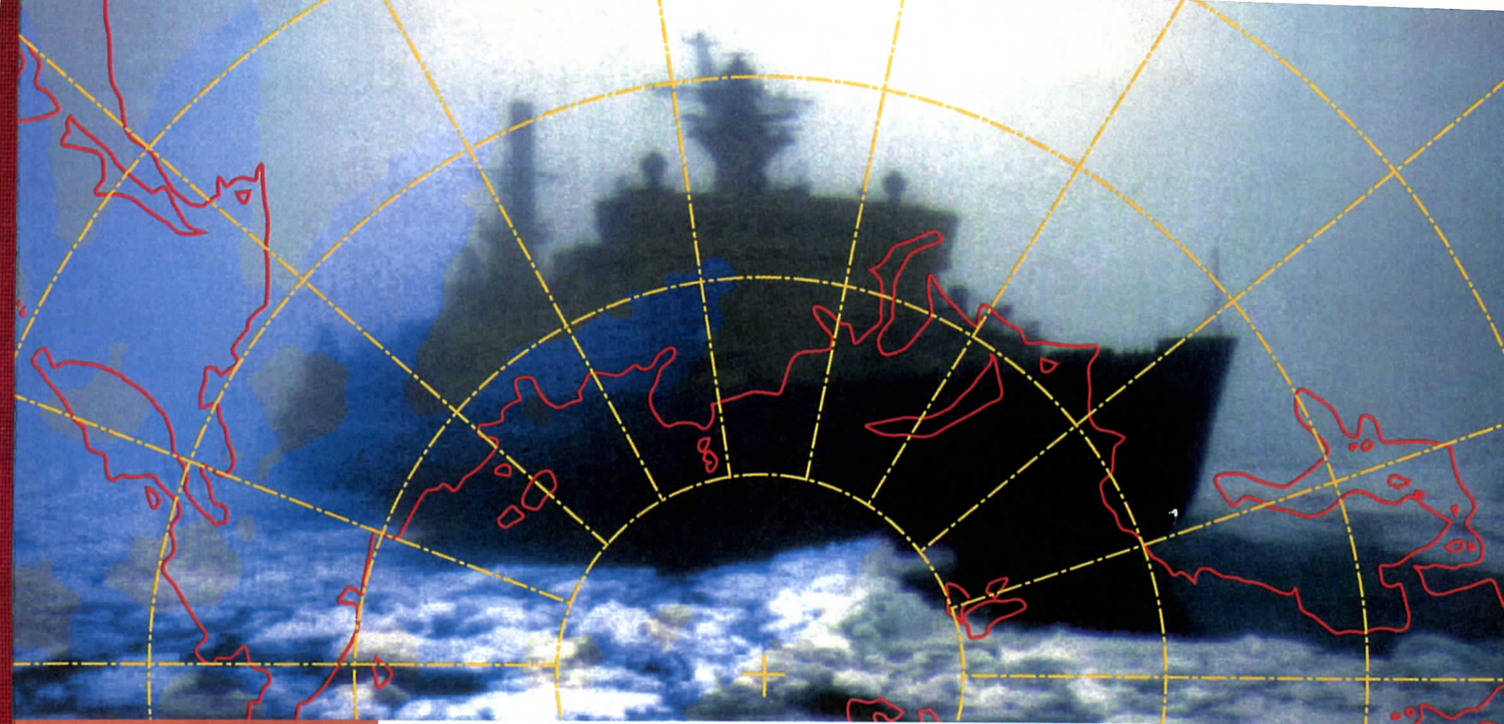
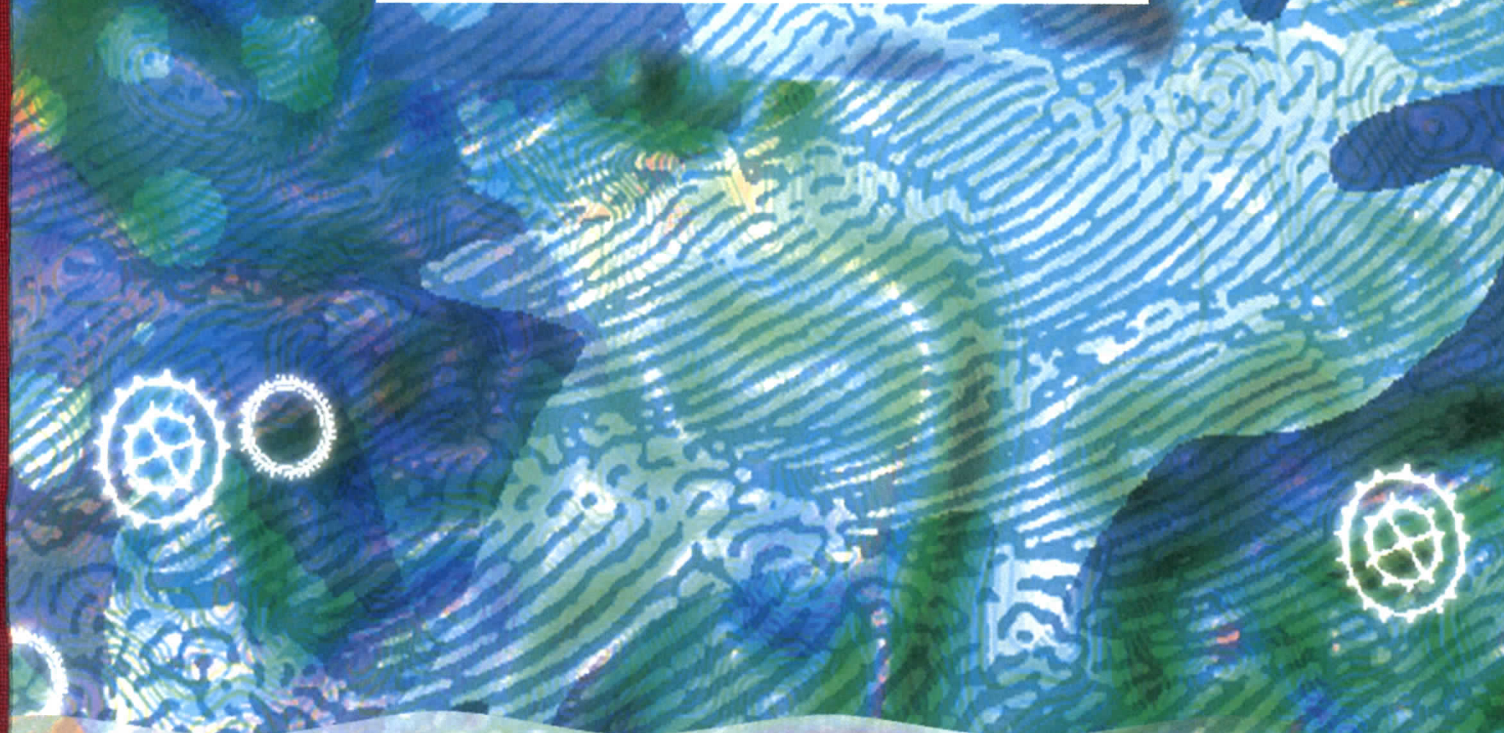


INSROP WORKING PAPER
NO. 86 - 1997, III.07.4

Seaborne Exports of Gas from Yamal.

By Nikolay A. Isakov, Eduard G. Logvinovich, Felix A. Moreynis, Anton E. Nikulin, Nadezhda V. Popovich, Anatoliy N. Silin, Nikolay N. Stenin, Igor L. Sverdlov and Vladimir A. Erashov



INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship & Ocean Foundation, Japan

INSROP WORKING PAPER NO. 86-1997

Sub-programme III: Trade and Commercial Shipping Aspects.

Project III.07.4: Seaborne Exports of Gas from Yamal

Supervisor: Yuri Ivanov

Title: **Seaborne Exports of Gas from Yamal.**

Authors: **Nikolay A. Isakov, Eduard G. Logvinovich, Felix A. Moreynis, Anton E. Nikulin, Nadezhda V. Popovich, Anatoliy N. Silin, Nikolay N. Stenin, Igor L. Sverdlov and Vladimir A. Erashov.**

Address: Central Marine Research and Design Institute
Kavalergardskaya Street 6
193 015 St.Petersburg
RUSSIA

Date: 17 September 1997

Reviewed by: Michael N. Tamvakis, City University Business School, London, Great Britain.

What is an INSROP Working Paper and how to handle it:

FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are **Central Marine Research & Design Institute (CNIIMF)**, St. Petersburg, Russia; **Ship and Ocean Foundation (SOF)**, Tokyo, Japan; and **Fridtjof Nansen Institute (FNI)**, Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

SPONSORS FOR INSROP

- Nippon Foundation/Ship & Ocean Foundation, Japan
- The Government of the Russian Federation
- The Norwegian Research Council
- The Norwegian Ministry of Foreign Affairs
- The Norwegian Ministry of Industry and Trade
- The Norwegian Ministry of the Environment
- State Industry and Regional Development Fund, Norway
- Norsk Hydro
- Norwegian Federation of Shipowners
- Fridtjof Nansen Institute
- Kværner a.s.
- Phillips Petroleum Company Norway

PROFESSIONAL ORGANISATIONS PERMANENTLY ATTACHED TO INSROP

- Ship & Ocean Foundation, Japan
- Central Marine Research & Design Institute, Russia
- Fridtjof Nansen Institute, Norway
- National Institute of Polar Research, Japan
- Ship Research Institute, Japan
- Murmansk Shipping Company, Russia
- Northern Sea Route Administration, Russia
- Arctic & Antarctic Research Institute, Russia
- ARTEC, Norway
- Norwegian Polar Research Institute
- Norwegian School of Economics and Business Administration
- SINTEF (Foundation for Scientific and Industrial Research - Civil and Environmental Engineering), Norway.

PROGRAMME COORDINATORS

- **Yury Ivanov, CNIIMF**
  Kavalergardskaya Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU
- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 11 19 00
  Fax: 47 67 11 19 10
  E-mail: sentralbord@fni.no
- **Ken-ichi Maruyama, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

FOREWORD - INSROP WORKING PAPER

The evaluation of marine gas export from Yamal is believed to be a closing stage in evaluation of the maritime trade development and commercial shipping in the western sector of the Russian Arctic.

The preparation of the whole economic project of gas export considerably exceeds the scope of the present research in terms of tasks and scale.

The authors of the project aim to attract the attention of ruling circles, Russian and foreign investors to the idea of LNG transportation along the Northern Sea Route by sea vessels.

The organization of such transportation would enable us to fulfill contractual obligations more reliably, to improve operations of alternative modes of transportation (pipe, rail, river), to determine practical ways to exploit the shelf fields of the Russian Arctic seas with a view to transport hydrocarbon materials from these fields.

In this respect, a technical economic feasibility study of Arctic going methane carriers has been conducted in the project on the basis of the last scientific technical achievements with due regard to practical experience acquired by the Merchant Marine of Russia through carriage of export/import and local commodities along the Northern Sea Route.

A project of technological transportation system of LNG export has been developed and coordinated with functions of separate elements (LNG production plant, LNG storage plant, port transshipment terminal) under the task schedule. An assessment of possible risks has also been made.

Export volumes of natural gas products are estimated to be 10, 20 and 30 bln cub. m. a year; these figures characterize respective operational stages of the technological transportation system.

A methodical approach is accepted in accordance with the research of the company "Drewry Shipping Consultants" which undertook a number of scientific studies in the sphere of economic evaluation of the LNG seaborne transportation.

This project will be of interest for Russian and foreign companies and skilled specialists shall be involved in the development of gas fields in the Arctic regions of Russia. Problems of oil & gas transportation from those regions are very important. The use of sea transport, as the project shows, has good economic , technological and organizational prospects.

CONTENTS

List of abbreviations

ACS - air conditioning systems
ACT - architect-constructive type
ADG - auxiliary diesel-generator
A/L - atomic icebreaker
APP - atomic power plant
B - breadth
D - loading capacity
DG - diesel-generator
DW - deadweight
E - efficiency
EBR - engine-boiler room
ER - engine-room
FM - frequency modulation
FO-fuel oil
GRS - global positioning system
GTE - gas turbine engine
GTU - gas turbine unit
H - depth
I/B - icebreaker
IGS - inert gases system
IMO - International Maritime Organization
IW/SW - intermediate waves/short waves
KK1 - icebreaker's class of the Register of the Russian Federation
L - length
LNG - liquefied natural gas
LPG - liquefied petroleum gas
ME - main engine
MSC-Murmansk Shipping Co.
NSR-northern sea route
NG - natural gas
NGM - tanker gas-carrier - methane-carrier
PP- power plant
RAC - remote automatic control
RF-Russian Federation
SG - shaft-generator
SCE - ship complement equipment
SI - strengthened ice class of the Register of the RF
SIA - strengthened Arctic ice class of the Register of the RF
SRP - regulated pitch screw
SS - salvage ship
STP - steam turbine plant
T - draught
TES-technical and economic substantiation
TTS-technological transportation system
W - capacity
WF - water fire extinguishing
VNIIGAS-state scientific and research institute of natural gases and gas technology
OCT- standard of industry
ГОСТ- Unified state standard

INTRODUCTION

Rapid world development of liquefied natural gas trade characterizes a priority of hydrocarbon raw material for the electric power production both nowadays and in the foreseeable future. After the first world plant designed for liquefaction of natural gas was put into operation in 1965, the average consumption of LNG was increasing by 20% per year.

International trade in natural gas amounted to 346,73 billion cu. m. in 1993; 263,49 billion cu. m. (about 76%) was delivered to consumers via pipelines and 83,24 billion cu. m. (more than 24%) - by methane-carriers. According to the company CEDIGAS (France) the volume of world trade in liquefied natural gas might reach 120-130 billion cu. m. a year by 2000 and exceed 200 billion cu. m. in 2010. The above volumes of trade ensure that new eight plants for NG liquefaction with total cost of not less than 40 billion USD will be put into operation in 1994-2000. At the beginning of 1992, the world fleet of methane-carriers consisted of 71 vessels with around 7 million cu. m. of the total carrying capacity.

It is expected that the consumption of LNG for the electric power production in Europe will be doubled by 2000; as a result of it Germany, Portugal, Turkey and Finland will become LNG importers. The increase in LNG consumption will cause a rise of transportation volumes covered by tankers (methane carriers). As a result, the orders for 80 new vessels to be built for LNG transportation will be placed up to 2001. Methane carriers will be handled by around 15 terminals in 10 European countries by 2000.

The above brief review on the position and prospects of LNG world trade implies a serious interest of Western Europe in delivery of this kind of fuel by sea transport, especially of those countries where an extensive network of gas pipelines from traditional natural gas deposits directly to consumers is already available.

The amount of NG exports from Russia to the countries of Western Europe via pipelines is about 100 billion cu. m. This fact becomes crucial for elaboration of Russian flexible technical policy for prospects of international trade in important hydrocarbon raw materials, with the existing highly developed material and technical LNG basis in Europe being available.

Potential resources of natural gas in the shelf of the Kara Sea are now estimated at 26,4 trillion cu. m. It is characterized by high concentration of resources in separate giant deposits. The Harasavey deposit, where the planned rate of NG annual extraction is estimated at 32 billion cu. m., is the most promising deposit for sea transport to be used.

It should be noted that the Russian northern territories, which are planned for the marine hydrocarbon extraction, are characterized by a rather poorly developed infrastructure and severe climatic conditions, that is, they are unique in the world practice; this fact should be taken into consideration when drawing up plans for these areas.

New technology of LNG production and transportation from shelf deposits of the Russian Arctic zone has a geopolitical importance for the national economy because it will help to solve a large number of strategic tasks, the most important of which are the following:

1. An increase in the competitiveness of Russian-foreign trade in natural gas ;

2. Protection of priorities of the Russian Federation's subjects when developing the shelf of the adjoining Arctic seas;

3. Growth of economic potential of the Far North regions by means of development of a network of joint stock companies and local commercial enterprises, and improvement in social life quality of the Far North nations;

4. Sea transport fleet revival with a view to use reliable transport means with the increased ecological protection of transport process from possible risks;

5. Conversion of military-industrial branches, with the highly qualified staff being kept up;

Exemption of Russian power sources from ungrounded claims and high transit duties in the countries where the pipelines run.

Wide employment of production process automation to produce technical factory-made plants ("Sevmashpredpriyatiye" and other high mechanized Russian enterprises being involved), promotes the development of labor- saving technologies in the Arctic and improvement in potential production quality. The work has been carried out in accordance with the requirements of normative document OCT 5.0064-84 "Development, co-ordination and approval procedure of ship project". This document stipulates the development of technical-economic requirements for a new ship project in accordance with ГОСТ 15.001-73 which must contain the following information :

- purpose and field of operation of the ship;
- feasibility study of the ship;
- preferred parameters and characteristics of the ship;
- operating parameters, modes and organization of work of the ship;
- a number of the ships recommended to build;
- other specific requirements.

1. LNG TECHNOLOGICAL TRANSPORTATION SCHEMES

1.1. Initial data

The present work on the project is proposed as a substantiation of natural gas liquefaction, selection of the type and sizes of Arctic going ships (methane carriers) in compliance with the characteristics of transportation technological systems and the development of the main technical operational requirements for designing Arctic going ships (methane carriers) within the framework of the feasibility study.

