads during the voyage

Maximum loads on various hull areas of the ship divided according to sea area and kind of operation are presented in Figure 35.

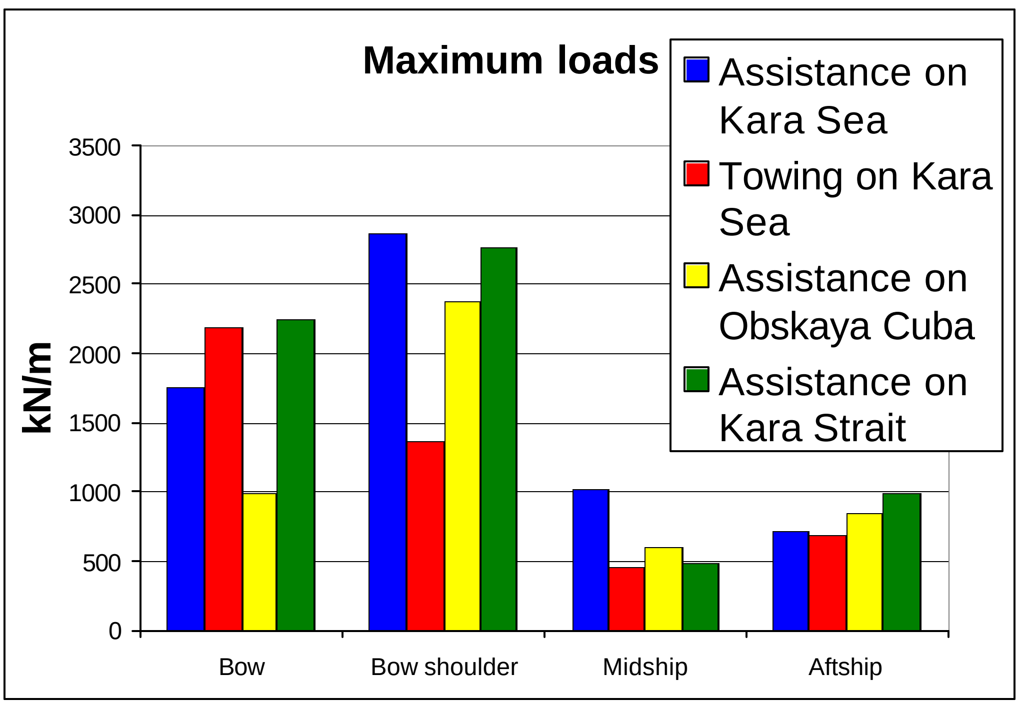


Figure 35: Maximum loads on different hull areas of M/T Uikku.

It can be noticed from Table 26 and from detailed data (D10A/5) that highest loads are frequently connected with special kind of operation such as approaching and attaching to the loading terminal or tight turns. Radius of turning has remarkable influence to the loads especially on aft and midship area. Figure 36 present two examples where the relation between angle of Azipod and loads on mid and aft ship area can be clearly seen.

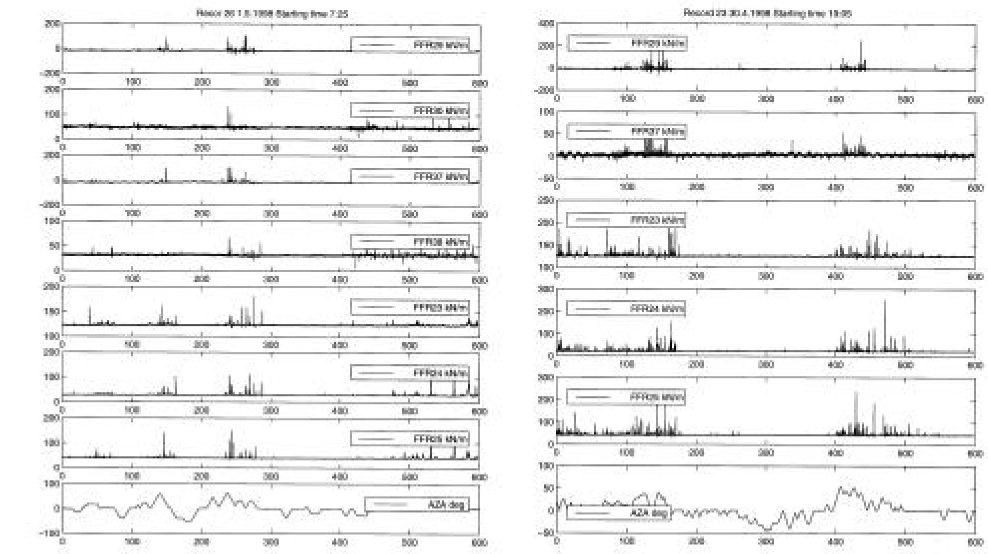


Figure 36 a and b: Examples of the relations between positive (clockwise) angle of azipod and loads on the starboard side of the ship

9.9. Ice class for the Northern Sea Route

The scope is to recommend a tanker's ice class for the safe transportation of hydrocarbons from Ob Bay to Murmansk and, if necessary, to use the findings of this research for refining the IACS, Unified Requirements for Polar Ships, which are currently under development.

In general ice class relates to the ship's capability to withstand the prevailing ice conditions for year-around or seasonal navigation in the area under consideration.
The performed research has shown that within the framework of the Russian methodology a satisfactory agreement between the predicted and recorded ice load values was obtained.
Since the methodology for the ice loads which is used in the IACS does not contradict the Russian methodology, it may be concluded that, in general, the experiment results obtained during ARCDEV confirm the justification of the solutions which form the basis of the IACS, which are under development.
In providing recommendations on the selection of an ice class for tankers transporting hydrocarbons from Arctic, consideration has been given to the fact that navigation in ice can be done either independently or with icebreaking support, depending to the ship's ice class.
In providing recommendations, past experience of marine operations in the Russian Arctic has also been taken into account.
In providing recommendations, reference is made to ice classes of the Russian Maritime Register of Shipping (RMRS), the Finnish-Swedish Ice Class Rules (FSR) and the Polar Classes of the Draft IMO Code of Safety for Ships in Polar Waters (PC#), as reflected in the IACS.
It should be noted that the recommended ice classes aim to ensure safety of the ice navigation between Murmask and OB Bay along any of the three possible routes.
It should be noted that, irrespective of the ice class, particular attention is to be paid to the fact that due to the shallow waters of the Ob Bay the bottom hull areas could be subjected to intense ice loads, as ice floe debris could be entrapped between the ship's hull and the seabed.

For the safe transportation of hydrocarbons from Ob Bay to Murmask the following recommendations are provided in Arcdev.

1. Within the traditional periods of the summer arctic navigation in open and very open floating ice, ships with ice classes L1 (RMRS), 1A (FSR) or PC7 (IACS), could be permitted to navigate with the assistance of icebreakers. For this period, ships with lower ice classes are likely not to be permitted to navigate due to safety concerns.