The volumes of NG export production are assumed to be of 10, 20 and 30 billion nm per year. At the stage of exploitation-economic evaluation, these volumes, to some degree, will be corrected taking into consideration the current technological norms and standards. The transportation is carried out evenly during the calendar year. The transport technological scheme consists of:

1. A loading terminal with LNG storage in areas of the port of Harasavey;

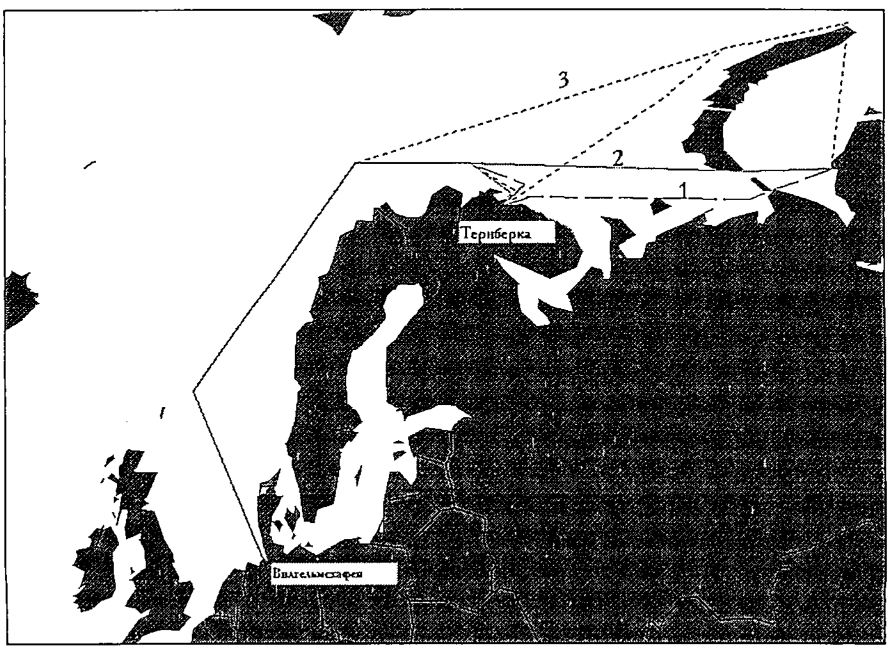
2. Arctic going methane carriers;

3. Supporting vessels - liner icebreakers and harbor icebreakers and tugs;

4. An unloading terminal with LNG tank storage farm in the area of Wilhelmshaven port. This port is assumed in the work as a design-basis port, taking into account that RAO "Gasprom" exports natural gas to Germany under long term Contracts and there was an offer to have a work meeting of specialists of Russia and Germany in 1993, in order to discuss the possibility of arrangement of an unloading terminal for methane carriers in this port. The LNG transportation is carried out according to the accepted transport schemes i.e. routes, which are agreed with the operative plans, taking into consideration changes in weather conditions.

The change of potential transport schemes-routes is considered as taking place in the Barents and the Kara Seas for the purpose of successful overcoming of ice fields in winter-spring period of navigation. The lengths of routes (transport schemes) are shown in Fig.1.(in nautical miles):

Fig.1. Transport schemes-routes of LNG export from the port of Harasavey



1. Harasavey-Yougorsky Shar Strait-Wilhelmshaven - 2147.
2. Harasavey-Kara Gates Strait-Wilhelmshaven - 2116.
3. Harasavey-Zhelaniya Cape-Wilhelmshaven - 2438.

The necessity of selection of favorable transport schemes as well as the necessity of choosing operatively safe routes for navigation in ice, usually give 10-12% increase in average length of routes for a calendar year, and therefore the main quantitative characteristics for the transport scheme Harasavey-Wilhelmshaven may be assumed as follows:

- A period of work of methane carriers according to the scheme is 365 days, including winter period-245 days and summer period - 120 days.
- A length of a round trip in summer is 4300 miles and up to 4700 miles in winter including the distance traveled with icebreaker assistance in the winter, which may come up to 1000 miles.
- Icebreaker assistance in winter is stipulated to be performed by icebreakers of "Arctica" and "Taimyr" types registered with the Murmansk Shipping Company, with preliminary laying- out the lines in the limiting ice areas having being made. An average service speed in ice has been estimated at 10 knots on the basis of average monthly speed for a number of trips .

1.1.1. Navigational conditions (1).

A number of limiting factors, which have been backed up with long time observations of hydrometeorological service, and ship data shown in Table 1.1, will affect the sailing conditions and the requirements for methane carriers for the area under consideration.

A trip from Murmansk to the port of Harasavey can be divided into four stages:

1. From the meridian of Murmansk to the Western edge of drifting ice. During the years of average ice conditions, the edge of ice fields lies along the meridian of Kolguev Island.

Table 1.1.

Shipping limiting factors at Harasavey-Wilhelmshaven

List of limiting factors	Quantitative evaluation	
	from	to
Port Harasavey		
Air temperature	+ 28	- 46
Fogs in July, days	18	26
Snow-storms, days	26	
Yougorsky Shar Strait		
Breadth, miles	1.5	1.7
Depth, m	10	36
Thickness of ice, cm	130	
South-western section of Kara Sea		
Thickness of ice, cm	160 - 190	
Duration of ice period, days	260	279

In extremely severe years, such as 1966, 1985, there were somewhere on the route the gray and white ice with some spots of first-year thin and middle thickness ice. It is not difficult to sail in this area for ice resistant ships of UL and ULA classes of the RF Register.

2. From Kolguev Island to the Novaya Zemlya straits. During the years of average ice conditions (in December) this area is covered with ice. During the winter-spring period of ordinary years the South-Eastern part of the Barents Sea is covered with gray and white ice and white close-packed ice of 8-10 numbers of concentration. In the West, ice thickness is varied within the limits of 25-40 cm, in the East - 50-80 cm. In the case when there is no compression, the ships of "Norilsk" type can sail freely through such ice. But due to active winter cyclonic activity in this area there are likely to occur frequent stronger winds that cause strong compression of ice and hummocking. The aggravation of ice conditions makes the navigation in approaches to the straits very difficult without icebreaker assistance. During the years of heavy ice conditions, the ice cover forms from heavier ice, which seriously impedes escorting transport ships even with the powerful icebreaker assistance. On average, the length of the route in this area is 200-250 miles.

3. During the winter-spring period, due to changes in ice conditions the navigation in the straits of Novaya Zemlya is possible only with icebreaker assistance. This area shows a great variability of ice cover because of a stream, that flows from the Barents Sea to the Kara Sea through the straits, and also because of wind drift and tidal streams. All these factors give rise to strong ice compression, which are observed more often in the approaches to the Yougorsky Shar Strait from the side of the Barents Sea in a zone of 10-20 miles in breadth. The compression is produced by south-western storm winds. The fragments of hummock barriers, hard-to-pass barriers of hummocks and drifting ice fields of the increased hummocking (up to 5 numbers) can arise because of the above storm winds blowing at the approaches to the Yougorsky Shar Strait. In this case the route that passes through the Kara Gates Strait along north-western and northern coast of Vaygach Island is the most realistic route for sailing with icebreaker assistance.

4. A part of the route from the Novaya Zemlya Straits to the Yamal Peninsula is covered with ice of autumn formation already in November . The biggest part of sea water areas in this region is covered by first-year ice with a hummocks and is characterized by up to 2 numbers in winter-spring period.

The ice cover of the south-western part of the Kara Sea consists of young ice, which reaches the thickness of 70-130 cm in winter-spring period. During the years of the complicated hydrometeorological conditions, the ice thickness may reach 160-190 cm. An increase in ice thickness is observed till the middle of May.

The average length of the ice zone in the route areas is slightly varying from December till May. A considerable reduction of ice zone caused by young ice melting in the south-eastern section of the Barents Sea, is observed in May. There is a reduction of length of zones with small ice thickness and an increase or formation of zones with the increased thickness of ice from February till May. It is brought about, first of all, by increase in ice thickness from November till May.

When evaluating the regime of the Kara Sea, a conspicuous role plays land floe ice, especially on the western coast of the Yamal Peninsula where it is used for unloading large quantities of cargoes from ships (including oil products in liquid state) during the winter-spring period (Cape Harasavey and an area of the river Mordyjaha). The land floe has unstable state in general, and becomes stable later (February) because of dynamic influences of wind, streams, drifting ice and other hydrometeorological factors which affect the durability and stability of the land floe. The repeated breaking of some land floes from the main land ice floes takes place during the autumn and winter. An average hummockness of the floe ice varies from 2 to 5 numbers. The hummockness is 0-2 numbers in a very shallow zone, a breadth of which varies from one to 2,5 km in different years. This zone is usually limited by a hummock ridge from the West. A hummockness increases up to 2-3 numbers and in some places behind the ridge up to 3-4 numbers.

A zone of increased hummockness is from 2 to 5,5 km in breadth , and ends, as a rule, with a barrier of hummocks, that lies at a depth of 10-13 m. The zones of hummockness of different degree alternate with smooth ice fields beyond the barrier and up to the edge of land floe. The land floe destruction begins in May and its complete disappearance take places in June-July.

The experience of operation of present-day liner icebreakers and carrying ships of icebreaker type shows that there is a possibility of stable traffic in the hardest winter-spring period despite of adverse weather and ice conditions.

An intensive destruction of ice in the south-eastern section of the Barents Sea and in the south-western section of the Kara Sea begins in May-June under influence of sun radiation and powerful flow of the Siberian rivers and the Gulf stream. Behind the land floe there are areas of open water (polynias) which become the centers where start clearing the seas from ice and breaking down ice cover into separate parts. The Novaya Zemlya ice massif which locates along the east coast of Novaya Zemlya is the main obstacle for navigation in spring and summer . A clear water space usually remains along the west coast of the Yamal Peninsula and from Beliy Island to the Enisey Gulf. Some years the ice massif stands close to Yamal when western and north-western winds are prevailing . The navigation without icebreaker assistance begins in the south-western section of the Kara Sea already in third ten days of July after the Novaya Zemlya ice massif becomes separated from the Central Polar Basin, and heavy ice stops coming to the south, which causes fast destruction of the ice massif. However, some years the ice fields may block the shipping routes in August and even in September. This initial data characterizes operational conditions of transport scheme of LNG seaborne export and is recommended to be taken into account in the next sections of the feasibility study.

1.1.2. Basic technical decisions for LNG loading terminal in the port of Harasavey

ESTIMATED FREIGHT TRAFFIC

Export of liquefied natural gas (LNG) is estimated at 21.6 mil. t. a year.

Division of LNG export into navigational periods (taking into consideration the complicated conditions of winter navigation in ice) is executed in two variants.

Table 1.2 shows a general freight traffic of the port of Harasavey during the estimated years with the division of freight volume by variants.

Table 1.2.

No	Type of navigation and kind of freight (navigation period /variant/)	Total (removal , delivery) mil. t.	Distribution by navigation periods			
			Summer (90 days)		Winter (275 days)	
			Total	During the month of max. activity	Total	During the month of max. Activity
	I. Export of LNG (methane)					
1 2	Variant I Variant II	21,6 21,6	30% - 6,6 40% - 8,6	2,75 3,58	70% - 15,0 60% - 13,0	2,08 1,80
	II. Delivery of cargoes for construction and exploitation					
1	General and construction cargoes	0.3	0.12	0.05	0.18	0.03
2	Oil products in bulk	0.1	0.04	0.02	0.06	0.01
	In all	0.4	0.16	0.07	0.24	0.04
	Total, var. I	22.0	6.76	2.82	15.24	2.12
	Total, var. II	22.0	8.76	3.65	13.24	1.84

THE DESIGN-BASIS TYPES OF CARGO VESSELS AND ICE BREAKERS

In accordance with the stock company "CNIIMF" recommendations, the methane tanker of NGM-125A type (ULA ice class) with the carrying capacity of 125000 cu. m. is taken as a design-basis type of LNG (methane) carrier.

Besides, the possibility of using 79000 cu. m. gas carrier is considered.

Delivery of cargoes for the construction and operation from the North-Western sea ports of Russia is planned to be provided by vessels of the following types:

- in summer - SL-7 (including palletized timber carriers of "Pioner Moskvy" type);
- in winter - SA-15 ("Noril'sk type) and SA-15M;

For partial delivery of bulk oil products to the Yamal peninsula in the summer, sea tankers are chosen: the existing - of "Ventspils" and "Samotlor" types, and the new - of NO-17A type, scheduled by the "Programme of Revival of the Russian Fleet".

For the period of winter navigation, only sea vessels (of ice class) conducted by icebreakers, are to be used.

To provide a sea cargo vessel escort in ice, the liner icebreakers of "Arctica" and "Capitan Sorokin" types, with diesel and nuclear power plants respectively, are used.

Delivery of cargoes (mainly, bulk oil) to the Yamal peninsula may be performed by river-sea vessels - only under favorable ice conditions of summer navigation.

PORT MARITIME TRAFFIC

Estimated port maritime traffic depends on: total volumes of cargo traffic in both directions, the design-basis vessel size and loading rate, as well as on variants of freight traffic distribution in summer and winter.

It is obvious from the data presented, that (in dependence of variants of traffic distribution by navigation periods) the average monthly number of vessels which arrive in and depart from the port, is : in summer - from 53 to 66; in winter - from 37 to 33, which shows comparatively low navigation rate.

Total annual freight and maritime traffics are given in summary-table 1.3.

Table 1.3.

No	Traffic direction	Navigation period variant	freight traffic, thous. t.			Maritime traffic, vessels:		
			Total	Including		Total	Including	
				summer three months	winter nine months		summer three months	winter nine months
1	Arrival in the port	I II	21600 21600	6600 8600	15000 13000	388 388	127 159	261 229
2	Departure from the port	I II	400 400	160 160	240 240	388 388	127 159	261 229
	Total	I II	22000 22000	6760 8760	15240 13240	776 776	254 318	522 458

GENERAL DEMAND FOR BERTHS IN THE PORT OF KHARASAVEY

General demand for berths needed for cargo operations and vessels' standing by, by all the variants, is taken similar and shown in table 1.4.

Table 1.4.

No	Berth designation	Number of vessels	Characteristics	
			Length, running meters	Depth, meters
1	Berths for loading and discharging LNG (of bollard type) Min {max.}	4 {6}	1300 {1980}	12,7
2	Berths for loading and discharging gas condensate in perspective	1	230	11,5
3	Berths for loading and discharging general and construction cargoes	2	500	11,5
4	Bunkering berths of oil -handling terminal	1	230	12,7
5	Berths for harbor craft	1	350	6,8
6	Berth for dredging craft	1	350	6,8
	Total Min {Max}	10 {12}	2960 {3640}	

BASIC TECHNICAL AND ECONOMIC CHARACTERISTICS AND RECOMMENDATIONS ON THE PORT CONSTRUCTION

Basic technical and economic characteristics of the recommended variant of the Mys Kharasavey port are given in table 1.5.

Table 1..5.

N	Characteristic	Unit	Value
1	Estimated freight traffic, total	mil. t.	22,0
	Including:		
	export of LNG	-"-	21,6,
	cabotage , total	-"-	0,4
	including: dry cargo	-"-	0,3
	oil products	-"-	0,1
2	Total number of berths (length)	vessels (running meters)	10 (2960)
	Including (as calculated) those for:		
	- discharging LNG		4 (1300)
	- oil-handling terminal	-"-	1 (230)
	- gas condensate handling	-"-	1 (230)
	- general and construction cargoes handling	-"-	2 (500)
	- harbor and dredging craft berthing	-"-	2 (700)
	- standing-by (of gas carriers and others)		2 (650)
3	Length of the approach canal (with the axis bend through the angle of 27° to the North)	km	4,0
4	Aquatorium area	hectares	120
5	Territorium area	"	30-40
6	Average annual port manpower, total	People	587
	Including: harbor craft personnel		113
	maritime personnel		103
7	Capital investments into the port construction, total/Ist stage		
	7.1 In the prices of 1984, total	mil. r.	517,6/269,5
	Including:		
	- coastal construction		458,1/239,5
	- harbor craft		59,5/30,0
	7.2 In the prices of 1991, total	mil. r.	844,8/436,0
	Including:		
	- coastal construction		742,1/388,0
	- harbor craft		102,7/48,0
	7.3 In the USD, total	mil. USD	810,5/439,0
	Including:		
	coastal construction		745,0/390,0
	harbor craft		65,5/49,0
8	Total fixed time of the port construction	years	5

It should be stressed that during the construction of a "harbor" type port, as a rule the main disadvantage is dredging works to be made on a large scale during the Ist stage of the construction.

To make the port administration more active and to recover the capital outlay, it is also recommended to consider the use of alternative design-basis gas carriers of smaller overall dimensions as compared to NGM-125A.

For instance, when using a gas carrier of the NGM-79A type, the scale of dredging works may be considerably decreased and the construction time shortened. Besides, for a variety of reasons the handling of the NGM-79A ships (in comparison with NGM-125A) will be undeniably more preferable under ice conditions of the Harasavey port.

To improve ice conditions around the approach canal and in the port aquatorium, the use of wasted warm water from LNG plant is envisaged. To specify the technical decision on the problem, it deems necessary to carry out scientific-research works on the ice-thermal regime of the canal and the port aquatorium.

While summing up, it should be noted that the territorial and geographical position of the Harasavey port is favorable for construction of bulk handling facilities capable to handle not only LNG, but gas condensate, oil and other hydrocarbons as well.

The above products may be transported from Yamal and the Western Siberia fields through a submerged pipeline crossing over the Gulf of Ob.

So, in the future the port of Harasavey may represent an industrial port servicing construction and development of facilities at:

- the Yamal gas condensate fields (Harasavey, Kruzenstern, Bovanenko, and some others, especially coastal ones);
- the shelf high-gassy structures of the Kara Sea (Rusanov, Leningradskoye and others);
- the oil-gas fields in the Western sector of the Arctic.

1.2. Arctic going ships - methane carriers.

1.2.1. Conception of formation of the Arctic sea transport system for exports of oil and gas.

As a result of a number of factors (technical, organizational and economic), the transfer of hydrocarbon raw material production to the Northern areas and to the shelf of the Russian Arctic seas is of particular importance for the creation and regular functioning the Arctic Sea Transport System (ASTS) intended to provide the production and exports of hydrocarbon raw materials.