2. During extended periods of the arctic navigation up to December – January, ships with ice classes UL (RMRS), 1A Super (FSR) or PC6 (IACS), could navigate under the escort of icebreakers with a fair degree of safety. For this period, ships with lower ice classes are likely not to be permitted to navigate due to safety concerns.
3. During the winter-spring period, that is all the year round, in the south-western part of the Kara Sea and in the Ob Gulf the reliable, safe and efficient navigation could be provided by ships with ice classes ULA (RMRS), or PC5 (IACS), under the escort of powerful nuclear icebreakers.
4. For operation in ice conditions equivalent to those experienced during Arcdev, with icebreaking assistance, ships with ice classes PC5, LU5 (new RMRS) or UL (RMRS), approximately corresponding to PC5 by the strength level, could be recommended. Ships of ice class 1A Super (FSR) could operate in these conditions only if they have been constructed and maintained with excessive strength margins above rule requirements.
5. For operation under the icebreaker pilotage in severe ice conditions, which are known to have occurred in the past, ships with ice classes PC4 (IACS), or LU6 (new RMRS) could be recommended.
6. For operation in ice conditions equivalent to those experience during Arcdev, but with less icebreaking assistance, ships with ice classes PC3, or LU7 or ULA, could be recommended. Such ships are likely to need icebreaking support only for operation during the winter-spring period in the Kara Sea.
7. Ships with ice classes PC1 or PC2 (IACS) could navigate independently on this route without icebreaking support (PC1) or almost without icebreaker support (PC2 – expect during severe ice conditions during the winter-spring period in the Kara Sea). However, the additional steel of hull ice strengthening structures could decrease their carrying capability and increase the cost of construction. Considering the availability of the powerful Russian icebreakers, the employment of commercial ships with ice classes PC1 or PC2 seems to be cost effective on this route.

A common understanding of the appropriate ice class will bring benefits for all the stakeholders in the transportation of hydrocarbons from the western Russian Arctic to Europe. The implementation of these recommendations in the "guide to Navigation through the Northern Sea Route" will provide transparency and level playing field.

9.10. Conclusions

The measuring system installed onboard M/T Uikku operated well through the voyage. The database gathered consists of time histories of all the instrumented channels and maximum values observed on 20 minutes periods monitored 24 hours/day.
The database gathered shows a wide scatter in the ice induced loads. This variation can be explained by the statistical nature of the ice loads and with the large amount of the factors that have an influence to the magnitude of the loads. The database presented offers good opportunity to look into the relationships between ice induced loads, ship navigation tactic and ice conditions.
Ice classes were evaluated during the project and comments for IACS (Unified Requirem ents for Polar Ships9, RMRS (Russian Maritime Register of Shipping) and FSR (Finish Swedish Ice Class Rules) applicability to Western Russian Arctic were given. M/T has FSR ice class 1A Super, but is build with extra strengthening of class requirements. Ar cdev voyage revealed that such a class is inadequate for the conditions met during the project, in order to ensure safe, cost effective and reasonable transportation of hydrocarbons.

10. ENVIRONMENT

The environmental protection work of Arcdev were objected to following main topics:

1. Preparation of a plan and actions in order to convince the people and local authorities of Yamal Peninsula that the voyage does not violate the environment and that every possible precaution measures are being taken to protect the environment.
2. Reporting on available and promising oil spill combating systems with respect to the use in ice covered waters. This item includes a literature search, a state-of-the-art review in oil spill combating techniques, evaluation of potential combat systems, development of recommendations.
3. Preparation of an analysis of the sources and extent of sea pollution on the basis of experience in coastal transportation in the Russian Arctic and a detailed definition of structural requirements for ships and a composition of the equipment protecting the environment. Development of recommendations to a “Safety Plan” and “Safe Operations Procedures” for the ships on this route.
4. Development of a “Contingency Plan” for the loading terminal. A contingency plan according to the “Shipboard Oil Pollution Emergency Plan” (SOPEP) should be developed considering local conditions at the loading terminal.
5. Evaluation of available technical oil spill combating equipment with respect to its efficiency in cold conditions.
6. A “Combat Plan” should be developed for a small spill to occur in unbroken level ice to prevent or minimise the spreading of oil.
7. As an option it was planned to carry out an “oil spill exercise”, depending on the permission of the local authorities and available technical combating device.
8. The study should be used as a basis for the definition of future research necessities in the field of environmental protection with respect to oil spills.

10.1. Actions for convincing the russian authorities

The environmental safe operation concerns two main aspects:

- ?? The environmental safe navigation through the Northern Sea Route.
- ?? The environmental safe ship-shore cargo operation in Yamal peninsula for loading gascondensate.

For the successful completing of the both tasks they were carried out together in a very close and efficient co-operation with the Russian authorities and the Russian teams (crew and scientists) on the ice-breakers and on the shore.
Prior to the start of the voyage from Murmansk to Sabeta (Ob River) with respect to the necessities of WP 11 Environmental Protection the FORTUM OIL AND GAS representative carried out the co-ordination work for convincing the Russian authorities in order to obtain the relevant permission. For the purpose of this task very valuable support was provided by AARI and CNIIMF.
It should be mentioned that these actions were a part of the whole permission-process to obtain the permission for the scientific research and for the Finnish tanker UIKKU to complete the voyage to Yamal peninsula as a commercial demonstration.
The actions for convincing the Russian authorities are briefly summarised.

10.1.1 Negotiations and discussions with Russian Authorities

Negotiations and discussions with the Chairman of the Environment Protection, Admi-nistration of the Yamalo-Nenetsky Autonomous District (YNAD), city of Salekhard
Following information was submitted on the authorities disposal:

- ?? ship’s particulars, specification and equipment
- ?? documentation related to the ship’s pollution prevention capabilities
- ?? ship’s crew qualification and owners training policy
- ?? Latest FORTUM OIL AND GAS ship’s environmental records in accordance to the Environmental Impact Assessment Program of the FORTUM OIL AND GAS Ship Management

?? information about the FORTUM OIL AND GAS and FORTUM OIL AND GAS SHIPPING's environmental records, policy and certification

The Chairman of the Environment Protection of YNAD was invited to a WP-11 meeting planned to be held in Hamburg on 19^{th}-20^{th} March 1998 for discussions focussed on the environmental protection in connection with the loading and transportation of gascondensate from Ob-River estuary.
A representative of YNAD was prevented to attend the meeting, however YNAD supported HSVA and FORTUM OIL AND GAS with a general description of the physical and chemical properties of gascondensate as well as of the procedures for the loading process by the shore personnel in Sabeta.

10.1.2 Discussions and negotiations with the environmental protection

On invitation from the Arctic and Antarctic Research Institute (AARI) a representative from FORTUM OIL AND GAS visited for discussions and consultations with Russian researchers the Conference on Barents Sea Impact Study in St. Petersburg. A meeting with representatives from the Moscow Environmental Protection Organisation was foreseen as an option during the conference, but it did not take place.
Contacts and discussions were carried out by the assistance of the Arctic and Antarctic Research Institute (AARI) in St. Petersburg. Russian Environmental authorities on highest level were familiarised with the high safety standards of the participants responsible, and were already convinced in the ability of their environmental safe operation during the execution of the ARCDEV activities. Granting of the permits was already in progress.

10.1.3 Russian environmental observer during the voyage

An observer from the Russian Environmental Authorities was foreseen by the Russian Authorities themselves to arrange the process of permission.
Two different options were discussed and agreed on:

?? Observer for the whole sea passage including the loading operations from highest level of the Russian Environmental Authorities

?? Observer for the loading of gascondensate in Sabeta from the Environment Protection, Administration of the Yamalo-Nenetsky Autonomous District, Salekhard.

10.2. Environment aspects in marine ice operations

Analysis of probable sources and extent of the operational pollution of sea was carried out on the basis of coastal transportation experience in the Russian Arctic. This traffic is intended for the supply of consumers with oil products in many points situated on the coast and islands of the Arctic seas of Russia. The marine oil traffic is carried out as rule from the oil handling terminals of Murmansk and Arkhangelsk in the western Arctic and from the Nakhodka in the eastern Arctic. At present the oil tanker traffic along the Northern Sea Route (NSR) is mainly effected by tankers of the "Samotlor" and "Partizansk" types owned by the Russian Shipping Companies and tankers leased in Latvia "Ventspils" type and Finland. The total volume of annual oil delivery is about $1 \cdot 10^6$ tonnes. About 20% of the delivery is unloaded onto the unequipped shore.
Sea pollution from tankers may occur due to the emergency oil spillage after stranding, collision, side or bottom ice damages and operational spillage in the process of cargo handling, ballasting, tank washing and stripping operations.
The majority of tankers operating in the Arctic have double structures; either double bottom and double sides or double bottom, or double sides. Therefore, over the last 30 years no events of the accidental pollution were recorded either in the western or eastern sector of the Arctic, although there were some cases of ice damages of the ships' hulls with the penetration of water only into the double structures without damage of oil tanks and spillage of cargo. All tankers are provided with segregated ballast tanks and slop tanks having a capacity sufficient to exclude the pollution while pumping out the ballast water and to allow retaining the slops generated by tank washing during the voyage. Besides, one should take into account the fact that under the domestic law any discharge into the Arctic seas of oil or oily mixture from any ship is prohibited except the discharge of processed bilge water from machinery spaces (without cargo pump room bilges) when the oil content of the effluent does not exceed 15 parts per million ($15 \cdot 10^{-6}$).

The discharge of oil with processed bilge water is insignificant. The quantity of bilge water in the machinery space depends on type and power of the engine, technical state of mechanisms and systems, and also on the qualification of crew.
The mean daily accumulation of bilge water with oil content up to 2% may be taken as 3000 litres. Then, the probable discharge of oil with processed bilge water would be $3 \cdot 10^3 \times 15 \cdot 10^{-6} = 0.045$ litres per day or about 1.5 litres per month. The total quantity of oil discharged into the sea with bilge water from all ships navigating in the Arctic would not exceed 1000 lit. per year.
Bearing in mind the above, the most probable pollution of sea is during the cargo handling and bunkering operations. These kinds of pollution are the results of human errors of the service personnel related to the tanks overflow, disconnection of cargo or bunker hoses without theirs preliminary drainage or as a result of the damage of hoses. For coastal transportation on the Arctic the unloading operations are the most typical ones. With unloading at berth in port the oil pollution of sea is practically improbable. However, during the unloading onto the unequipped shore with the use of hoses or pipelines the pollution is possible in case of the damage of hoses or pipes and leakage through joint between individual sections.
Unloading onto the unequipped shore is carried out when there is stable fast ice or through ice free water. Pipes or hoses are laid through ice or float over water. Hose operations involve also pressure testing at the beginning of unloading and the blow - through at the end of unloading. Unloading is carried out under continuous observation of hoses for the protection of any leakage of oil. Accidental oil outflow can amount in such case to several tens of litres and depends on the quantity of cargo transferred and on conditions of ice, sea state and weather. However, it shows that it is necessary to take special precaution measures for the prevention of oil spills in the process of loading operations in ice conditions.

10.2.1 Structural survivability requirements

Polar regions are important and especially vulnerable components of the global ecosystem where should be prohibited to discharge any oil products and other hazardous substances. The remoteness of these region as well as severe and dangerous conditions of navigation in ice make rescue or clean up operations difficult. The ships operating under ice conditions are exposed to the additional risk because of the probable hull ice damages. The sinking of any tanker or ship carrying hazardous cargo is ecological catastrophe and is inadmissible. Therefore all ships navigating in Arctic waters should meet additional structural safety requirements to mitigate and possibly avoid the risk of the hull ice damages and the marine environment pollution.

Hull of Ship

a) Ice resistance and design of the hull should comply the requirements of the Rules of Register of Shipping for ships of ice resistance category “UL” (type of m/s *Samotlor*) or requirements of the Det Norske Veritas (DNV) for ships of ice resistance category “Ice IA Super” (m/s *Uikku*).
b) All tankers should have a double bottom throughout the entire width of ship and over the length between the forepeak and afterpeak bulkheads and double sides over the entire length of cargo tanks.
c) Cargo tanks as well as the fuel and oil tanks should be located at a distance of not less than 0.76 m from the outer shell plating of the ship’s hull taking into account statistical data on the ice damage penetration.
d) Tanks in double bottom and double sides may not be used for storage of petroleum products or other harmful substances. It is allowed to use double bottom tankswithin the length of the aft machinery space for the storage of fuel and lubricants when the capacity of any tank not exceeding 20 m^3.