The first of these tasks has been solving for a long time with participation of the marine transport, and the second task is now at the projecting stage; many specialists involved in production of oil and gas in Russia consider the construction of oil and gas pipelines as preferable.

But the advantages of development of the sea transport system unlike the pipeline system, were ascribed to the following:

• sufficient flexibility in work with prospective consumers and ensuring desirable independence on external market;

• smaller specific capital investments owing to decreasing metal consumption, labor intensity, implementing progressive assembly methods of high productivity and reducing the start-up periods;

• reduction of land used for the construction of pipelines and its maintenance etc.

The oil and gas deposits situated on the shelf and on the coast of the Russian Arctic Seas, are characterized by:

• large extent of the territory of the Arctic shelf - from the Barents Sea in the West to the Bering Strait in the East;

• limited resources of some deposits, which are doomed to be exhausted for a foreseeable time interval;

• lack of the well developed infrastructure in adjoining areas of tundra zone;

• shallow water in shelf zone and small quantity of convenient sheltered and deep bays for construction of up-to-date ports or special cargo handling complexes;

•heavy ice and climatic conditions with extreme negative air temperatures.

The main problem of development of the Arctic deposits is the preservation of ecological background of vulnerable tundra zone and places of sea animals habitation in the Arctic seas covered with ice during the most part of the year, especially those places where populations can not leave an area of distress.

The listed characteristics of the Arctic zone, to a considerable extent, make the requirements to shipping policy differ from that formed and being developed in the world shipping. A general principle of decreasing transport costs, for example, by way of increasing carrying capacity of transport unit, compels us to take into account the results obtained by solution of such tasks as:

• evaluation of influence of limiting depths;

• capital investments into strengthening ship hull and providing additional power to overcome ice cover;

• capital investments for arrangement of unloading terminals, which guarantee safe and regular conditions of handling the ships in a year-round mode;

• evaluation of ecological risks;

• evaluation of reliability of ship's work under extreme conditions etc.

All of that indicates that the organization of transport of oil and gas from the Arctic deposits must be based on the developed strategy and complex calculation of costs of production, transportation and environmental protection, with prospective risks being taken into account.

To formulate the conception, let's view the terms of formation of the Arctic Sea Transport System in three aspects: technical, organizational and economical.

The **technical aspect** characterizes two versions of implementation of shipbuilding policy:

• building of the ice classified tankers with the increased ice strength, which use icebreaker assistance when running in ice in spring, winter and late autumn;

• building of icebreaking tankers which need no icebreaker assistance when sailing along the main routes in the Arctic.

In the first version, the sizes of transport ships correspond to operating potential of icebreaker fleet, ensuring work of these ships in ice.

The main requirement for the second version is the ability to sail without icebreaker assistance along the main routes, and to use icebreaker assistance in ice when maneuvering in narrow passages and in the harborage area.

At present , the development of sea transport fleet follows the first version.

The **Organizational aspect** characterizes two versions of organization of tanker fleet operations within:

1. Main waterway-feeder transport-technological system (TTS) of oil and gas exports from the Arctic deposits with transshipment at an intermediate terminal in ice free port of the Kola Peninsula (for example, the ports Pechenga, Teriberka);

2. Main waterway transport-technological system of oil and gas exports from the Arctic deposits excluding the above mentioned transshipment;

The main waterway-feeder TTS of transportation of oil and gas ensures the carriages according to two transport schemes:

• the first transport scheme includes operations of the Arctic going ships from an area of deposit to an ice-free port of the Kola Peninsula. A key task of transport by this scheme is to finish the process of production of oil (gas) and to make it meet the requirements of world standards in terms of both the product quality itself and its marketable appearance (type of a ship, quantity of goods in one shipment, time of delivery and other);

the second transport scheme - from an ice free port at the Kola Peninsula to a customer in one of the European ports, is identical to traditional world schemes of oil and gas transportation in the aspect of selection of tanker sizes and the contracted terms of carriages as well.

Main waterway TTS of oil and gas exports ensures direct carriages from an area of deposit . The main requirements to the ships (ice class, architectural-constructive type, type of engine and power etc.) in this version correspond to the requirements for the Arctic going ships of maximum dimensions in terms of cargo capacity and carrying capacity. Deadweight of the Arctic going tankers of some foreign projects varies from 120000 t up to 200000 t .

In this version, a positive task to bring the quality of the goods (oil, condensate and other) up to the world standards under conditions of the development of several deposits, could be problematical, and this fact naturally must affect the price of goods.

Domestic experience of sales of oil and gas is that hydrocarbon raw materials are transported via pipelines to our borders (trade counter), where they are sold and further transported to the consumers via the pipeline transport of foreign countries or by shipment aboard Russian or foreign ships.

This policy is effected in full measure in organization of the main waterway-feeder TTS of oil and gas exports from the Arctic deposits through an ice free port at the Kola Peninsula.

Organization of services and icebreaker fleet operations consists in a traditional form of regular cargo carriages in the Russian Arctic. The shipping companies of Russia have collected rich half century experience concerning shipping planning and management in the Arctic in the summer and winter periods of Arctic navigation; the last period involves sailing along the Dudinka route as well as experimental commercial voyages.

An economic aspect characterizes integrated cost evaluations for the versions of oil and gas export transportation from the Arctic deposits including cost analyses on: vessel construction, port handling facilities, technical supplies and storage, operating expenses depending on organizational versions, compensating expenses for environmental protection. Comparable economic evaluation of oil and gas exports carried out by domestic fleet or jointly with foreign companies must be here concerned.

In comparison with a traditional vessel, an ice going vessel is more expensive due to the ice strengthening as well as the necessity to meet some additional requirements (to output, vessel's equipment etc.). This cost increase varies from 20% - for multi-purpose vessels to 8-15% - for methane and LPG carries.

Expenses on port facility construction, technical supplies and storage in the Arctic areas will increase not only due to natural factors but also due to creation of necessary infrastructure (pioneering construction bases) .

Operational expenses are higher in the Extreme North areas due to higher current expenses connected with: icebreaker fleet, Arctic going service vessels, regional navigational systems of safe shipping as well as a certain rise of specific power cost relative to the unit of transportation product.

Final economic characteristics of the main waterway feeder TTS differ from those of the main waterway TTS in terms of costs of the ship's passages including icebreaker expenses. Increase in transportation cost, due to the transshipment at an intermediate port, is USD 6-10 on average per 1 t. of oil that might be compensated by oil refining and therefore its price will increase.

As an investment project, the main waterway feeder TTS might be realized through an Arctic productive transportation system and traditional main water way system of tankers operating in ice free seas. In this case economic evaluation of risks must also distinguish the difference between Arctic and non-Arctic operational conditions that might present certain advantages to foreign ship-owner partners who have no experience in Arctic operations.

Thus, the formation of the Arctic marine transportation system in order to provide extraction and transportation of hydrocarbon products from the Arctic areas should reasonably be substantiated on the basis of :

• organization of a reliable feeder transportation system both from the Arctic fields up to an ice-free Kola port ensuring connection between the developments of transportation and icebreaker fleets in relation to its technical and technological correspondence. Such system is a specialized chain in the productive transportation system for extraction - transportation and processing raw materials up to international standards:

• consideration of economic interests of investment project partners and indigenous people of the Extreme North according to the whole cycle: *Production-Transport-Consumption.*

1.2.2. Technical and operational requirements to the Arctic going ships (methane carriers).

In comparison with the existing ships, the methane carriers for Arctic carriages should not only be characterized by ice strengthening and propulsion power. They must meet the operational and technological requirements and recommendations for improvement of the loading particulars (specifically, architectural and constructive type and ship's cargo handling equipment) in conformity with the purpose and specific navigation conditions. In this respect, it may be reasonable and even necessary to digress from traditional marine stereotypes, for instance, while setting correlation between principal dimensions, hull shape, ship's lines etc. It may require for implementation of special research at further stages of the work.

In recent years the researches of the Institute which related to technical and operational problems of the creation of effective specialized and multipurpose ice classified ships of different functions, are devoted to: technical improvement of several parts and equipment of the carrying ships and icebreakers, increasing of ice-going capability, decreasing of damages in ice, securing of work ability under Arctic conditions etc.. The basis of these researches is long experience in ice navigation, results of the model experiments, findings of specialized institutions and theoretical estimations.

The scientific and technical progress in shipbuilding, instrument-making and mechanical engineering, especially in the field of creation and using of cold-proof materials, decreasing of fuel consumption and improvement of ecological parameters as well as the development of specific equipment, structures and others for using in the Arctic (such as pneumatic hydrowashing, new forms of icebreaking hull, system of communication in high latitudes and others) allow one to offer the new versions of ships for certain Arctic carriages as the parts of local and global transport and technological systems of different kinds, which would compete with the world traditional transport systems.

The development of high latitude routes outside of those now in use, including the land floe route already researched as well as the shortest one between the Bering Sea and the Bering Strait, removes the strict limitations of draught, which are usual for NSR regular way. In this case, it is possible to use the ships of substantially higher carrying capacity.

A prospective increasing of sizes and power of icebreakers will promote the development of cargo ships in this direction. For example: if the existing icebreaker "Arctica" with a power of 55 Mw ensures escort of cargo ships with a breadth of up to 30 m, then the designed icebreaker with a power of 66,2 Mw - up to 35 m, and the prospective icebreaker - leader (110 Mw) - up to 40 m. A permissible length of assisted ships will increase as well.

A permissible draught and dimensions of the bulk cargo ships practically determine its main parameter : the deadweight or carrying capacity. An increase in the latter favorably affects the economy of carriages which are not limited by quantity of cargoes in each cargo lot, for instance, such cargoes as gas and oil.

Moreover, when there is a lack of strict limits to dimensions of ship , the old idea of creation of new transportation and technological system arises anew; this system involves the use of icebreaking cargo ships of autonomous (or active) sailing i.e. carrying icebreakers which are not connected with icebreaker assistance at the routes of the NSR. They are designed and equipped to carry bulk cargoes, and their ice going performance is equal to the corresponding performance of the main waterway icebreakers as far as the hull strengthening and power are concerned. The versions of such transport and technological schemes have to be operationally and economically compared to the alternative (including non-Arctic), traditional or similar schemes, the feasibility of which is obvious.

Therefore, taking into account the experience of operation and designing of Arctic ships, two versions of transport and technological schemes are considered as the most realistic for functioning in the Arctic throughout the year: the use of ice going ships of ULA category with icebreaker assistance, and the use of icebreaking ships of autonomous sailing with the increased ice strengthening and increased power. It stands to reason, however, that the second version can be realized only in the distant future.

It is necessary for new Arctic ships to fulfill the requirements of modern rules of shipbuilding, which may vary depending on place and terms of their application and on the presence or absence of icebreaker assistance. In accordance with the Rules of the RF Register, the ships which operate during the whole year in the Arctic with icebreaker assistance, are classified among the ships of ULA ice-category, and the cargo ships-icebreakers - among the respective LL1 category.

The ice going capacity of a ship is defined by the power of its main engines and its weight, propellers, shape of the hull and shape of bow structures given sufficient strength, i.e. mostly by its ice category. The Rules of the Register of the USSR fixes the minimum power of the main engines for the ships of ULA category, while the power of LL1 category is defined by ice going capacity. A level of ice going capacity of ice going ships shall be defined more precisely with allowance for economic and operational factors attributed to the operating areas.

At the same time, all the latest achievements in science and technology important for designing new ships, have to be used, especially in the field of energy consumption, ergonomics, ecological friendliness, economic use of ship as a whole, and of some particular mechanisms etc. Thus, new effective means have recently been developed and tested. These means essentially contribute to the increase of ice going capacity; for example, new ship's lines, pneumatic hydrowashing etc. have been designed.

Mechanical and other ship equipment of the ships under consideration is to meet the requirements of long operations in the Arctic in terms of appropriate outputs, capacity, duplicating and reserving. It is necessary to take into consideration low temperatures of air and water, polar night conditions, and also compulsory forced measures for protection of the hard-to-restore Arctic nature environment. All of that must find a reflection in detailed technical elaboration in relation to the peculiarities of operations of different purpose ships.

Early works of the Institute have shown that for large ice-going vessels, a plant that utilizes nuclear energy is the most effective engine from the operational point of view (although there are yet problems with economics) due to a number of advantages connected with round-the-year navigation in the Arctic seas. Particularly, to supply high power engines with fuel oil, the increased expenditures for the delivery of fuel oil to areas of the Far North should be provided. However, until now, there have not been international rules regulating operations of sea commercial ships with nuclear plants aboard, i.e. calling at foreign ports and servicing these ships in foreign ports are practically impossible. Prospects of such kind of regulations are not clear. It makes meaningless to consider nuclear vessels at this stage of research.

Icebreakers and ULA ice category vessels, until recently, preferred to use electric propulsion installations which capable to increase the twisting moment while the load endured in ice conditions by the propeller, is growing. However, the efficiency of such installations is low and this fact is especially undesirable for bulk cargo vessels. This circumstance, and the best operation of the propeller in ice, can explain the design and construction of ice-breakers and ice-going carrying ships with adjustable-pitch propellers. The weak side of the latter is unsatisfactory adjustment for load fluctuations. An increase in load in ice will lead to a certain increase in twisting moment and to reduction of a pitch of the adjustable-blade propeller and of energy input, and, as a consequence of the above, to decrease in ice-going capacity and speed as well. According to some specialists' opinions, this circumstance can affect negatively the efficiency of ship in ice as compared to diesel-electric vessel. This disadvantage of the adjustable-pitch propeller may be corrected to a certain degree by inertial fly-wheels fixed on a shaft and through improvement of automatic engine control.

The efficiency of adjustable-pitch propeller used in ice going diesel ships is also determined by conditions of continuous maneuvering in ice.

In order to protect propellers from damage, ballast tanks volume in ice going ships must provide deeper draught in ice than the draught required for conventional vessels in ice-free water; actually the draught must be close to cargo draught. To provide it, an increased volume of isolated ballast tanks is required for ice-going tankers.

The double skins and double bottom must be provided for Arctic tankers as well as for regular tankers. Double structures, apart from protection against accidental spillage, decreases expenses for cargo heating and increases the volume of isolated ballast tanks. The role of double skins for ice going tankers becomes vitally important because of the frequent hull damages when sailing in ice. To decrease heat losses of cargo in winter, an upper deck shall be doubled in the tank area, with under deck tanks installed along the ship's sides in places where it is possible to dispose an isolated ballast as is the case with the bulk-tankers. To facilitate and to expedite the process of tank washing, it is reasonable to have the ship provided with vertically corrugated transverse bulkheads and longitudinal bulkheads in the center line.

From two feasible versions of power plant (diesel and diesel-electrical) of ice going tankers, a diesel plant with direct transmission to the controllable pitch propeller can be recommended as the cheapest one with lower fuel consumption. Taking into consideration the possible reduction of speed in ice when using a controllable pitch propeller, a special elaboration can be dedicated to select a power plant type for certain ice going tankers.

The slow speed diesel is recommended for the main engine of ice going oil carrier, modern models of which ensure lower fuel consumption as compared to the middle speed diesel; dimensions of aft extremities of large tankers enable us to allocate a diesel rationally.

In the operation of gas carriers with cargo capacity of 30-135 thous. cu. m, the steam turbine or diesel of traditional world and domestic manufacturing is used as the main engine. The diesels have lower fuel consumption, but steam turbines are easier adjustable to use evaporating methane. Utilization of evaporating gas to a considerable degree neutralizes the main deficiency of the steam turbine unit - high fuel consumption, especially perceptible with high power of the main engines. A steam-turbine unit can be profitable for a gas carrier -

icebreaker because of comparatively small dimensions, absence of the developed boiler unit and possible use of evaporating methane as a fuel.

For the ice going gas carriers as well as for oil carriers at this stage of elaboration, the low speed diesels are recommended as main engines. Final selection of type of power plant for ice going gas carriers is possible at further stages of working on technical proposals or directly when projecting.

A spherical shape of cargo tanks is recommended for the ice going gas carriers in accordance with assessments of many specialists; it is the safest structure when working in ice. In this case, a close-to-minimum specific surface of tanks, and consequently, the least heating of cargo and the least evaporation are ensured .

The Rules of the Register of Russia do not allow one to operate unattended mechanical equipment when sailing in ice, i.e. an automation class is not higher than A2. Taking into consideration a great extent of ice-free water areas occurred in possible voyages and the increased operational expenditures in the Arctic, it is possible to recommend an automation sign that corresponds to class "Watch-1" of Norwegian Veritas. In this case ship's crew can be reduced to 18-25 members.

1.2.3. Choosing the row of types and sizes

In case of the year-round delivery of gas from the Yamal Peninsula without transshipment in intermediate ports, there are two possible versions of TTS operations with the use of:

- gas carriers - icebreakers of LL1 ice category;
- Arctic going gas carriers of ULA ice category, working with icebreaker assistance.

As for the second version of TTS , the most realistic at the present moment is to make use of icebreakers of "Arctica" type and in perspective - of "Yamal" type icebreakers with a power of 66 Mw, and an icebreaker - leader with a power of 110 Mw.