Subdivision and Damage Stability

a) In accordance to the requirements of the MARPOL Convention, 73/78, every oil tankers of more than 225 m in length shall comply with the subdivision and damage stability criteria after the assumed side or bottom damage applied anywhere in the ship’s length. In tankers of more than 150 m, but not exceeding 225 m in length - anywhere in the ship’s length, except involving either after or forward bulkhead bounding the machinery space located aft. The machinery space shall be treated as a single compartment, which can be flooded. In tankers not exceeding 150 m in length the damage shall be applied anywhere in the ship's length between adjacent transverse bulkheads with exception of the machinery space.

b) Ships operating under ice conditions run into an extra risk of probable hull ice damages. Probability of getting side damages in the zone exposed to the impact of ice loads is higher than that at the collision of ships sailing in open water. Therefore for the purpose of reducing the probability of the loss of ships as well as diminishing the risk of the environmental pollution, more strict additional requirements for the subdivision and damage stability should be imposed upon Arctic ships in the case of ice damages. At the same time, one should bear in mind that sizes of ice damages are considerably smaller than those of the damages caused as a result of the collision of ships moving in open water at a higher speed the location of damages over the ship's length and hull height being different. Therefore, polar class ships, along with meeting the subdivision requirements established by the International Conventions and Codes in force for conventional ships should meet supplementary requirements for the damage trim and stability of ships taking into account location and sizes of ice damages to be determined on the basis of statistical data. Supplementary requirements may be based both on the probabilistic and deterministic approach. At the moment the probabilistic requirements exist only for passenger and dry cargo ships. Therefore at the first stage for all types of ships it is expedient to adopt supplementary requirements based on the deterministic approach.

c) Statistical data on the parameters of ice damages given in the (D12/1) permit to recommend assuming in the calculation of the damage trim and stability the following sizes of ice damages in the zone of their location from the base line up to the level 1.2 d_S within the length L (here L is the length of ship along the waterline corresponding to draft d_S up to the summer load line):

?? longitudinal extent is 0.045 L if the centre of damage is located at a distance

?? of 0.4 L from the forward perpendicular and 0.015 L in any other part of the ship

?? transverse extent of the damage measured at right angles to the ship's shell plating at any point of the calculated damage area is 0.76 m

?? vertical extent is 0.2 d_S in the zone of the location of damage from the base line up to the level 1.2 d_S within the length L

The above ice damages for all Arctic tankers may be located at any place within the zone of ice damages (two compartment standard of subdivision).
With such sizes of ice damages Arctic tankers should meet the damage stability criteria specified by the MARPOL 73/78 (Reg. 25.3.c). Moreover the following additional requirements should be met:

?? emergency waterline after equalisation of the ship, and in cases when the equalisation is not provided after flooding, runs below the bulkhead deck and lower edge of any opening through which progressive flooding may take place

?? initial metacentric height at the final stage of symmetrical flooding calculated by the constant displacement method before taking measures for its increase should be not less than 0.05 m

?? the angle of heel in the case of unsymmetrical flooding should not exceed 20° and after taking measures on the equalisation -12°.

These supplementary requirements are directed towards the prevention of the entry of ice during its shearing onto the bulkhead deck and of the damage of watertight deck structures as well as towards making possible for people to move over decks in the presence of icing.

10.3.Description of precaution measures

Prior to the voyage a questionnaire concerning the gascondensate specifications, the loading procedures, prevention measures etc. has been sent to the Environment Protection Administration of YNAD.
A response of the questions was given in Russian language and can be summarised as:

- ?? At low temperatures there is an increase in density as well as in viscosity of the gascondensate. In this case there is no evaporation and the gascondensate remains fluid at temperatures as low as -40°C.
- ?? In the cases of leakage the gascondensate does not penetrate the ice and remains in ponds on the ice surface and could completely exterminated by burning.
- ?? Prior to the installation of the pipeline inspections of the ice road will be carried *out.*
- ?? After installation, the pipeline will be proved by pressing air through the system when the valves at one end are closed. Any decrease in pressure would indicate a leakage of the pipeline. The pressure in this case is about twice of the maximum pressure under working conditions (80 bar). The results will be documented.
- ?? During the loading process there will be a radio link 24 hrs/day to respond in time if an emergency case occurs (stop pumping, closing the valves etc.)
- ?? A truck of the fire brigade will be on duty during the loading process.
- ?? After finishing of the loading process the pipeline will be emptied by pressing air through the tubes and than dismantled.
- ?? In case of an spill the gascondensate will be pumped off from the surface into sludge tanks at the deposit.
- ?? On shore there will be used two mobile pumps and one stationary pump Type Y8-MA2 in order to pump the gascondensate through two pipelines of 4 in. and 6 in. diameter to the tanker.

Specification of gascondensate:

- ?? The gascondensate is an opalescent-yellow coloured liquid substance which contains mostly light fractions, i.e. the heavy fractions are less than 5%.
- ?? The condensate does not contain any:
- - mercaptan sulphur
- - hydrogen sulphide
- - water soluble acids
- - lead
- ?? The total mass of sulphur is less than 0.01 %
- ?? If any spill would occur it is expected that a huge extent of spilled gascondensate on the ice evaporates in a few hours. The velocity of evaporation is depending on the predominant temperature of the environment.
- ?? Less than 1% presenting the heavy fractions may remain on the surface of the ice or snow. As an comparative example crude oil can be used , which is in contrary to the gascondensate due to the huge amount of heavy fractions and less evaporation.

10.4.Prevention of oil spills in loading operations

In addition to the precaution measures taken at the loading terminal site in Sabeta comprehensive precaution measures on the tanker have been carried out.

10.4.1 <u>Precaution measures prior to the loading process</u>

a) Preparing the ship and the crew

- ?? Dry docking the vessel
- ?? Full check of all cargo loading/unloading systems and appliances

?? Full check of the implementation of the Environmental Impact Assessment Program of FORTUM OIL AND GAS Ship Management / ISO 14001

?? Checking the vessel's equipment and preparedness for the expedition

?? Selecting an experienced crew with operation in Arctic conditions

?? Training the crew to make them familiar with certain special precaution measures for the cargo operation in Arctic conditions involving ship-shore communications, flexible hoses – steel pipelines connections on ice, pressure control device etc.

?? Enhancing the oil pollution prevention preparedness of the crew by intensive instructions about the additional risks and hazards when operating in Arctic conditions before and during the expedition voyage.

?? Four additional 20 m long flexible hoses of 6 in. diameter (test pressure 10 bar) for connecting the ship's manifold to the end of the shore to the terminal pipeline were supplied to the vessel. The hoses were tested and certified before the voyage.

b) Main equipment available on the tanker MT UIKKU for oil pollution prevention

? ? The main equipment is summarised in Table 27

c) M/T UIKKU's Pollution Management

The pollution management is organised, implemented and controlled on board by the nominated ship's Environmental Protection Officer in accordance to the FORTUM OIL AND GAS Ship Management Environmental Impact Assessment Programme under the supervision of the FORTUM OIL AND GAS Ship Management certified with ISO 14001 and in full compliance with ISM Code.

?? MT UIKKU has not discharged any quantities of garbage, grey waters or sewage over board during the whole passage through the Northern Sea Route. The ship has the capacity and is certified for storing on board grey waters for at least 30 days - in compliance with the requirements of that particular Arctic navigation area.

?? The ship had carried out at least one additional total ballast water change after leaving Norway and before approaching Ob estuary for loading respectively before commencing deballasting operations in Sabeta (total ballast quantity of about 6000 m^3)

?? Ship's Oil Pollution preparedness : Vessel's Pollution Contingency Muster List (see Tab. 4.3 a-c)

?? FORTUM OIL AND GAS Ships Environmental Preparedness :

?? FORTUM OIL AND GAS Ship Management Environmental Impact Assessment Program

Table 27 Main Equipment for Oil Pollution Prevention on Board MT UIKKU

MAIN EQUIPMENT FOR OIL POLLUTION PREVENTION ON BOARD MT UIKKU	
Type of Eqipment	**Location / Quantity / Capacity / Type**
Adsorbent (Sawdust)	**Cargo and Bunker Manifolds: 2 x 100 dm^3** **Stores - Fore: 10 x 150 dm^3** **Stores - Aft: 5 x 100 dm^3**
Portable Wilden Pump (air driven)	**Capacity: 4 m^3 / hr** **Location: main deck, port side, aft part**
Degreasant and Solvent	**Type: NESTE Oil AND GAS Shampoo** **Quantity: 600 litres**
Floating Oil Booms	**Length: 400 m** **Location: store - fore**
Fixed Line Draining Pump	**Capacity: 8 m^3 / hr**

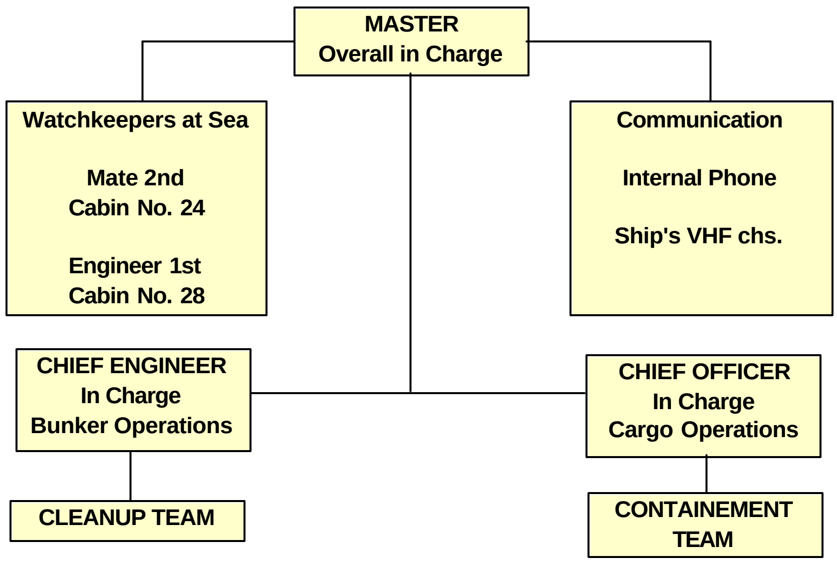
VESSEL' S POLLUTION CONTINGENCY MUSTER LIST for MT UIKKU

ACTION:

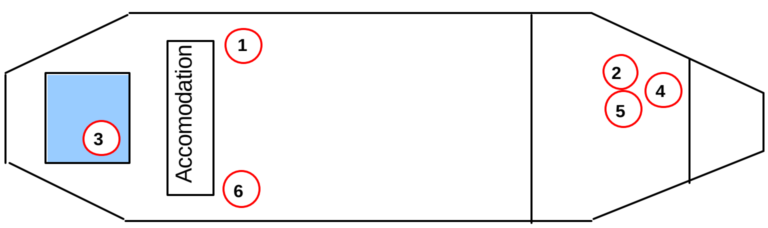
1.) IN PORT: ON ALARM SOUNDING; ALL CREW TO MUSTER AT THE COMMON MUSTER STATION
AT SEA: ALL CREW OTHERS THAN WATCHSTANDERS TO MUSTER AT THE COMMON MUSTER STATION

2.) STOP OR MINIMISETHE SOURCE OF POLLUTION AND NOTIFY THE RELEVANT AUTHORITIES

3.) INITIATE THE CLEANUP RESPONSE



EQUIPMENT LIST:



1 Absorbent
2 Portable Pump
3 Liave
4 Portable Wilden Pump with hoses
5 Floating "Oil Booms"
6 Fixed line Draining Pump

Table 28 Muster List of MT UIKKU

10.4.2 Precaution measures during the loading process

a) Precaution measures on board of the vessel

The ship was prepared for loading in all respects according to the international practice and regulations including also enhanced safety and operational precautions considering operation in Arctic conditions.

?? All emergency and fire equipment was in position, clearly marked and ready for use.
?? The persons involved in the cargo operation were briefed regarding the cargo to be loaded and the hazards.
?? All persons involved in the cargo- and deck operations were equipped with the relevant protection gear.
?? The deck was clean from obstructions, watertight doors were kept closed, scuppers blocked, emergency pumps ready for operation.
?? Before loading the international “Ship-Shore Check List” according to the ISGOTT (International Safety Guide for Oil Tankers and Terminals, last edition) was completed and countersigned by both parties.
?? There was a 24 hours deck watch for the ship’s safety and to supervise the successful performance of the of the loading operations.

b) Watch organisation on the shore site

?? A continuous watch was organised at the pump station in Sabeta and at the end of the pipeline at the „loading terminal“ in order to control the cargo pumping capacity, pumping pressure and to be on duty for emergency readiness.
?? A duty motor vehicle was used for periodical supervision along the approximately 4 km long pipeline between the shore facilities (pump station) at Sabeta and the loading ice-terminal respectively the ship.

c) Communications between ship and shore

?? Operational communications: VHF radio
?? Emergency communications: VHF radio
?? Wireless connection between Ship and Shore
?? Priority language used between ship and shore personnel: Russian
?? Translation Russia-English-Russian
?? 24 hours availability of the Ice-Pilot and the Russian Radio Officer on board the ship

d) Other precaution measures

Special precaution measures for preventing accidental oil spillage and leakage especially into the ice free water and on ice surface should be taken during loading operations.

These measures include as follows:

?? During loading of tankers in ice conditions the cargo hoses are used for ship to shore cargo pipelines connection. Loading operations should be carried out under permanent observations the hoses in order to prevent any oil leakage.
?? Hoses and pipelines shell be manufactured out of materials retaining their specification characteristics at open air temperature of -30^{o}C. The hoses should be of sufficient length to avoid over-stressing and to compensate for possible movement of ship during loading operations.
?? All the joints of hoses and pipelines used for the transportation of oil or gascondensate from ship ashore and vice versa should have capacities to collect probable spillages.
?? Loading hose should be properly balanced by the lifting gear to avoid chafing and kinks. The minimum bending radius should be not less than 6 nominal bore of the hose (in accordance with the recommendation of ICS and OCIMF).

?? During loading operations the ship to shore communications should at all time be in satisfactory working order for immediate suspending of all operations in cases that can lead to oil spillage.