In accordance with the recommendations of work (4), length and breadth of a gas carrier following an icebreaker, are determined depending on icebreaker's dimensions. The breadth of gas carrier should not exceed the breadth of an icebreaker by more than 2 m. The dimensions of the present icebreakers of "Arctica" type and of perspective "Yamal" and "Leader" types make it possible to get a row of types and sizes of prospective gas / methane carriers:

- Arctic going tanker/ gas - methane carrier with a cargo capacity of about 39 thous. cu. m. of LNG (code NGM-39A). The breadth is about 30 m., length - about 180 m., draught with cargo - 9.8 m.;

- Arctic going tanker/ gas - methane carrier with a cargo capacity about 67 thous. cu. m of LNG (code NGM-67A). The breadth is about 36 m, length - about 220 m, draught with cargo - 10.4 m.;

- Arctic going tanker/ gas - methane carrier with a cargo capacity about 92 thous. cu. m. of LNG (code NGM-92A). The breadth is about 40 m, length - about 240 m, draught with cargo - 10.7 m;

- Arctic going tanker/ gas - methane carrier with a cargo capacity about 125 thous. cub. m of LNG (code NGM-125A). The breadth is about 44 m, length - about 270 m, draught with cargo - 11.3 m;

- Arctic going tanker/ gas - methane carrier with a cargo capacity about 135 thous. cu. m of LNG (code NGM-135A). The breadth is about 45 m, length - about 290 m, draught with cargo - 11.7 m.

The last two ships included in the row, show trends of the development of world gas carrier shipbuilding and practice of transportation of liquefied natural gas of the fixed volumes and distance of carriage. These ships will demand the increased expenses for icebreaker assistance, thus, the construction and operation of gas carriers of this type and size require an additional feasibility study.

An additional limitation for the main dimensions of gas carriers except of the dimensions of building place at domestic shipyards, permits us to include in this type/size row the Arctic going tanker/ gas - methane carrier with a cargo capacity of 79 thous. cu. m of LNG (code NGM-79A). It has a breadth of about 38 m, length - about 230 m, draught with cargo - 10.6 m.

In view of the above, we get the rated type/size row as follows: NGM-39A, NGM-67A, NGM-79A, NGM-92A, NGM-125A, NGM-135A. The main dimensions and main characteristics of these types of gas carriers are listed in Tables 1.6, 1.7.

Table 1.6

MAIN CHARACTERISTICS OF GAS CARRIERS NGM-39A, NGM-67A, NGM-79A, NGM-92A AND NGM-125A FOR THE MAIN WATERWAY SCHEME OF LNG TRANSPORTATION ON THE LINE YAMAL - WESTERN EUROPE

Gas-carrier type	**CNIIMF**				
	NGM - 39À	**NGM - 67À**	**NGM - 79À**	**NGM- 92À**	**NGM- 125À**
Ice class	ULA	ULA	ULA	ULA	ULA
Length L bp , m	178.00	220.00	232.00	245.00	269.00
Breadth B, m	30.00	36.00	38.00	40.00	44.00
Depth H, m	18.00	21.00	22.00	23.50	24.70
Draught T, m	9.80	10.35	10.60	10.75	11.30
Coefficient of corpulence	0.730	0.735	0.740	0.745	0.753
Displacement D, t.	39140	61750	70870	80450	103180
Diameter of cargo tank, m	25.08	30.10	31.77	33.44	36.96
Capacity W, cu. M	39040	67460	79350	92540	124950
Carrying capacity P, t	18750	32400	38100	44440	60000
Deadweight DW, t	21300	35900	41930	48090	64190
Mark of the main engine	B&W	B&W	B&W	B&W	B&W
Output of the main engine, nominal N, kW	15600	19500	21000	23500	29000
Open water speed V, kn.	17.00	17.40	17.60	17.80	18.50
Transmission type	direct	direct	direct	direct	direct
Type of propeller	CPP	CPP	CPP	CPP	CPP
pumps :supply cu. m/hour m	10*350	10*600	10*750	10*800	10*1200
pressure, m of water	100	120	120	125	125

The use of Arctic going methane carriers with a cargo capacity of 125 and 135 thous. cub. m permits us: to reduce substantially the need in the ships required to carry the planned volume of cargo, to hold working efficiency of the transport system on a level of alternative world LNG carriages by sea.

The main characteristics of the developed versions are listed in Table 1.7. It can be seen from the Table that the ice going capacity, and hence the output of the main engine have varied for these ships.

As a rule, a kind of power plant and the power of the main engine of ice going ships are determined depending on the necessity to move in ice and on the fixed ice going capacity as well. Economically warranted speed in ice-free water is achieved with a partial use of power, which is 30-65% of N nom. However, taking into consideration high price of methane carrier, it may occur that the most effective speed can be achieved with more or less full use of the power. For this purpose, for the developed row of the ships, speeds have been determined both with full and with partial load of the engines.

Table 1.7.

MAIN CHARACTERISTICS OF GAS CARRIERS NGM-135A AND NGM-135 LL1 FOR THE MAIN WATERWAY SCHEME OF LNG TRANSPORTATION ON THE LINE YAMAL-WESTERN EUROPE

Type of gas carrier	CNIIMF				
	NGM	NGM	NGM	NGM	NGM
Ice class	ULA	ULA	ULA	LL1	LL1
Ice going capacity h, m	1.10	1.35	1.50	1.50	1.65
Length max., L max., m	292.00	292.00	292.00	322.50	322.50
Length L bp, m	281.00	281.00	281.00	308.50	308.50
Breadth B, m	44.80	44.80	44.80	45.00	45.00
Depth H, m	25.00	25.00	25.00	25.00	25.00
Draught T, m	11.53	11.65	11.70	11.76	11.80
Coefficient of corpulence	0.740	0.740	0.740	0.720	0.720
Displacement D, t.	110100	111240	111700	122750	122950
Diameter of cargo tank, m	37.86	37.86	37.86	37.86	37.86
Capacity W, cu m (100%)	137900	137900	137900	137900	137900
Capacity W1, cu m (98%)	135150	135150	135150	135150	135150
Carrying capacity , P, t.	66220	66200	66200	66200	66200
Deadweight DW, t.	70250	70000	70000	71100	71125
Mark of main engine	B&W	B&W	B&W	B&W	B&W
	2*6L80MC	2*8L80MC	3*8L80MC	3*8L80MC	3*8L90MC
Output of main engine, nominal N, kW	31000	56400	76000	73000	96000
operational N1	27900	50760	68400	65700	86400
open water N2	27900	31000	31000	35600	35600
Open water speed under N2 V, kn.	18.30	19.00	19.00	19.00	19.00
Open water speed under N1 V,	kn18.30	22.30	24.60	23.70	25.60
Transmission type	direct	direct	direct	direck	direct
Type of propeller	CPP	CPP	CPP	CPP	CPP
pump-s: supply cu. m/hour	10*1400	10*1400	10*1400	10*1400	10*1400
pressure, m of water	140	140	140	140	140

As it was noticed in previous section, the absolute majority of the methane carriers of the discussed class has STP as the main engine, and only some methane carriers have a low speed diesel (LSD).

Methane as a fuel is easier to use for a steam turbine plant; methane has fewer price, but when using oil fuel, such plant has a specific consumption which is substantially higher than that required for a low speed diesel.

When comparing STP and LSD, it is obvious that the consumption of liquid fuel is more preferable for diesel power plant. Moreover, as for materials of MAN-B&W Company, an opportunity arose to make this advantage more clear, using a version of gas and diesel power plant.

Taking into consideration negative domestic experience of STP operation and a number of defects of this plant, the versions of the methane carriers have been developed, which have LSD as the main engine (see Table 1.7) and as an alternative - a number of versions of methane carriers with STP. The main characteristics of the methane carriers with STP are listed in Table 1.8.

Table 1.8.

MAIN CHARACTERISTICS OF GAS CARRIERS NGM-135A AND NGM-135ALL1 FOR THE MAIN WATERWAY SCHEME OF LNG TRANSPORTATION ON THE LINE YAMAL-WESTERN EUROPE*

Gas-carrier type	CNIIMF				
	NGM - 135À	NGM-135A1	NGM - 135À1	NGM-135LL1	NGM - 135LL1
Ice class	ULA	ULA	ULA	LL1	LL1
Ice going capacity h, m	1.10	1.35	1.50	1.50	1.65
Length max., L max., m	292.00	292.00	292.00	322.50	322.50
Length L bp, m	281.00	281.00	281.00	308.50	308.50
Breadth B, m	44.80	44.80	44.80	45.00	45.00
Depth H, m	25.00	25.00	25.00	25.00	25.00
Draught T, m	11.41	11.51	11.58	11.64	11.72
Coefficient of corpulence	0.740	0.740	0.740	0.720	0.720
Displacement D, t.	109000	109900	110600	119250	120070
Diameter of cargo tank, m	37.86	37.86	37.86	37.86	37.86
Capacity W, cu m (100%)	137900	137900	137900	137900	137900
Capacity W1, cu m (98%)	135150	135150	135150	135150	135150
Carrying capacity P, t.	66220	66200	66200	66200	66200
Deadweight DW, t.	69170	69370	69370	69760	69780
Type of main engine	B&W	B&W	B&W	B&W	B&W
Output of main engine, nominal N, kW	28000	51000	68800	66000	87000
operational N1	28000	51000	68800	66000	87000
open water N2	28000	31000	31000	35000	35000
Open water speed under N2 V, kn.	18.35	19.00	19.00	19.00	19.00
Open water speed under N2, V, kn.	18.35	22.35	24.60	23.45	25.70
Type of propeller	CPP	CPP	CPP	CPP	CPP
Pump-s: supply cu. m/hour	10*1400	10*1400	10*1400	10*1400	10*1400
Pressure, m of water	140	140	140	140	140

Economic efficiency of the main waterway scheme of gas transportation is discussed in further sections.

It is also possible to use a version of the main waterway - feeder scheme of LNG transportation, when from the area Yamal-Teriberka gas is transported by gas carrier of ULA class and from the area Teriberka-Western Europe - by gas carrier without any ice class. For this case there have been considered prospective generations of the gas carriers for LNG transport with a cargo capacity of 165 thous. cu. m for the period of up to 2005 with further increasing of cargo capacity up to 200 thous. cu. m; their characteristics are introduced in Table 1.9.

Table 1.9.

MAIN CHARACTERISTICS OF NON ICE GOING GAS CARRIERS

Gas-carrier type	NGM	NGM	NGM
Number of spherical cargo tanks	5	4	5
Length max., L, m	301.80	286.00	328.00
Length L bp., m	290.80	275.00	317.00
Breadth B ,m	47.80	50.50	50.50
Depth H, m	27.00	27.00	28.00
Draught T, m	12.10	12.25	12.60
Coefficient of corpulence	0.709	0.700	0.707
Displacement D, t.	122230	122060	146200
Diameter of cargo tank	40.46	43.20	43.20
Capacity W, cu m (100%)	168370	168770	204940
Capacity W1, cu m (98%)	165000	165400	200840
Carrying capacity P, t.	80850	81040	98400
Deadweight DW, t.	84770	84960	101930
Type of main engine	B&W	B&W	B&W
Output of main engine, max. N, kW	42000	42000	65000
operational N1, kW	42000	42000	65000
Open water speed under V, kn.	20.50	20.55	23.00
pump-s: supply cu m /hour	10*1400	8*1650	10*1650
pressure, m of water	140	140	140
Ice class	Л3	Л3	Л3

If a constructive type of five spherical cargo tanks has been chosen for ice classified methane carriers, a number of cargo tanks for methane carriers of ice-free sailing lies within 4 - 5 items.

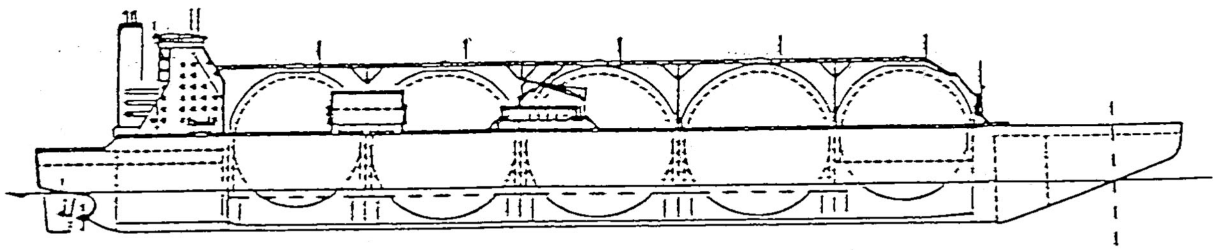
The decreasing of a number of cargo tanks will allow one to decrease the weight and cost of cargo tanks and the length and cost of hull as well. However, as a result of it the breadth of hull is increased, that results, for the ships with ice strengthening, in sharp increase of ice resistance and required power. Therefore a version with four cargo tanks has not been considered for the ships of ULA and LL1 classes.

The STR is proposed as the main engine at non ice-classified gas carriers. In addition, a potential opportunity of using only methane as a fuel carried by these ships, is taken into account. In this case the main deficiency of steam turbine plant - large consumption of liquid fuel, is neutralized. It can turn to be economically effective to use as a fuel only methane carried by the ships.

The schemes of general arrangement for gas carrier of ULA class with five spherical cargo tanks and non ice-classified gas carrier with four and five spherical cargo tanks are shown in Fig. 2 and 3(a, b).

SCHEME OF GENERAL ARRANGEMENT OF ICE GOING GAS CARRIER FOR LNG TRANSPORT WITH A CARGO CAPACITY OF ABOUT 135000 cub. m

Fig.2



Principal particulars:

Main engine output, kW	31000	56400	76000
Ice going capacity, m	1.10	1.35	1.50
Length overall, m	292.0	292. 0	292.0
Length BP, m	281.0	281. 0	281.0
Breadth, m	44.8	44. 8	44.8
Depth, m	25.0	25. 0	25.0
Draught, m	11.53	11.65	11.70
Cargo tanks volume (100%), cu. m	137, 900	137, 900	137, 900
Cargo tanks volume (98), cu. m	135, 150	135, 150	135, 150
Deadweight, t.	70, 250	70, 000	70, 000
Speed, kn.	18.3	22.3	24.6

SCHEME OF GENERAL ARRANGEMENT OF NON ICE GOING GAS CARRIER FOR LNG TRANSPORT WITH A CARGO CAPACITY OF 165000 cub. m

Fig.3-a (five cargo tanks)

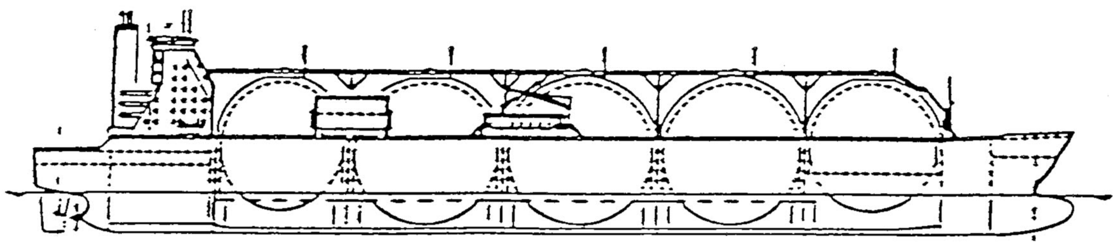
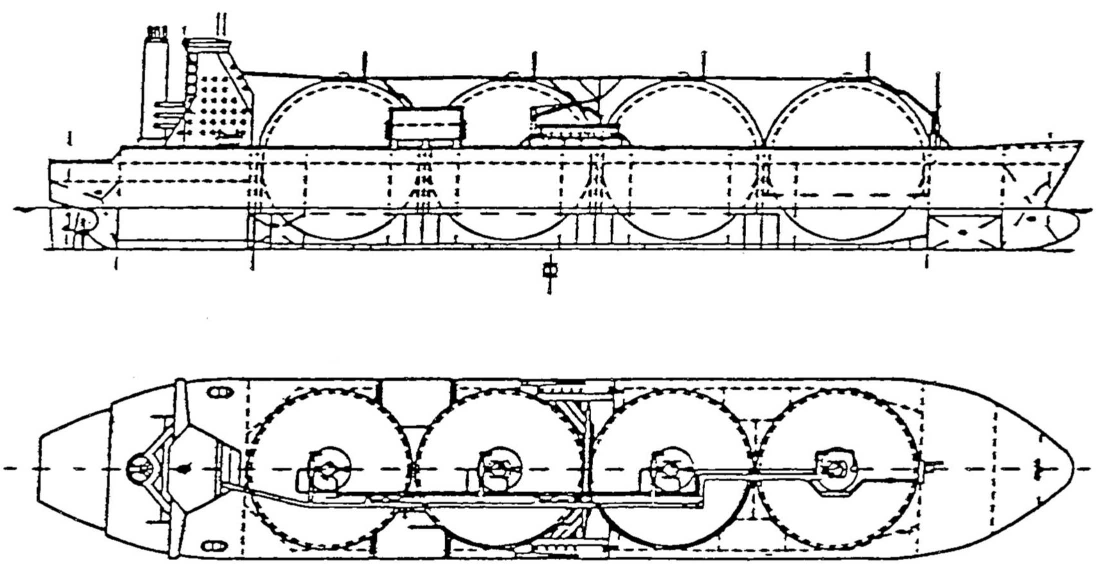


Fig.3-b (four cargo tanks)



Principal particulars:

Number of cargo tanks	5	4
Length overall, m	301.8	286. 0
Length BP, m	290.8	275. 0
Breadth, m	47.8	50. 5
Depth, m	27.0	27. 0
Draught, m	12.10	12.25
Cargo tanks volume (100%), cu. m	168, 370	168, 770
Cargo tanks volume (98), cu. m	165, 000	165, 400
Deadweight, t.	84, 770	84, 960
Speed, kn.	20.50	20.55

Daily fuel consumption

Calculation of daily fuel consumption for a row of gas carriers NGM-39A - NGM-125A is introduced in Table 1.10.