?? For safe cargo loading operations it is necessary regularly to check the pipeline and hose pressure in addition to the estimated quantity of cargo loaded. Any drop in pressures or any marked discrepancy between tanker and ashore estimates of quantities could indicate pipeline or hose leaks and require that cargo operations be stopped until investigations have been made.

?? Procedures for protection of environment under accident ice conditions should be included into the complement of "Shipboard Oil Pollution Emergency Plan" (SOPEP) by sections taking into account the peculiarity of ice navigation.

10.5.Recommendations for the Improvement

From the experience made during the ARCDEV voyage in April-May 1998, it is proposed to take the following minimum requirements into account:

?? Improvement of the efficiency of the communications
- VHF-radio link (one additional set for redundancy)
- Use of a portable satellite telephone on the shore to be considered also as a future option for emergency communication

?? Improving the communications' reliability for carrying out cargo operations and completing the relevant documentation:
- Improving the understanding between ship and shore personnel during cargo operations. So far the Russian ice pilot and the radio officer on board the foreign ship have served as interpreters. They are not necessarily specialised in oil tankers and terminals operations and in case of emergency situation misunderstandings may possibly occur during the translation.
- A translator or interpreter familiar with the terminology of oil tanker and terminal operations should assist the communications between ship and shore during the loading operations and the completion of the official cargo documents as well.
- For correct understanding and completion of the International Ship-Shore Check List according to the **ISGOTT** (International Safety Guide for Oil Tankers and Terminals) it should be officially translated into Russian language and the translation should be attached to the check list. An other option is the preparation of an official two languages Ship-Shore Check List.

?? Improvement of watch procedures
- A round the clock shore watch should be established at the loading terminal site respectively near to the ship for operational and safety procedures (inspection of flexible hoses, leakage control, de-icing of valves, to give the alarm for stop pumping in emergency case, etc.).
- For continuous watch at the loading terminal site by shore personnel a shelter should be provided. The electric power supply could be provided from the tanker.
- A duty motor vehicle equipped with VHF radio for periodical inspection of the approximately 4 km long pipeline should be foreseen.
- Sufficient flexible hoses in number and length should be provided in order to avoid a small bending radius during handling. Too short flexible hoses between the ship's manifolds and the shore pipeline ends may often experience tension, which may cause leakage of cargo at the connections.
- According to the international practice and regulations the loading terminal on the ice is a part of the oil terminal onshore and therefore under the responsibility of the shore personnel and not of the ship's crew. Thus operational and environmental safety actions therefore should be carried out at first by the shore personnel themselves.

?? It is recommended for oil tankers to carry out regular ballast water change before entering the Western Siberian ports for deballasting and loading their cargo.

?? Recovery device (scraping device, pumps, hoses, absorbents and sludge tanks of sufficient capacity should be available close to the terminal.

?? For cleaning up the spilled gascondensate: adsorbents as sawdust or other appropriate material, mechanical means for cleaning the contaminated ice-surface and snow as spades, shovels and proper tight containers for its collection and transportation should be provided at the terminal site.
?? Four-wheel drive trucks, tracked vehicles, crane vehicles, caterpillar track and fire-fighting truck as well as fire extinguishers should be on stand-by at the terminal site.
?? At the terminal the valves between pipeline and hoses should be insulated and kept warm to avoid freezing.
?? Responsibilities
  - Ship's deck watch is responsible for combating the part of the spill, if any, on the ship's deck according to the Ship's Oil Pollution Emergency Plan (SOPEP). For the „loading terminal" an „Oil Spill Contingency Plan" should be available.
  - In case of a spill, the crew has to meet their obligations according to the Ship's Response Plan with the highest priority.
  - The crew may assist the shore personnel only, if it is possible at all under certain emergency circumstances, but nevertheless their main obligation is to be responsible for the ship's safety.
  - The personnel working at the shore site respectively terminal is responsible for the terminal's safety.
  - Equipment at the terminal site should be provided for the personnel working at the shore site respectively the loading terminal.
?? If burning of gascondensate is unavoidable, this should not take place in the dangerous vicinity of the oil tanker and terminal.

According to the operational practice in the Russian Arctic, the icebreaker is on a stand-by close to the tanker, when she is alongside the ice terminal.

?? For enhancing the icebreaker's preparedness for assisting the loading terminal in oil pollution prevention operations additional appropriate equipment should be provided on the icebreaker.
?? For the future benefit of both parties the oil tankers and the oil terminals representatives of the Russian Environmental Authorities could assist the monitoring of the environmentally safe cargo operations until more sophisticated loading facilities will be established in the Arctic.

10.6.Summary and conclusion

Sea transportation of oil and gas from the Arctic is upcoming and will be a more risky and expensive business compared to transportation in open water. The Arctic Ocean with the Russian Arctic shelf areas are the most vulnerable environment on earth due to the low temperatures and the presence of ice. Especially oil spill accidents are considered much more harmful in the ice covered ocean than in warmer climates. Therefore, it is most important to take every reasonable precaution to prevent an spill of gascondensate or spill with crude oil.
Previous to the month-long round trip of MT UIKKU from Murmansk - Sabeta - Rotterdam with respect to the necessities of WP 11 Environmental Protection the FORTUM GAS and OIL representative carried out the co-ordination work for convincing the Russian authorities in order to obtain the relevant permission. For the purpose of this task very valuable support was provided by AARI and CNIIMF. Effort has been made to avoid any violation on the environment and every possible precaution measures have been considered in order to protect the environment.
The environmental safe operation concerned two main aspects, i.e.
a) the environmental safe navigation through the western part of the Northern Sea Route and
b) the environmental safe ship-shore cargo operation on Yamal peninsula for loading gascondensate.
The successful completion of these tasks was carried out in co-operation with the Russian authorities and the Russian teams (crew and scientists) on the icebreakers and on the loading terminal.
A literature search and review of oil spill response equipment and methods in ice covered waters was carried out. An analysis of the sources and extent of sea pollution on the basis of experience in coastal transportation in the Russian Arctic and a detailed definition of structural requirements for ships and a composition of the equipment protecting the environment was prepared. Recommendations to a "Safety Plan" and "Safe Operations Procedures" for the ships on this route were made.

The facilities of the loading terminal and the tanker is well documented and recommendations have been made where necessary. A “Contingency Plan” for the loading terminal is proposed, and different techniques are given as examples to respond oil spills in ice and snow covered areas.
During the voyage as well as the loading process there was no incident concerning environmental violation observed. However, future research is necessary with respect to the further improvement of environmental protection, e.g. additional structural requirements for the ships of different Polar Classes taking into account the probability of oil spill in the event of ice damages. The Ship Oil Pollution Emergency Plan (SOPEP) should be complemented by additional sections taking into account specific cases of operational emergency spillage in various ice conditions.
Comprehensive oil spill response management systems taking the peculiarities of the loading sites into account are required for an effective oil spill response. Since there is a certain precariousness in the behaviour of gascondensate / oil concerning the penetration and distribution into snow or ice, detailed basic laboratory investigations for different types of hydrocarbons should be carried out.
Existing oil spill recovery equipment has to be improved, prototypes of suitable oil spill recovery device and adsorbent materials for the operation in cold climate conditions has to be developed, designed and tested in laboratories and under realistic conditions in the field.
Feasibility studies and research projects e.g. ice model tests of various types of loading terminals for different ice conditions should be initiated.