In Tables 1.11 and 1.12, the daily fuel consumption is introduced for ice going gas carriers with a cargo capacity of 135 thous. cu. m. each for the whole row of gas carriers of variable power in the case of full and a partial use of power when sailing in ice-free water. Data on the methane carriers with LSD plant is in Table 1.11 and with STP - in Table 1.12.

Calculation of daily fuel consumption for non ice-class gas carriers with a cargo capacity 165 and 200 thous. cu. m., which are used in the main waterway - feeder scheme, is introduced in Table 1.13.

Table 1.10.

FUEL CONSUMPTION OF THE ARCTIC GOING GAS CARRIERS OF LNG - 135A AND LNG - 135LL1 TYPES

	NGM - 39A	NGM - 67A	NGM - 79A	NGM - 92A	NGM - 125A
Type of main engine	SSD	SSD	SSD	SSD	SSD
Output max., kW	18000	22500	24200	27000	33500
Operational output N1=0.9Nmax, kW	15600	19500	21000	23500	29000
Speed, kn.	18.3	22.3	17.6	17.8	18.5
Oil fuel consumption					
Qt, gr./kW hour	162	165	167	163	163
t./ day.	70.0	77.2	84.2	91.9	113.4
Boiling methane quantity					
cu. m / day.	70.2	120.6	142.2	165.6	225.0
t./ day.	34.4	59.1	69.7	81.1	110.3
Fuel consumption at sea	need. - 70 t. Black oil or 59.1 t. of methane	need. - 77 t. black oil or 65 t. of methane	need. - 84 t. black oil or 70.9 t. of methane	need. - 96 t. black oil or 81 t. of methane	need. - 114 t. black oil or 96.2 t. of methane
	Boiling gas is useful 34.4 t +29 t. Black oil (59% of gas)	Boiling gas is useful 59.1t +7 t. black oil (abt.91% of gas)	Boiling gas is useful 69.7t +2 t. black oil (abt.97% of gas)	Boiling gas is useful 81.1t. +0 t. black oil (abt.100% of gas)	Boiling gas is useful 110.3t. +0 t. black oil (abt.100% of gas)
Fuel consumption at sea in ballast	need. - 70 t. Black oil (34.4 t. of gas +29 t. black oil)	need. - 77 t. black oil (59.1 t. of gas +7 t. black oil)	need. - 84 t. black oil (69.7 t. of gas +2 t. black oil)	need. - 92 t. black oil (81.1 t. Of gas +0 t. black oil)	need. - 114 t. black oil (81.1 t. of gas +0 t. black oil)
Fuel consumption at the port under handling a day	24 t. Diesel oil	26 t. diesel oil	28 t. diesel oil	31 t. diesel oil	38 t. Diesel oil
Fuel consumption at the port without handling (a day)	4 t. Black oil	4.5 t. black oil	4.6 t. black oil	5.2 t. black oil	6.3 t. black oil

Table 1.11. CONSUMPTION OF THE ARCTIC GOING GAS CARRIERS OF LNG - 135A AND LNG - 135LL1 TYPES

	NGM - 135A	NGM - 135A1	NGM - 135A2	NGM - 135LL1	NGM - 135LL1
Type of main engine	SSD	SSD	SSD	SSD	SSD
Mark of main engine	2*6L80MC	2*8L80MC	3*8L80MC	3*8L80MC	3*8L90MC
Output max. ,kW	31000	56400	76000	73000	96000
Operational output N1=0.9Nmax, kW	27900	50760	68400	65700	86400
Speed, kn.	18.3	22.3	24.6	23.7	25.6
Oil fuel consumption					
Qt, gr./kW hour	170	170	170	170	170
t./ day.	114.0	208.0	280.0	269.0	353.0
Boiling methane quantity					
cu. m. / day.	202.5	202.5	202.5	202.5	202.5
t./ day.	99.2	99.2	99.2	99.2	99.2
Fuel consumption at sea Laden per day under N1=0.9 N max.	need. - 114 t. black oil or 95.7 t. of methane	need. - 208 t. black oil or 174.2 t. of methane	need. - 280 t. black oil or 234.7 t. of methane	need. - 269 t. black oil or 225.4 t. of methane	need. - 353 t. black oil or 296.5 t. of methane
	Boiling gas is useful only +0 t. black oil (100% of gas)	Boiling gas is useful only 99.2 +90ò t. black oil (abt. 57% of gas)	Boiling gas is useful only 99.2 +162 t. black oil (abt. 40% of gas)	Boiling gas is useful only 99.2 +141 t. black oil (abt. 44% of gas)	Boiling gas is useful only 99.2 +238 t. black oil (abt. 33% of gas)
Fuel consumption at sea In ballast	need. - 114 t. black oil (95.7 t. of gas +0 t. black oil)	need. - 208 t. black oil (99.2 t. of gas +90 t. black oil)	need. - 280 t. Black oil (99.2 t. of gas +162 t. black oil)	need. - 269 t. black oil (99.2 t. of gas +141 t. black oil)	need. - 353 t. black oil (99.2 t. of gas +238 t. black oil)
Main engine output at open water N, kW	27900	31000	31000	35600	35600
Speed, kn.	18.3	19.0	19.0	19.0	19.0
Oil fuel consumption					
Qt, gr./kW hour	170	170	170	170	170
t./ day.	114.0	127.0	127.0	145.0	145.0
Boiling methane quantity					
cu. m. / day.	202.5	202.5	202.5	202.5	202.5
t./ day.	99.2	99.2	99.2	99.2	99.2
Fuel consumption at sea Laden per day under N1= N	need. - 114 t. black oil or 95.9 t. of methane	need. - 127 t. black oil or 106.8 t. of methane	need. - 127 t. black oil or 106.8 t. of methane	need. - 145 t. black oil or 122 t. of methane	need. - 145 t. black oil or 122 t. of methane
	Boiling gas is useful only +0 t. black oil (100% of gas)	Boiling gas is useful only 99.2 +9 ò t. black oil (abt. 93% of gas)	Boiling gas is useful only 99.2 +9 ò t. black oil (abt. 93% of gas)	Boiling gas is useful only 99.2 + 27 t. black oil (abt. 81% of gas)	Boiling gas is useful only 99.2 + 27 t. black oil (abt. 81% of gas)
Fuel consumption at sea In ballast	need. - 113.8 t./ black oil (95.7 t. of gas +0 t. black oil)	need. - 127 t. black oil (99.2 t. of gas +9 t. black oil)	need. - 127 t. black oil (99.2 t. of gas +9 t. black oil)	need. - 145 t. black oil (99.2 t. of gas +27 t. black oil)	need. - 145 t. black oil (99.2 t. of gas +27 t. black oil)
Fuel consumption at the port under handling (a day)	30 t. Diesel oil	30 t. Diesel oil	30 t. Diesel oil	30 t. Diesel oil	30 t. Diesel oil
Fuel consumption at the port without handling (a day)	6 t. black oil	6 t. black oil	6 t. black oil	6 t. black oil	6 t. black oil

Table 1.12.

CONSUMPTION OF THE ARCTIC GOING GAS CASSIERS OF LNG - 135A AND LNG - 135LL1 TYPES

	NGM - 135A	NGM - 135A1	NGM - 135A2	NGM - 135LL1	NGM- 135LL1
Type of main engine	ST	ST	ST	ST	ST
Output max., kW	28000	51000	68800	66000	87000
Operational output N1=Nmax,kW	28000	51000	68800	66000	87000
Speed, kn.	18.35	22.35	24.60	23.5	25.7
Oil fuel consumption					
Qt, gr./kW hour	310	310	310	310	310
t./ day.	209	380	512	491	648
Boiling methane quantity					
cu. m / day.	202.5	202.5	202.5	202.5	202.5
t./ day.	99.2	99.2	99.2	99.2	99.2
Fuel consumption at sea Laden per day under N1=Nmax	need. - 209 t. Black oil or 175.8 t. of methane	need. - 380 t. black oil or 319.6 t. of methane	need. - 512 t. black oil or 430.5 t. of methane	need. - 491 t. black oil or 413 t. of methane	need. - 648 t. black oil or 545 t. of methane
	Boiling gas is useful 99.2 +91 t. black oil (abt. 56% of gas)	Boiling gas is useful only 99.2 +262 t. black oil (abt. 31% of gas)	Boiling gas is useful 99.2 +394 t. black oil (abt. 20% of gas)	Boiling gas is useful 99.2 +373 t. black oil (abt. 24% of gas)	Boiling gas is useful 99.2 +530 t. Black oil (abt. 18% of gas)
Fuel consumption at sea in ballast	need. - 209 t. black oil (99.2 t. of gas +91 t. black oil)	need. - 380 t. black oil (99.2 t. of gas +262 t. black oil)	need. - 512 t. black oil (99.2 t. of gas +394 t. black oil)	need. - 491 t. black oil (99.2 t. of gas +373 t. black oil)	need. - 648 t. Black oil (99.2 t. of gas +530 t. black oil)
Main engine output at open water N, kW	28000	31000	31000	35000	35000
Speed, kn.	18.4	19.0	19.0	19.0	19.0
Fuel consumption at sea Laden per day under N1= N	need. - 209 t. black oil or 175.8 t. of methane	need. - 231 t. black oil or 194.3 t. of methane	need. - 231 t. Black oil or 194.3 t. of methane	need. - 261 t. Black oil or 219.5 t. of methane	need. - 261 t. black oil or 219.5 t. of methane
	Boiling gas is useful 99.2 +91 t. black oil (abt. 56% of gas)	Boiling gas is useful 99.2 +113 t. Black oil (abt. 51% of gas)	Boiling gas is useful 99.2 +113 t. Black oil (abt. 51% of gas)	Boiling gas is useful 99.2 +143 t. Black oil (abt. 45% of gas)	Boiling gas is useful 99.2 +143 t. black oil (abt. 45% of gas)
Fuel consumption at sea in ballast	need. - 209 t. black oil (99.2 t. of gas +91 t. black oil)	need. - 231 t. Black oil (99.2 t. of gas +113 t. black oil)	need. - 231 t. Black oil (99.2 t. of gas +113 t. black oil)	need. - 261 t. Black oil (99.2 t. of gas +143 t. black oil)	need. - 261 t. Black oil (99.2 t. of gas +143 t. black oil)
Fuel consumption at the port under handling a day	30 t. Diesel oil	30 t. Diesel oil	30 t. diesel oil	30 t. Diesel oil	30 t. Diesel oil
Fuel consumption at the port without handling (a day)	6 t. black oil	6 t. black oil	6tn black oil	6 t. black oil	6 t. black oil

Table 1.13.

FUEL CONSUMPTION OF NON ICE GOING GAS CARRIERS OF NGM-165 AND NGM-200 TYPES

	NGM-165	NGM-200
Type of propulsion	Steam turbine	Steam turbine
Output of main engine N max., kW	42000	65000
Operational output N1,kW	42000	65000
Speed, kn.	20.5	23.0
Oil fuel consumption		
Qt, gr./kW hour	312	312
t./a day	314	487
Boiling methane quantity		409,4
cu. m/day	247,5	300.0
t./day	121,3	147
Fuel consumption at sea laden (day)	need - 314 t fuel oil or 264,5 t methane	need - 487 t fuel oil or 409,4 t methane
	might use 99.2t gas +91 t fuel oil (abt.56% gas)	might 99.2t gas +262 t fuel oil (abt31% gas)
Fuel consumption at sea in ballast (a day)	need - 209 t fuel oil (99.2t gas+91 t fuel oil)	need - 380 t fuel oil (99.2t gas+262 t fuel oil)
Fuel consumption at port under handling without handling	30 t. diesel oil	30 t .diesel oil

1.2.4. Feasibility study of type and size row.

Estimation of building cost.

The building of a methane carrier from the inception of this kind of shipping trade till nowadays, is an extra-ordinary event for shipbuilding industry.

Such state of things is connected first of all with the two economical factors: high specialization and ultra high capital investments in these ships.

The first factor is accounted for the fact that there are no ships - methane carriers on the free world freight market and that navigation of these ships is severely restricted by the terminals for loading and unloading of LNG which they are bound to use.

The second factor can be explained by specific features of the cargo. At the expense of cost of cryogenic equipment and, in particular, of durable and strong materials for ensuring secure and safe transport of LNG with a temperature of about- 160 C, a building cost of methane carrier is about 10 times higher than the price of any other transport ship of the same deadweight. The above- mentioned stipulates building of the ships - methane carriers in connection with a certain long term contract for delivery of LNG that includes the guarantees of the compliance with the provisions made at a Government level.

It is not possible to give in detail the components of the building cost of methane carriers on the basis of open statistics because the international special periodical press gives extremely scanty information on this problem and, besides, there are complete absence of domestic experience of building of such ships. According to the Lloyd's data it is known that an average building cost of a methane carrier, built in the Far East, was (in million dollars):

Years	Average cost of the vessel USD, mil.		Specific cost of one cu. m. USD ths./a ton	
	Capacity of the vessel ths cu. m		Capacity of the vessel ths cu. m	
	75 cu. m LNG	125 cu. m LNG	75 cu. m LNG	125 cu. m LNG
1991	175.0	260.0	2.33	2.08
1992	165.0	230.0	2.20	1.84
1993	150.0	225.0	2.00	1.80
1994	150.0	255.0	2.00	2.04
1995	150.0	255.0	2.00	2.04

Source: "Lloyd's Shipping Economist" June 1995 data

Information about certain contracts for the construction of methane carriers which could be found in special periodical press was generally related to the building of small series of such ships put into service in 1994-1997 (up to 10 units) with a capacity of 125-135 thousand cu. m. of LNG. The tentative contract prices of these vessels were close to the Lloyds average price, moreover, the cost of methane carrier with a capacity of 135 thousand cu. m. of LNG, constructed by the Scandinavian company "Kvaerner" was lower than the tentative costs of 125 thousand cu. m methane carriers of South Korea and Japan construction, which may be explained apparently by the policy of protectionism pursued by these two States which are also, owing to their geographic location, the largest world consumers of LNG carried by sea.

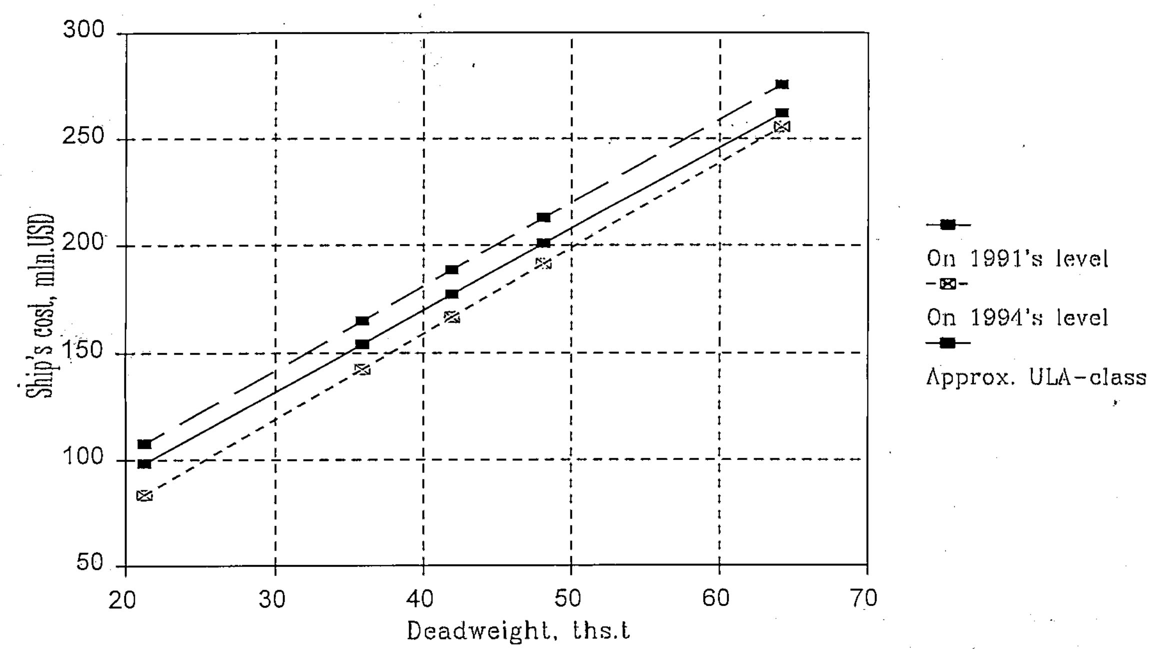
However the methodical elaborations of CNIIMF makes it possible to calculate, with sufficient correctness, the technical-operational characteristics of types and sizes of the Arctic going methane carriers which comply with the requirements to different versions of the main waterway and main waterway-feeder carriages of LNG by sea for export from the Arctic regions of Russia. Owing to this fact, it became possible to carry-out an analytical estimation of specific building expenses for ordinary ship - methane carrier without any ice strengthening. The deadweight of a methane carrier increased by a ton was considered to result in potential increase of its capacity at 1.8-1.9 cu. m of LNG.

In this case the building cost increases practically in direct proportion to the increasing of vessel's cargo capacity since the specific building cost expressed with reference to one ton of deadweight, changes very slightly. Such thing is easy to explain, if the aggregated components of methane carrier's cost is taken into account. It was accepted by experts that the cost of hull and engine of a ship - methane carrier was comparable with the cost of a bulk-carrier of the corresponding deadweight. Approximation of the Lloyd's data for bulk-carriers of a deadweight from 20 to 70 thousand tons gave the values within the range of 18 to 28 million dollars respectively. These values for the tankers would be at 40-50% higher but they would include the costs of tanks and special equipment which are fairly large but the order of these costs are not comparable with the order of costs of cryogenic equipment required for methane carrier.