11. GENERAL CONCLUSIONS OF THE ARCDEV PROJECT

In April/May 1998 the EU sponsored Arctic Demonstration and Exploratory Voyage (ARCDEV) was carried out to demonstrate the technical feasibility of transporting oil/gas condensate from the Russian Arctic to Western Europe by icebreaking tanker and to evaluate the economical situation of such transport. A convoy of two ships – the icebreaking tanker M/T Uikku and Russian icebreaker IB Kapitan Dranitsyn – started at Murmansk for carrying gas condensate from Sabeta at the Ob-River to Rotterdam. The convoy made a record voyage, even though the ice conditions in the Kara Sea were severe. At the northern trip of Novaja Zemlya, where the ice conditions became too heavy for IB kapitan Dranitsyn the most powerful nuclear icebreaker IBN Rossija took over the lead of the convoy.

70 scientists from seven countries in Europe – mainly from Russia, Finland and Germany – carried out investigations on the ship's performance in the Arctic ice. In spite of the overall success of the voyage a number of issues have been defined, where research would significantly improve the technical and economical performance of such a transport system. Any research and development should therefore focus on reducing the transportation costs and on simultaneously caring for the protection of the Arctic environment.

The evaluation of Arcdev results by each work package has resulted in the following conclusions.

WP-1 Commercial aspects

The main target of the project was to create transparent cost figures for Western flag vessel operating in the NSR area. This was fully achieved. The overall cost for transportation was 780.000 USD (73 USD/ton), which is roughly double the cost for similar distance in Baltic area. The biggest differences come from the NSR fee including icebreaker assistance (250.000 USD), for low average speed (approx. 7 kn) and long time for loading (4 days). Also the obligatory visits to Murmansk for customs and immigration. In addition to these, the small amount of cargo available increased the cost/ton value.

For future operations it is recommended to minimise the time for the voyage through more efficient ice routing and use of advanced technology for improved performance in ice. The cost for icebreaker assistance should be reduced through the development of the whole fee policy in the NSR. The use of larger size vessels and bigger cargo parcels would of course also contribute to the reduction of the costs.

WP-2 Legal and Regulatory Questions

Thanks to the previous experience to handle the permitting processes, no bigger problems were met. However the whole process with vessel examination as well as customs and immigration procedures caused delay of at least two days compared to procedures in any other area.

For planning long term investments into vessels specially designed for the area, there should be a more solid regulatory basis with long term permissions for foreign vessels to be able to operate in the area and visit all the ports and terminals.

WP-3 Ice conditions

The ice conditions during the voyage were worst for 30 years. This has influenced the results of all work packages and provided additional value to all recordings. The several methods used for ice data collection resulted in a large scatter in the recordings. The onboard ice information and ice forecasts were mainly based on satellite images and helicopter observations. The best satellite images were from the visual light range and this was thanks to the good weather conditions. Since this will not be the case always, it seems that there still is development work to be done especially in the area of multisensor satellite observation technology.

WP-4 Ship Performance

The average speed of the convoy was 6-8 knots over the whole route. On the other hand, the shaft power used by the vessels in the convoy was also relatively low. The icebreaker Dranitsyn used shaft power of 10 MW of the 16 MW available and the tanker Uikku approx. 6 MW of the 12 MW available. Certainly the safe convoy operation does not allow the use of 100% shaft power, but still it seems that some improvement in convoy operations can be done and the use of more independent icebreaking cargo vessels should be studied.

WP-5 Ice Routing

No automatic routing tools were available during the voyage. The use of satellite images and helicopter observations were the only methods used. The high onroute speed, mainly close to 10 knots, shows that with the methods used it is possible to find relatively easy ice conditions. On the other hand the distance sailed was increased by more than 50 % and thus the average great circle speed was less than 8 knots. With proper ice forecast methods and more accurate satellite image analyses it should be possible to increase also the great circle speed. Adoption of improved ice charts based on long-term weather forecasts together with computer based route selection tools could lead to better results. Development and verification of such systems should be done in an area with well developed infrastructure for ice navigation, like the Baltic.

WP-6 Navigation and operations

The relatively low power used by the vessels in the convoy requires further analyses so that the best can be made out of the performance capability of modern vessels.

WP-7 Tanker Loading System

The relatively simple method used for the tanker loading showed, that with proper design the loading operation can be done in a safe way even in the difficult environmental conditions. The low performance of the loading system, however, makes the economics of the whole transportation questionable. The proper loading system and the selection of optimal terminal type are key issues for any commercial operation.

WP-8 Ice Loads

The measured load values, more than 2000 kN/m, were well above the original Baltic ice class 1 A super requirements (1200 kN/m). If the year round traffic is carried on continuous basis, vessels with higher ice class are required. Based on the measurements it seems that the requirements should be somewhere between the requirements of UL and ULA in the Russian Register rules. If hull loading will be one criteria for routing purposes, more data with ice information need to be collected.

WP-9 Required Ice Class for Polar Navigation

The measured data does not support the requirements of the proposed unified Polar Class Rules, where the loading distribution over the hull is based on collision with heavy multy year ice. The main reason for this is that the operation on this route is in first year ice only. This type of operation in relatively difficult but still first year ice should be taken into account when the ice rules are developed further. Another aspect in the ice rules, which has not been considered is the independent operation of cargo vessels.

WP-10 Remote Service and Maintenance

During the voyage a complete system with software and hard ware for remote maintenance was tested. The system covered video conferencing with virtual reality and shared images and shared data basis utilising internet connections. The technology and devices tested operated without any major problems. The development work in future should concentrate on the applications and improvement of the high latitude telecommunication methods.

WP-11 Environmental Protection

The demonstration showed that with high level of precautions the operation can be made in an environmentally safe manner. For larger scale regular operations the whole environmental protection plan should be reviewed.

WP-12 Data and Information Management

The data management was satisfactory throughout the project covering both Russian and Western data. There should however be more effort in standardisation of the stored data to make the use of the data in post-project analyses more effective.

WP-13 Trafficability

It was very difficult to find any good correlation between gathered data and the convoy performance. There were a number of reasons for this. First of all the collected data did not include all the critical parameters from the ice conditions. The number of ridges and especially the description of ice under pressure were not detailed enough for the correlation, further complicated by the fact that the convoy speed is not covered by the existing trafficability models in proper way. For the future it is recommended that additional testing will be done in an area with more sophisticated infrastructure for data production and transmission.

WP-14 Navigation Simulation

The data collected during the voyage gives a first indication of the problems to be simulated in a training simulator. The material as such can be used for training purposes, but a lot of additional data gathering is required until the simulator can be developed.

WP-15 Russian Participation co-ordination

The scientific work by the Russian participating institutions was on satisfactory level. There were some minor problems with administrative procedures.

12. APPENDICES

A. Appendix List of Arcdev reports *

Deliverable N0/Part	Report title	Issuing Organisation
D3/1	WP-1 Commercial Aspects Final workpackage report	FORTUM
D3/2	Final report - Russian contribution	ASS,CNIIMF
D4/1	WP-2 Legal and Regulatory Questions Final workpackage report	FORTUM
D4/2	Final report – Russian contribution	NSRA,CNIIMF
D5/1 D5/2 D5/3 D5/4	WP-3 Ice Conditions Final report – Ice, Ridge and Snow Properties Contribution – Pressure Ridge Profiling (MS-Word with hyperlinks to images) Contribution – Airborne Laser Profilometry Contribution – Satellite imagery (mainly radar imagery) Note: Includes also NERSC's contributions to WP-10	KMY HSVA HUT NERSC
D5/5	Contribution – Physical and mechanical ice properties	AARI
D5/6	Contribution – Ice observations and measurements by Russian team	AARI
D5/7	Contribution – Satellite imagery (incl. Russian satellite images)	AARI
D5/8	Contribution – Dynamic Ice Strength Tests (Drop Ball device)	KSRI
D6/1	WP-4 Ship Performance Final workpackage report on ship performance	KMY
D6/2	Russian view and experience on ship performance in the Arctic	CNIIMF
D7/1	WP-5 Ice Routing Final Report - Ice Routing Note: Comprises also EOS' report for the "Ice Route" project.	EOS
D7/2	Russian ice routing methodologies and experiences	AARI
D8/1	WP-6 Navigation and Operations Final Report – Navigation and Operations	HSVA
D8/2	Russian navigation and operations experience in the Arctic	CNIIMF
D9/1	WP-7 Tanker Loading Systems Final workpackage report on loading systems for tankers in arctic conditions	TECNOMARE
D9/2	Future possibilities and perspectives for tanker arctic loading systems	TECNOMARE
D10A/1	WP-8 Ice Loads Report on ice Load measurements on M/T Uikku Note: See also the affiliated reports assembeled under D10B.	HUT
D10A/2	Graphical presentation on ice Load measurements on M/T Uikku	HUT
D10A/3	Ice load analysis Note: D10B / 4 comprises mainly data to be assembeled in the data collection.	HUT
D10A/5	Ice load statistics. Note: D10B / 6 comprises mainly data to be assembeled in the data collection.	HUT
D10A/7	Report on ice Load measurements on IB Kapitan Dranitsyn Note: D10B / 8 comprises mainly data to be assembeled in the data collection.	AARI
D10A/9	Conclusions and recommendations for future research (see also D5 / 8)	KSRI
D10B/1	WP-9 Required Ice Class for Polar Navigation Executive Summary on WP-9	LR
D10B/2	View and expereiences from AARI's team	AARI
D10B/3	View and experiences from CNIIMF	CNIIMF

D10B/4 D10B/5 D11	Recommendations for ice strengthening Analytic ice load assessment WP-10 Remote service and maintenance Final and overall workpackage report	KSRI KSRI REMTEC
D12/1	WP-11 Environmental Protection Final Environmental Protection Report	HSVA
D12/2	Environmental Protection Report	FORTUM
D12/3	Environmental Protection Report	CNIIMF
D13	WP-12 Data and Information Management Final and overall workpackage report	FORTUM/ HYDROMOD
D14/1	WP-13 Trafficability Final workpackage report	HSVA
D14/2	Trafficability simualtion	CNIIMF
D15A/B	WP-14 Navigation Simulation Final workpackage report	ISSUS
D16	WP-15 Russian Participation Co-ordination Conclusive workpackage report	KMY
D17A-E	WP-0 Project Management and Co-ordination Cummulative Mangement and Progress Final Report	FORTUM
TA	ARCDEV's Technical Annex (included for reference purposes)	FORTUM
DWP-16Report	WP-16 Overall Evaluation and Identification of future R&D needs Final Report – Conclusions and recommendations	HSVA
D17A-E	ARCDEV Summary Report - Ice Conditions Conclusions and recommendation for future research	KMY
D17I	WP-0 / WP-12 The ARCDEV Public Web Site Documentation	FORTUM/ HYDROMOD
D17J	WP-0 Executive Project Summary by Project Manager / public	FORTUM
PEX1	Satellite Radar Ice Monitoring for Ice Navigation of the ARCDEV Tanker Convoy in the Kara Sea, Contribution ot POAC'99, L. Pettersson et. al.	NERSC;NIERSC, MSCO
PEX2	Maritime Freight Management in Arctic Regions, EU Transport Conference 1999, I. Ivanov	FORTUM
PEX3	The NSR Tariff System Present Practice & Future Requirements - Focus on the ARCDEV Experience, INSROP'99, Presentation, I. Ivanov	FORTUM
PEX4	The NSR Tariff System Present Practice & Future Requirements - Focus on the ARCDEV Experience, INSROP'99, Final Script, I. Ivanov	FORTUM
PEX5	Suggestion for Future Northern Sea Route Shipping based on NSR Experience, INSROP'99, J. Säävälä	FORTUM
PEX6	Letter to the Editor of Lloyds List, I. Ivanov	FORTUM

*Reports can be confidential, restricted or public.

B. Appendix List of Arcdev partners and contacts

Project Co-ordinator:

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West European Partners:

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Helsinki University of Technology (HUT)
Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA)
MTW Schiffswerft GmbH (MTW)
Earth Observation Sciences Ltd. (EOS)
Tecnomare S.p.A. (Tecnomare)
Remtec Systems Ltd. (Remtec)
Shell Vankor Development B.V. (SHELL)
Lloyd's Register of Shipping (LR)
Nansen Environmental and Remote Sensing Center (NERSC)
Fachhochschule Hamburg - Institute of Ship Operation, Sea Transport and Simulation (ISSUS)

Russian Partners:

Ministry of Transport of the Russian Federation-Northern Sea Route Administration (NSRA)
Central Marine Research & Design Institute Ltd. (CNIIMF)
Murmansk Shipping C ompany (MSCO)
Arctic Shipping Services (ASS)
Krylov Shipbuilding Research Institute (KSRI)
State Research Center of Russian Federation -The Arctic and Antarctic Institute (AARI)

Major sub-contractors:

Hydromod Scientific Consulting (HYDROMOD) - contracted by Fortum