Consequently, from 70 to 85% of building cost of a methane carrier lies with special equipment determined by cargo features. Moreover, the bigger is the deadweight of such a ship, the larger can be the share of special equipment. In particular, these circumstances can explain the fact that specific building costs expressed with reference to one cu. m. of capacity for a ship of 75 thousand tons in accordance with the Lloyd's data of 1994, are lower than that for a ship of 125 thousand cu. m. capacity. But some subjective factors such as changing of market situation and small statistical samples may not be excluded. On the whole, a trust interval of possible range of building costs of the developed type of ships - methane carriers is shown in Fig.4 (a) and (b).

Fig.4(a) reflects a field of the most probable values of the building cost of the type of methane carriers with a cargo capacity of 39 to 135 thous. cu. m. of LNG, with the increase of costs, when building ULA class ships, being taken into account.

Fig. 4(a) Calculated average cost of building LNG-carriers.



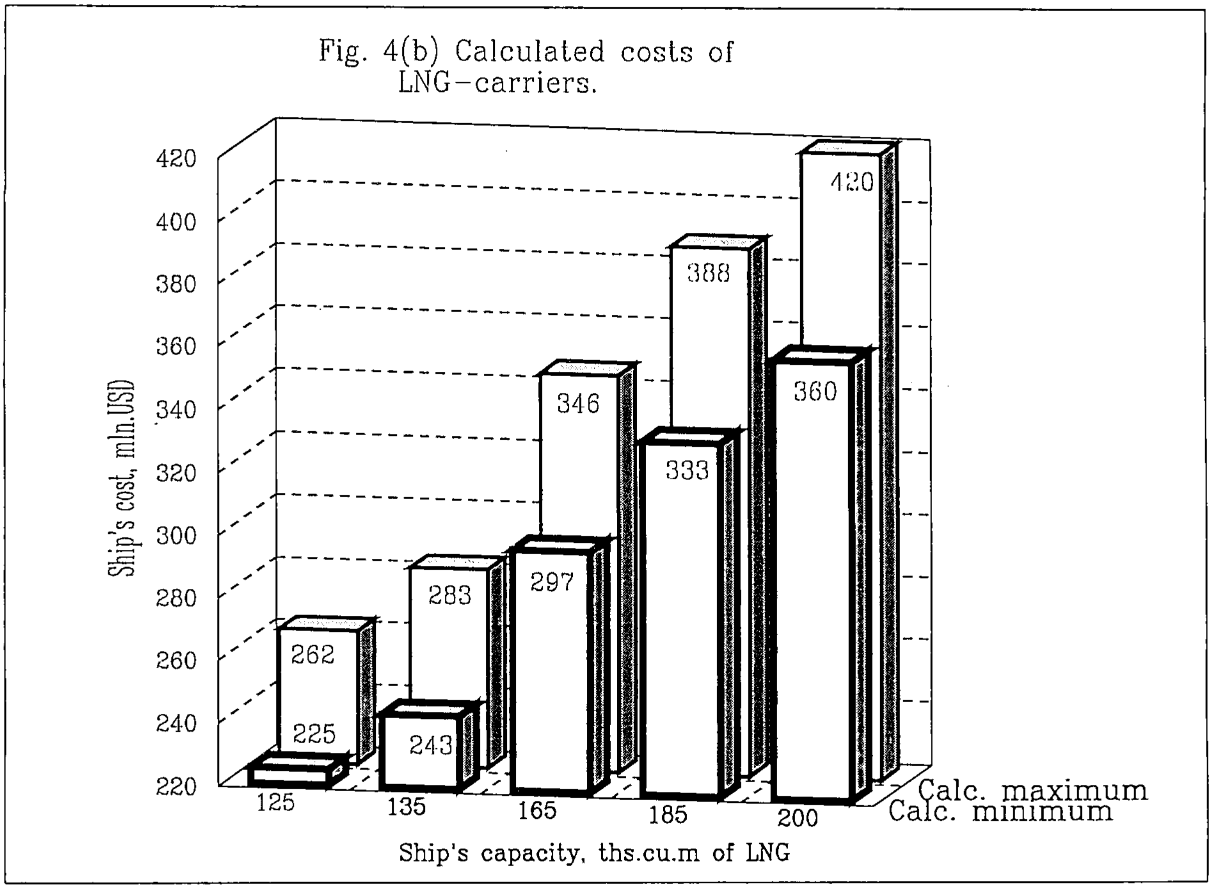


Fig.4 (b) reflects an interval of costs for non ice going methane carriers of the prospective building with a cargo capacity of 125-200 thous. cu. m. of LNG within the borders of the investigated price trends.

In Fig.4 (a), the lower curve is a slight parabola practically almost a straight line, has been approximated in accordance with 1994 trend and medium curve - with 1991 trend.

The upper border is a maximum limit of the building cost of the similar ULA class vessels. This limit has been determined expertly by adding 50% of building cost of a similar deadweight bulk-carrier to the cost determined at the upper bound of cost of an ordinary methane carrier in accordance with the trend of 1991.

It is known from experience that ice strengthening increases cost of ordinary transport ship (non methane carrier) by up to 20% of its building cost.

When building an Arctic going methane carrier, it is clear that its hull and engine are to be changed as compared with conventional carriers, and so the increase in building cost should and was taken proceeding from the cost of a corresponding bulk-carrier on a level of the approximated Lloyd's data for the beginning of 1994.

Therefore, 30% of building cost was added to the bulk-carrier of a corresponding deadweight taking into consideration specific and possible additional expenses which can come into being in process of development of the project and building of ULA classified methane carriers.

It was also taken for granted that the cost of cryogenic equipment and of storage tanks to store LNG with a temperature of about- 160 C, remains the same as for the ships not designed for ice navigation. Although it is obvious that power consumption required to maintain proper temperature of LNG under Arctic conditions will be a little less than under the conditions of south latitudes, where the similar carriages take place nowadays. On the whole, the results of the carried out graphic-analytical researches in reference to the considered type/size row can be grouped in Table 1.14.

One can see from the analysis data that with increasing ship's capacity the range of scattering values of the calculated building cost (from 18% for 39000 t to 2% for 125000 t) decreases so does the specific cost of engine and hull in relation to the cost of the ship.

It shows that an increase in methane carrier's cargo capacity within the range of the allowable parameters increases its economic efficiency; besides, a certain decrease of the specific component of ice strengthening expenses and a certain reduction of the costs of transport production at the expense of increasing vessel's carrying capacity, are readily seen .

In August-September of 1995, the American Company "AMOCO", German Company "HOWALDTSWERKEDEUTSCHE WERFT AG" and Finnish Company "KVAERNER" offered to develop a project aimed at export of oil gases and at designing the Arctic going ship - methane carrier with a cargo capacity around 135 thous. cu. m with an expert price about 235 mil. USD.

Table 1.14

Indices	Type of ship-methane carrier					
	NGM-39À	NGM-67À	NGM-79À	NGM-92À	NGM-125À	NGM-135À
Cargo capacity, thous. cu. m. LNG	39	67	79	92	125	135
Deadweight, t.	21291	35909	41930	48093	64192	70000
Price. mil. USD						
1991	98	154	177	200	260	280
1994	83	142	166	191	255	275
max. ULA	107	164	188	212	275	300

In this respect with a view to get comparable results for the alternative versions, the calculated expenses for vessels of prospective building have been brought to the basic level of evaluation made by foreign companies:

NGM-79A - 170 mil. USD

NGM-135A - 235 mil. USD

NGM-135LL - 310 mil. USD

NGM-165 - 250 mil. USD

NGM-200 - 310 mil. USD

The expected costs for the manufacturing of prototype models of methane carriers can increase at 20-35% of those for series consisted of 8-10 vessels.

Annual operational costs

The operating costs for the methane carriers will consist of five main items:

1. Crew expenses
2. Repair and maintenance expenses
3. Insurance expenses
4. Materials and material supply costs
5. Administrative and other expenses

1. Crew expenses.

The methane carriers are complicated and highly technological ships both in construction and operation. To ensure their due operation and maintenance, the personnel of high qualification are required. In international practice, the crew of methane carriers consists mostly of the natives of Western Europe and America, who require significantly higher salary than the natives of Asia who are employed at the ships under "the flag of convenience".

Crew expenses include several components, the most important of which are the salary established with due regard to fluctuation of the personnel, repatriation costs, food costs, insurance and ship's owner payments for social and pension security.

2. Repair and Maintenance expenses.

Ship's repair and maintenance expenses have a trend to change depending on the cost of ship's hull, and therefore on the capacity of a gas carrier; these expenses are also depend on ship's age.

3. Insurance expenses.

This item of constant operating expenses includes:

• a premium for hull and engine, which covers completely or partly the losses from wreck or damage of hull, engine and equipment of ship and also the legal and liquidation expenses and/or cost of compensations for losses in the case of an insurance incident, which are paid by the ship's owner;

• a sum, which guarantees protection of ship owner's interests and/or compensation of losses covering the liabilities of ship's owner imposed on him due to an insurance incident, which are not covered by the premium for hull and engine;

• a guarantee sum of military and other risks.

Common expenses for insurance of a ship are directly proportional to total capital investments into the considered ship and a degree of any risks (in other words, a probability of coming insurance incidents). In reference to the methane carriers, it is known from world practice that these risks have a significantly lower level than those for ordinary ships.

4. Materials and material supply costs

Materials and material supply costs for ships - methane carriers consist of expenses on specifically consumed deck and engine materials such as lubricated oil and liquefied inert gas used for filing up cofferdams between cargo tanks. This item of costs changes in its absolute value depending on size of the ship, and is a relatively small part of operating expenses of a methane carrier.

5. Administration and others expenses.

Expenses for these items in the judgment of competent specialists unlikely to change very significantly with the size of ship , however for some ship's owners in reference to the ships of the same size, a significant fluctuation in such expenses may occur.

6. Average annual constant operating costs for Arctic going methane carrier.

The foreseeable annual operating costs for methane carrier with a cargo capacity of 125 thousand cub. m. of LNG are accepted in accordance with the information of "Drewry Shipping Consultants Ltd." Company (in thous. doll./year):

1. Crew......................... 510....40%
2. Repair and Maintenance........ 750....20%
3. Insurance .... 868....23%
4. Materials and material supply... 350.....9%
5. Administrative and others ...... 334.....8%
Total for ship .... 3812...100%

After this, the calculated coefficient of increment of operating costs taken proportionally to the increment of average building expenses was determined (in 1980 it was USD mil.). Therefore, a value of 7079 thousand USD/year for a methane carrier with cargo capacity of 125 thous. cub. m. has been calculated for the year of 1995.

The data of the same Company concerning the ships of LPG type were studied later; these ships are more close, in terms of the type of the cargo carried and technology of sea carriage, to the surveyed types of methane carriers with a range of cargo capacity from 12 to 75 thous. cu. m. of LNG, which (methane carriers) have a good correlation of the operating expense items to ensure a necessary precision of calculations.

Due to the data of analytical research, an 1% increasing of cargo capacity of ordinary tanker - gas carrier gives approximately a corresponding 0.3% increase of current constant expenses for a ship .

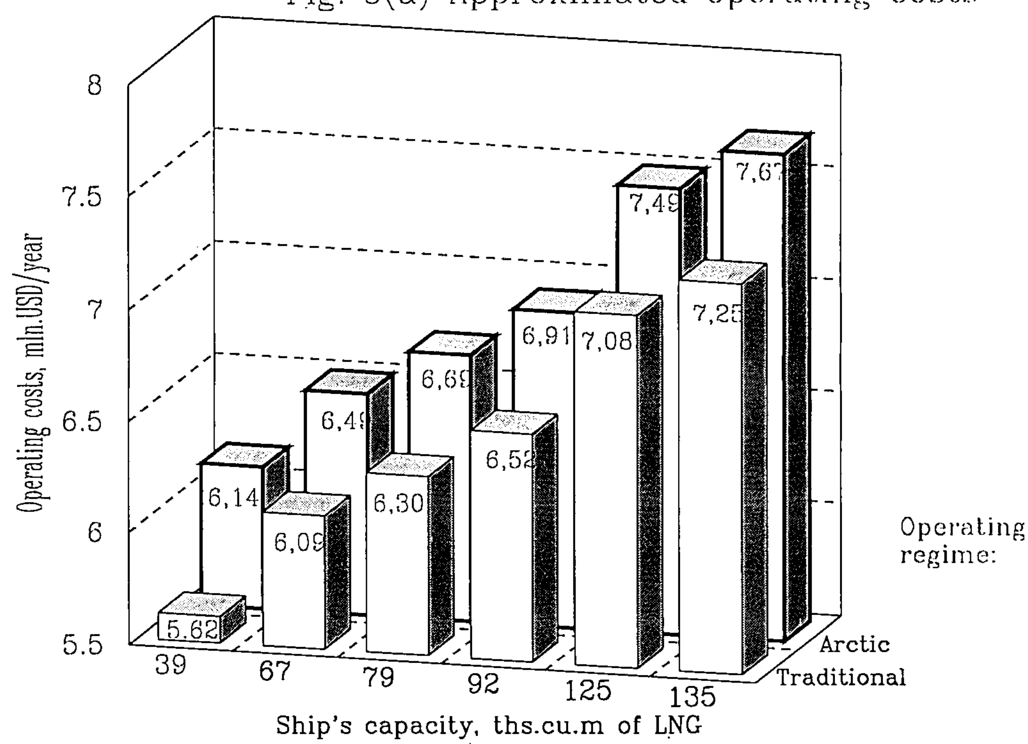
After that the second approximation curve has been built; the curve reflects the supposed increasing of operational costs due to Arctic special features and reflects a directly proportional relationship to the increment of cost of construction of ULA class methane carriers, with the cost of construction having been determined in advance.

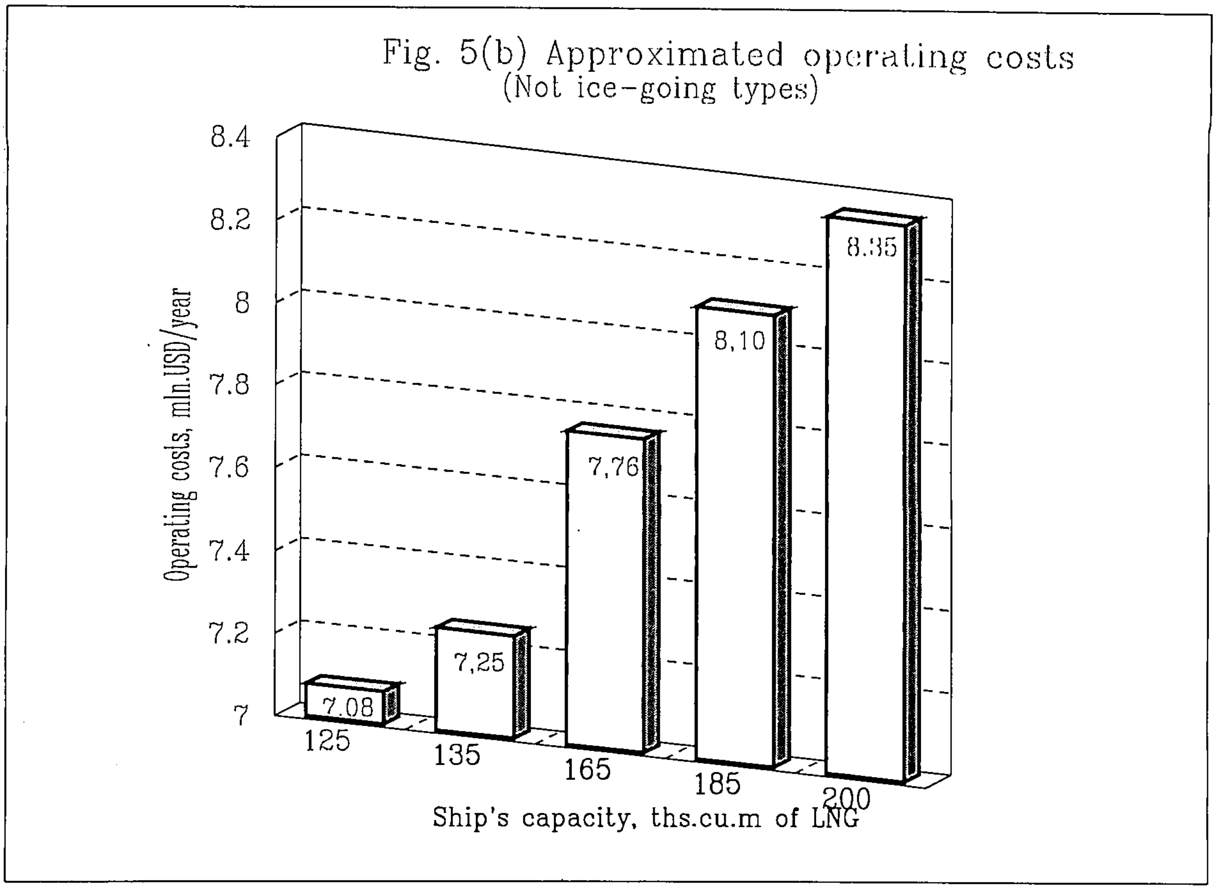
The data of analytical calculations are shown in Fig.5(a) and Fig.5(b).

Fig.5(a) reflects the calculated dynamics of changing of annual constant operating expenses for methane carriers with respect to the traditional ship row with a cargo capacity of 39-135 thous. cub. m. of LNG taking into consideration the increase of costs attributed to work in Arctic conditions.

Fig.5(b) reflects the calculated dynamics of changing annual constant operating expenses for methane carriers of the prospective building within the limits of the researched price trends with a cargo capacity of 125-200 thous. cub. m. of LNG for operation in ice-free conditions.

Fig. 5(a) Approximated operating costs



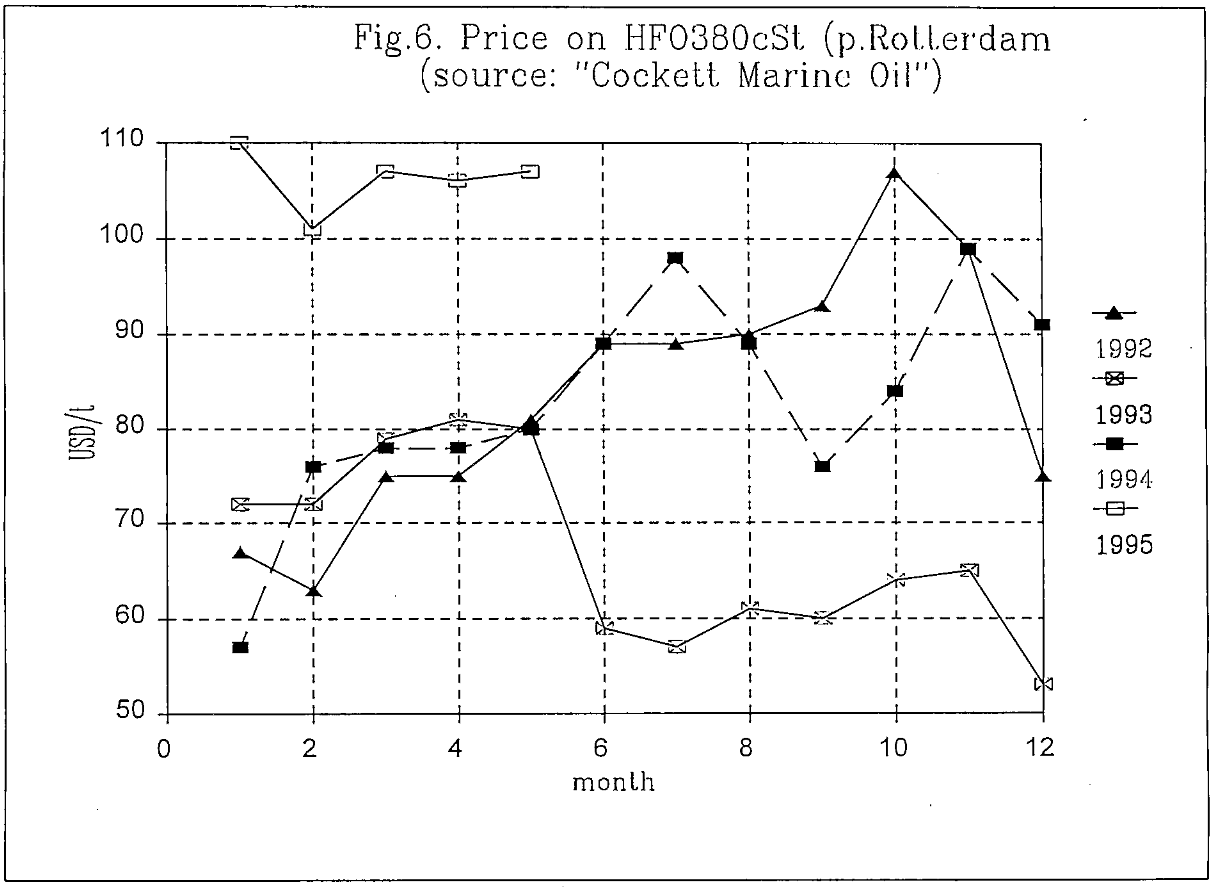


7. Fuel costs.

These ship expense items are variable and depend on ship engine power, type and price of the consumed fuel, correlation of sailing and berthing time in relation to ship budget and also on operating period and navigation conditions.

A possibility to use evaporating cargo (methane) as a source of energy for ship engine was considered in the calculations. But, the regeneration of evaporating cargo in some cases has been recognized as unprofitable from an economic point of view.

An interval of the market determined prices of bunker was accepted on the basis of statistical data analysis of "Kockett Marine Oil" Company for the port of Rotterdam for the last 3.5 years (Fig.6) and technical calculations made by CNIIMF concerning fuel consumption of relevant types of engines.



As one can see from the analysis of statistics, a most likely price of FM 380 cSt is up to 100 USD/t and of DO - up to 160 USD/t.

There are all reasons to believe that these prices will remain within the said limits at least till the end of the decade. This level of prices for the port of Rotterdam is one of the lowest in the world and apparently the domestic prices of same kind of bunker in domestic ports for the foreseeable future will also be close to it.

Technical-economic evaluation of the calculated type/size row.

When choosing the most rational type and size of a methane carrier, with other things being equal, one should be guided by an indicator of ship's operating expenses per unit of cargo carried (cu. m. of LNG).

It is obvious that the cost of carriages on the one hand will be directly proportional to the carrying capacity, and on the other hand, will be inversely proportional to ship's operating expenses taken in relation to the days of operation. For the considered type/size row of the ships, carrying capacity grows more significantly than gross operating expenses depending on cargo capacity.

Therefore, a conclusion can be made that from an economic viewpoint, a methane carrier of bigger cargo capacity will be a more effective carrier.

The upper limit depends only on technical restrictions.

In accordance with perspective elaborations of CNIIMF and in view of technical parameters taken for merely main waterway version, the ships with a cargo capacity from 39 up to 135 thous. cu. m. of LNG can be used in TTS .

The calculated economic characteristics of this type/size row have been accepted from elaborations of CNIIMF taking into consideration the up-to-date information.

A computer graphical analysis of the aggregated indices of potential economical efficiency of every type and size taken as a whole and treated as the limited independent system under conditions of complete comparability of the operating- technical parameters, has been made on the basis of the above characteristics; so the following indices are:

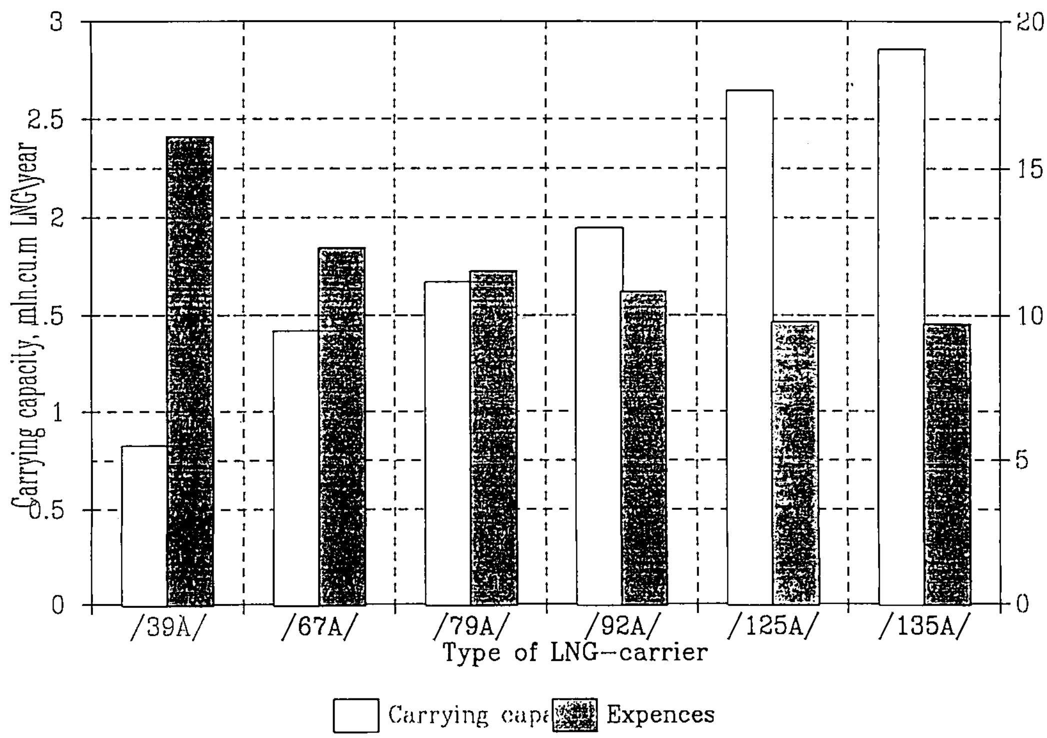
• potential carrying capacity and the calculated cost of carriage;

• current, constant operating costs plus capital investments in a form of depreciation for 15 years per 1 cu. m. of LNG potentially transported.

The resulting indices of this comparative analysis are presented in Fig.7.

One can see clearly from the diagram that with increasing cargo capacity a carrying capacity of the type/size sharply rises, and at the same time the cost of carriage smoothly comes down, and economic significance of this fact is greater, the bigger is cargo flow to be handled.

Fig.7 Comparative economic efficiency of ship types.



Therefore two alternative types and sizes of methane carriers should be accepted for further calculations.

The first type - with a cargo capacity of 135 thous. cu. m of LNG is maximum to meet technical restrictions. This type and size is more widely spread in the world practice; orders for such ships can be placed at South Korean, Japanese, French, American or Scandinavian specialized shipyards depending on market situation and their experience of building ice classified ships .

The second type - with a capacity of 79 thous. cu. m. of LNG is maximum in relation to technical capabilities of the domestic shipbuilding.

Positive and negative sides of these two alternatives in terms of protection of interests of domestic producers, the development of conversion process, interests of gas extraction branches, political aspects and protection of economic interests of Russia on the whole, must be considered in detail in separate research when developing a business-plan for realization of the project.

2. THE MAIN TECHNICAL-OPERATING REQUIREMENTS FOR PROJECTING ARCTIC GOING METHANE CARRIERS

This Section has been made in accordance with the requirements of the normative document OST 5.0064-84 " Order of development, co-ordination and adoption of ship construction project". This document stipulates an elaboration of technical-economical requirements for project of a new ship in accordance with the GOST 15.001-73, which must contain the following information:

- purpose and field of operation of the ship;
- parameters and characteristics of ship;
- operating conditions, organization and modes of ship's work;
- a number of ships recommended to build;
- a feasibility study of ship;
- other special requirements.

2.1. Purpose and field of operation of the ship.

An Arctic going methane carrier is intended for year- round export of the liquefied natural gas (LNG) from the port of Harasavey.

Substantiation of an architectural-constructive type (ACT).

The prismatic semi-diaphragm tanks are less common for vessels designed for LNG transportation than diaphragm or spherical ones. The diaphragm tanks of Technigas type have a shell of crimped stainless steel with insulation of cork tree or balsa and veneer or foam poliuretan strengthened by fiberglass. In the diaphragm tanks of Gas Transport type for diaphragm production, invar (stainless steel with 36% nickel) is applied which has extremely low coefficient of temperature extension and, therefore disappears the necessity of constructive measures to be taken to prevent the heat extension and compression. The second barrier in such tanks is identical to the first and being the rows of boxes from the glued veneer with an insulation layer of perlit. A special tank of Moss Rosenberg type is the only one of its kind, it rests on a cylindrical shell (skirt), placed on double bottom. The heat changes of the sizes are absorbed fairly well by deformation of the tank and skirt.

Gas carriers with diaphragm tanks are shorter in length and breadth, not so large in depth, have larger displacement and less register cargo capacity as compared with the gas carriers fitted with spherical tanks of equal capacity. A weakening of a ship's deck by cuts and rising of cargo tanks above the deck can be attributed to the shortcomings of spherical tanks, which complicate the arrangement and maintenance of equipment and pipelines. Besides , the spherical tanks are more expensive than the diaphragm ones. In spite of the mentioned disadvantages, when choosing the design of cargo tanks of carriers intended for LNG transport from Yamal, a preference apparently can be given to inserted spherical tanks. In this case, the highest reliability and safety of gas transportation must be considered as decisive factors. When a vessel is possibly beset by ice and affected by ice pressure, the inserted spherical tanks will not perceive a deformation of ship's hull. On the contrary, a damage of the cargo tanks is probable for a ship with diaphragm tanks when damage of the hull takes place. It should be taken into consideration that significant vibrations and impact loads occur when sailing in ice. A damage of thin diaphragms is quite possible in these conditions. Therefore, more reliable system of cargo tanks of "Moss Rosenberg" type is offered .

Last time, four spherical tanks having the same total cargo capacity as five conventional tanks are installed in many ships for decreasing evaporation of cargo down to 0.15% per day and also for simplifying ship operation and maintenance. .In this respect an area under cargo tanks is reduced, a length of the ship and weight of metal structures are decreasing.

In our case, taking into account the restrictions of breadth imposed by icebreaker, it is not expedient to arrange four cargo tanks because in this case the capacity is sharply lowered (with a given breadth). The general arrangement scheme of such gas carrier is shown in Fig.2.

If a constructive type with five spherical cargo tanks has been chosen for ice classified methane carriers , a number of cargo tanks for methane carriers of ice-free navigation has been varied between 4 and 5. The scheme of general arrangement of such gas carrier is shown in Fig.3 (a, b).

A final choice of the number of cargo tanks and their location is also made after the main dimensions is chosen .

2.2. Parameters and characteristics of ship.

Main dimensions, cargo carrying capacity and cargo capacity.

The row of ULA ice classified gas carriers has been offered above with cargo capacity of about forty, seventy, eighty, ninety and one hundred thirty five thousand cu. m., main dimensions of which are determined by conditions of operations with icebreaker assistance, dimensions of the building places and willingness of designer to use more competitive ships from the types and sizes existing in the world nowadays.

Assuming statistical ratios, the main dimensions and capacity presented in fig. 2.1-2.3 of Appendix 2, the length and breadth of new vessels will be obtained on the assumption that Dt = 0,83 - 0,84 B and Ltank=0,75 Lbp and 0,67Lbp for five and four cargo tanks respectively, and then one can make a drawing scheme of cargo tanks allocation. It is finally shown that under a fixed tank breadth, the version of five cargo tanks should be selected for ice going vessels. Main dimensions, capacity and other characteristics of ice going vessels are presented in Tables 1.6-1.8 and of non ice going ones - in Table 1.9. Main dimensions of new vessels and their ratios are in accordance with the up-to-date trend for design of 30-135 thous. cu. m gas carriers with spherical tanks .

In accordance with the Regulations of the Maritime Register of the RF, an ULA ice category is assigned to the ships working with icebreaker. Minimum output of power unit calculated by formula of the Register is introduced in Table 2.1. In the same Table, the powers are introduced, which have been got by way of recomputation made on the basis of computations for the operated gas carriers with spherical tanks of similar cargo capacity. A power that has been got by recomputation for prototypes is a little bit higher than nominal, and an ice going capacity and speed are higher as well. A further increasing of power is apparently not reasonable in terms of economy. A value of speed of the ships has been calculated with use of the Admiralty coefficient. It should be taken into account that this coefficient must be decreased when counting more heavier ice strengthened hull. When decision-making on a new engine, an allowance for 15% reserve should be made.

A calculation of ice going capacity, i.e. thickness of solid ice overcome by a ship at steady motion, was carried-out by formula [3]:

$$h = K\, 0{,}32\, Pe/B{*}D^{1/6}\ , \mathrm{m}$$

where Pe - a total thrust of the propellers, kN;

B - a breadth of a ship, m;

D - a displacement, t;

K - empirical coefficient;

K = 0,123 - 0,08 - for the transport ships;

$$Pe = Ke(dp\ Ns)^{2/3}$$

where d p- a diameter of a propeller, m;

Ns - total power at the shafts, kW

0,78 - for a single-screw ship;

Ke 0,98 - for twin-screw ship;

1,12 - for three-screw ship.

K = 0,5 - for 2- and 3-shafts units;

K = 0,6 - for single shaft units

Finally, the main dimensions and other characteristics of new ships are obtained as a result of combined solution of the equation of masses and equation of cargo capacity:

$$Pi - D = 0$$

$$W - Wo = 0$$

$$D = LBT = D + Dw = Pst.h + Ptot + Pcr.eq. + Pt. + Pins. + Ppp. + Pcc + Pst.\ ,$$

where $Pst.\ h. = 1{,}53(L^{1.03*}\ B^{0.75*}\ H^{0.33})$ - weight of steel hull, taking into account the ULA ice class;

$Ptot. = 0,207(LBH)^{0.805}$ - weight of ship's equipment;

$Pcr. eq. = 0,1 * Ptot.$ - weight of cryogenic equipment;

$Pt. = 0.281(LBH)^{0.802}$ - weight of tanks;

$Pins. = 0.275 W^{0.862}$ - weight of insulation of TANKS;

$Ppp = 0.135 N$ - weight of power plant (LSD);

$Pcc = Wo\ 0.98$ -cargo carrying capacity (weight of a cargo);

$Pst. = 0.24(Pcc)^{0.5} + 50$ - a crew and weight of stores;

$Pf = q\ (R/V) / 24$ - fuel stocks T

POWER OF THE MAIN ENGINES OF GAS CARRIERS OF ULA ICE CLASS

Particulars	NGM-39A	NGM-62-A	NGM-67À	NGM-79À	NGM-92À	NGM-125À	NGM-135À
Minimum output of main engine as per the Register, kW	13160	15975	16588	17979	19513	23464	28156
Ice going capacity under minimum output, m	0.800	0.925	0.940	0.965	0.985	1.047	1.073
Output recalculated, kW (for non ice class vessel)	15600	18500	19500	21000	23500	29000	31000
Ice going capacity under output recalculated according to prototype, m	0.900	0.975	0.990	1.015	1.050	1.090	1.100

To determine the elements of weight load, the recommendations and results of works [4] and [5] were used.

$$W = 5 \frac{4\pi}{3} \left(\frac{0.82 B}{2} \right) 3$$

A calculations of daily fuel consumption for the whole row of gas carriers are introduced in Tables 1.6-1.9.

Finally, for the main waterway scheme, the NGM-135A gas carriers has been chosen, and for the feeder scheme - the NGM-79A.

The final results of choosing the main dimensions are given in Table 2.2.

Table 2.2.

MAIN CHARACTERISTICS OF GAS CARRIERS NGM-79A AND NGM-135A

Gas carrier type	NGM-79A	NGM-135À
Ice class	ULÀ	ULÀ
Length L b/p, m	232.00	281.00
Breadth B, m	38.00	44.80
Depth H, m	22.00	25.00
Draught T, m	10.60	11.53
Coefficient of corpulence	0.740	0.740
Displacement D, t.	70870	110100
Diameter of cargo tank, m	31.77	37.86
Capacity W, m3	79350	137900
Carrying capacity P, t	38100	66220
Deadweight DW, t	41930	70250
Mark of main engine	B&W	B&W
Main engine's output N, kW	21000	31000
Open water speed V, kn.	17.60	18.30
Transmission type	direct	direct
Type of propeller	SRP	SRP
Pumps: supply, cu. m/hour	10*750	10*1400
pressure, m of water	120	140

Power plant

Steam turbines have been installed on the vessels accounted for 80% of all vessels working both at liquid and at gas fuel. Practically, STP have been provided for one hundred per cent of prospective gas carriers designed for LNG transportation, both ice going and ice-free going carriers being taken. Evaporating methane neutralizes the main deficiency of steam turbine plant - high fuel consumption. But taking into consideration a lack of shipbuilding base for STP, negative experience of servicing personnel and also significant advantage of diesel, that is relatively low fuel consumption, LSD is proposed as a main engine.

The loads on a main engine are substantial at ships of ULA ice class. It is known that most suitable for such operating conditions, is a power plant with high indices of duration of constant moment at the screws and high maneuverability, namely the plants with electric working and hydro-mechanical transmission.

Choice of the main engine for the ships under consideration has also affected such circumstances which make it difficult (and may be unreasonable) to arrange transmission of entire power to one screw, with ship's dimensions being fixed. Therefore, those power plant is to be accepted which consists of two or three main engines.

With a quantity of engine's revolutions less than 100 r. p. min. and direct transmission to the screw, it is unlikely to provide a screw and rudder complex with necessary dynamics characteristics in any version of power plant to overcome effectively ice thickness.

Taking into consideration that an electrically driven power plant requires a substantially larger engine room (ER) and has a substantial total weight and, besides, requires an additional maintenance staff, it is considered as reasonable to provide a power plant which consists of two and of three low speed engines operating through a hydro-transformer to a controllable pitch screw, for the discussed ships with a view of ensuring high ice going capacity and sufficiently high economic indices. To decrease weight and whole dimensions of the hydro-transformer and make it more effective, it is necessary to provide a step-by step speed reduction gear for the hydro-transformer and also a possibility of direct transmission to the screw, bypassing around the hydro-transformer which is wise to do, because during the long voyage the ship is likely to sail in ice-free waters where the hydro-transformer is practically of no use . Existense of the reduction stage permits us, if necessary, to take power for other ship's needs.

Taking into account all the above, it is recommended to use slow speed diesels of B & W Company as the main engines which rotate controllable pitch screws through hydro-transformers. Steam turbine plants as an alternative version were considered for gas carrier with a cargo capacity of 135 thous. cu. m.

STP was proposed as a main engine for not ice classified gas carriers. A potential opportunity of using only evaporating methane as a fuel carried by those ships is taken into consideration . In this case, the main deficiency of steam turbine plant - high liquid fuel consumption - is neutralized. It can be economically effective to use as a fuel only methane carried by ships.

<u>Auxiliary equipment and systems, operating a power plant (PP).</u>

Composition of auxiliary equipment which provides main engine's work and characteristics of this equipment, are chosen on the basis of recommendations made by a Company- supplier of assemblies, Rules of the Register and practice of operations.

The principal schemes of systems operating a PP, are also regulated by the suppliers of assemblies and are quite traditional. As an exemption, there is a system of cooling mechanisms and devices which can be introduced both in traditional form with branching-out systems of sea cooling water and by a central cooling system. Rather long experience of operation of the central cooling systems in domestic ships as well as foreign experience speak for the central cooling system, despite a little bit higher initial price. The system is thought to consist of a sea water circuit with a central cooler and two circuits (of high and low temperatures) of cooling by fresh water. Such system has the following advantages as compared to the traditional one:

• minimum length of sea water pipelines, that sharply reduces the necessity of using corrosion-proof materials, which are distinguished by high price;

•high reliability and long life of the system on the whole;

• high degree of keeping up the temperature of fresh cooling water at an optimal level, regardless of load and external conditions;

• possibility of reducing expenditure of power on driving cooling pumps due to changes in the number of switched-on pumps or in their capacities depending on a degree of deviation from the rated conditions.

As the ship will work in the areas with maximum temperature of sea water +32 C not more than 5-10% of operation time then it is reasonable to supply the system of cooling sea water with three pumps, each pump has an 50% output of the maximum required. Therefore, under extreme conditions, the functioning of two pumps with one being in reserve is supposed to be provided and in other cases the system being operated with one pump, is to be selected. In accordance with the data of the ALFA-LAVAL Company, a designer of this system, such possibility can be realized when sea water temperature falls by 2°C below the rated one.

Heat exchangers are recommended as coolers, the central of which must have titanic plates and coolers of oil and water can have stainless steel plates.

The use of plate heat exchangers makes it possible to unify the spare parts for them, since all of them can be of one type, but with different number of plates. The high heat-technical and operating characteristics of the heat exchangers of the ALFA-LAVAL Company have been proved for long operating period on domestic ships. Unfortunately, similar domestic heat exchangers have extremely low serviceability.

Systems of fuel preparation.

The fuel with a viscosity of 380 cSt is proposed as a basic kind of fuel. This kind of fuel ensures an optimal combination of relatively low expenses with reasonable costs of preparation of fuel to burn under ship conditions. This is also supported by the data of the MAN-B and V Company , in accordance with which a share of the said fuel in the bunkering application of foreign ship's owners according to the results of information processing in 1989-1991, was around 70-75%. It is necessary to note that a fuel with higher viscosity is now absent at the domestic bunkering stations and seems not to be available in the near future;

furthermore, the areas in the Far North where storage and possibilities of bunkering the fuel of higher viscosity than 380 cSt, are connected with substantial energy expenditures.

However, taking into account that a ship will operate not only in the Arctic zone but in a temperate zone as well, and probably in a tropical zone, then a possibility of using of a higher viscosity fuel (up to 600 cSt) must be considered.

The characteristics of equipment for a fuel preparation system (separators, filters, pumps, heat exchangers etc.) and supply of complete sets of equipment, shall be chosen in view of provision made for reservation and for optimum characteristics of operating conditions.

Auxiliary boiler plant

The ship must be provided with auxiliary boilers (if needs be) proceeding from the necessity to ensure the increased reliability of the heat supply to an active ice going ship, and also from the necessity to use exhaust gases to ensure work of the inert gas plant.

For this purpose, a boiler plant is proposed which consists of two auxiliary boilers. It is possible to accept a version of using boilers of various outputs, the biggest of which shall ensure ship's needs for steam and functioning inert gas plant, and the smallest one (if the result of estimation is favorable) shall ensure supply of the ship with steam.

Two utilization boilers for main engines should be also provided for as a part of the boiler unit, and the use of exhaust gas heat coming from auxiliary diesel-generators can be elaborated as well.

In a process of further development of ship project, it is necessary to pay attention to using exhaust gases of the diesel-generator to obtain inert gases (the MOSS-ROSENBERG Company has such units).

It would probably allow us to decline the boilers of various outputs and to mount the two equal boilers with a total output of about 150% of the ship's essential needs for steam.

A possibility of using a thermal liquid as a heat vehicle instead of steam has been considered in the process of the elaboration. One of important advantages of this heat vehicle is that it is freezing-proof at low temperatures, which is very important for a ship operating in the Arctic conditions. However, changing-over to the thermal liquid in full measure is connected with significant expenditures of hard currency for lack of adequate domestic equipment. Therefore, the steam system is preferable, but nevertheless it is proposed to use thermal liquid in a system of heating air for the needs of ventilation and air-conditioning. For this purpose, it is necessary to provide a heat exchanger for thermal liquid with circulation pumps as a part of steam system. The thermal liquid can also be used for heating a ballast, but this will enlarge a volume and overall dimensions of system's equipment.

Auxiliary engines.

A ship, designed for operations under the conditions closely related to the ULA ice class, i.e. when it is practically impossible to ensure stable maintenance of loads and high-speed modes of the main engine, even with the use of a hydro-transformer, it is reasonable to make provisions for an electric power-station with a main-engine-independent drive.

Availability of auxiliary engine will not reduce the number of mounted diesel-generators (DG) as compared to a traditional complete set of equipment (three DG), and there is a need to use two parallel working DG when maneuvering and handling the cargo.

In case of using hydraulic submersible cargo pumps, as it is stipulated in this study, it seems reasonable to provide for a shipborne electric power-station, consisting of two diesel-generators and one diesel to drive generator and main hydro-block. One more diesel is provided for driving hydro- block only.

For driving an auxiliary hydro-blocks, used in a cargo-heating mode, it seems reasonable to provide fore hydro-transformers with a hydro-block capable to be driven by electric motor too. In such a version, an auxiliary engine working mode can be shown as follows:

Motion + Heating of cargo - 1 Auxiliary DG + 1 main hydro-block

Unloading - 1 Auxiliary DG + 1 main hydro-block

Mooring, maneuvers - 2 Auxiliary DG + 1 small hydro-block (with electric drive)

Washing of the tanks - 1 small hydro-block with electric drive.

As drive engines the diesels of the MAN-B. & W. Company or VARTSILA-DIESEL are recommended, they are widely used in the ships of domestic and foreign shipping companies. Further, it is reasonable to elaborate a version of completing electric power-station with a shaft-generator.

On the basis of the developed recommendations for choosing an architectural-constructive type of the Arctic going ships - methane carriers with substantiation of ship systems and ship equipment, the recommendations for ship complete equipment (Makers-list)have been prepared, and these recommendations determine potential suppliers for ships - methane carriers NGM-79A and NGM-67A to be built at Russian shipyards.

Ship systems.

A technology of cargo operations for ships carrying liquefied and natural gases in liquid phase (at t = - 162 C) is to be realized in the following order:

A. Filling with inert gas. Before loading of LNG into ship's tanks, cargo pipeline and a room between the first and second barriers are filled with inert gases. Inert gases are usually obtained by evaporation of liquid nitrogen or in special unit from exhaust gases of the main engines. When using, the nitrogen should be sprayed and cooled to the temperature a little bit higher than that in tank , and it should be loaded into the tanks through a gas removing pipe. The air is removed from the tanks through the pipe branches of the gas pipeline located near the bottom of the tanks. The loading is made until the oxygen content in the gas that is removed from the tank, is below the limit of explosion danger, i.e. not more than 5% of volume.

B. Drying. Before loading, tanks are "frozen up" by gaseous methane to reduce moisture content. When filling with nitrogen, the moisture content is small and the process of drying needs not be carried out.

C. Cooling. To lower the temperature of a tank, a cooling by means of spraying LNG in inner room of the tank has to be carried out, and the evaporated gas must be released in atmosphere or return ashore. The duration of cooling depends on heat weight of the tank, insulation and speed with which the evaporating gas can be removed. The speed of cooling is controlled by measuring temperature gradients along the whole tank.

D. Loading. LNG is loaded into every tank by shore pumps through the pipes which end near the tank's bottom. The evaporated methane is removed, thus, increasing of excess pressure in the tanks is prevented . The tanks is filled at a low speed of fluid (5-7 m/sec) in the pipeline.

E. Carriage by sea. It is carried out with the parameters of LNG as -follows:

boiling point - 160.0 - 163 C, specific weight 0.43-0.49 t/cub. m. depending on composition of LNG. The pressure in tanks is a little bit higher than in the atmosphere - .03-1.07 kg/sq. cm. An amount of evaporating cargo, during a voyage, depends on insulation system, type of the tanks etc. As a rule, the evaporated cargo is used as a fuel for the main engine.

F. Unloading. A pipeline for fluid is cooled before unloading by way of circulation of LNG flow through it. After the connection of the ship pipeline with a shore pipeline is finished, the ship pumps are to be turned on. To maintain pressure in the tanks during unloading, a cleared room is filled with gaseous methane. The cargo pumps are switched off automatically in response to vacuum values and to the values of lower level in the tanks. Some amount of LNG should remain in the tanks to be used during the ballast voyage for cooling the tanks and as fuel for the main engine.

G. Ballast voyage to the port of loading. During the ballast voyage, the tanks are maintained in the cooled condition so that upon arrival in the port of loading, the ship will be ready for loading.

For these purposes during the ballast voyage, a proper amount of LNG is left, which should be injected into the tanks to cool them. When there is a plant for the repeated liquefying at the ship then it is not necessary to leave LNG for ballast voyage.

If there is a need to present the tanks for inspection and to repair it, then the following operations are necessary:

H. Heating. To enter inside a tank, it should be heated to the outside air temperature. The heating is carried out technically by way of circulation of gaseous methane in the closed circuit from the tanks through the gas compressors and heat exchangers and back into the tanks. When heating tanks, the gas should be periodically removed from the tanks to maintain constant pressure.

I. Decontamination of tanks. After heating, the tanks must be decontaminated. Inert gas is conveyed to the bottom of tank by a cargo pipeline and light methane is pumped out by a gas pipeline. Decontamination is carried out until the content of methane in the remained gas reaches an explosion danger level.

J. Blowing by air. Before entering the tank for inspection or repair, its blowing by air should be made. When pumping out inert gases from the bottom of the tank, it is replaced by air which comes through the opened manholes. The pumped out mixture is used to control its composition.

After inspection or repair of tanks, a preparation of ship for loading should be carried out in the above-mentioned order.

Cargo systems.

For methane carrier of 80 000 cu. m. there are no principle differences in providing cargo equipment and no particular requirements for special systems.

Taking into account that there are no methane carriers in Russia and equipment for liquefying and pumping is not manufactured there, the requirements have been formulated according to materials taken from foreign sources.

To carry out cargo operations and transportation of liquefied natural gas, with all measures taken to ensure the safety of ship, the following systems supplied with necessary equipment must be provided:

1. Cargo system.
2. System of cooling the tanks and main cargo pipeline.
3. System of inert gas.
4. System of gas release through safety-valves.
5. The means of automated control.

The cargo system is to ensure:

- carrying out cargo operations by the closed method, with the evaporated methane being removed ashore;
- availability of loading and unloading of liquid and gaseous methane from any side;
- decontamination of cargo tanks and cargo pipeline;
- removing air from cargo tanks;
- constant pressure in the tanks;

• carrying out all operations required for ensuring cargo operations (heating or cooling of the tanks etc.).

To carry out the above operations , the cargo system must include:

• pipeline with fittings;
• cargo pumps;
• compressors;
• heaters for gaseous methane;
• evaporator of LNG;
• a dryer fan for spherical tanks;
• system of watering for spherical tanks.

The pipeline should consist of pipes for liquid and gaseous methane produced of a material which can work reliably for a long period at temperatures + 50 C - 165 C.

It is allowed to produce the pipelines of copper and aluminum for the inside of cargo tanks.

All pipelines and supports to the pipes in tanks and on the deck must compensate deformation caused by temperature fluctuations.

Cargo pipeline must enter the tanks only through the dome of tank.

There must be two cargo pumps in every tank.

A total output of all pumps must ensure unloading a ship for 12 hours, working temperature - 162 C. The centrifugal pumps of submerging type are recommended.

In case of damage of the pumps, emergency unloading devices must be provided.

To create pressure needed to supply gas into power plant, two types of compressors are required:

• compressors for removing gases from tanks during loading and for filling the empty room when unloading. An output of compressors must be equal to the sum taken over LNG loaded and the speed of evaporation of LNG and when unloading - must be equal to total output of the cargo pumps;

• compressors for compression and supply of LNG evaporated during the voyage and using LNG as a fuel for ship engines; their output should be chosen proceeding from the amount of the gas evaporated.

Compressors must ensure reliable work at temperature -140 C.

The heaters of gaseous methane must ensure heating of the evaporating methane which is supplied into power plant with a temperature of -140 C to + 40 C.

An evaporator of LNG must ensure evaporation of LNG for filling the released room in the tanks during unloading and for expelling inert gas from the cargo tanks after their inspection or repair.

An output of evaporator must be not less than a total output of ship pumps; intake temperature is 162 C.

The fans must ensure ventilation of spaces in the vicinity of the tanks. Not less than 2 fans must be mounted in the ship, each with an output not less than 900 cu. m/hour.

The dryers must ensure that the air conveyed to the vicinity of the tank is dried up to dew-point -5 C.

A watering system must provide water to cool spherical surface of the tanks, which projects over the main deck of the ship.

A system of cooling of tanks and cargo main pipeline must cool the cargo pipeline before loading and maintain the cargo tanks in cooled condition during the ballast trip.

The way of cooling by injecting of liquid methane is recommended.

The system of cooling must be made taking into account a design and type of cargo tank.

The system must include pipelines, coming into each tank and one or two pumps, located in the cargo tanks. An output of the pumps must be not less than 50 cu. m./hour, a pressure of 100 mm of w. p., a temperature of pumped stuff - 162 C.

A system of inert gas (SIG) must maintain an inert medium between the tanks and hull of the ship or between the barriers (depending on design of the tanks).

The SIG must also ensure decreasing of moisture content in the vicinity of the tanks and blowing of the cargo tanks before cooling or heating to protect them from explosive mixtures of air with methane.

It is recommended to use nitrogen as inert gas. The SIG must include:

a) two tanks with nitrogen;

b) an evaporator of nitrogen;

c) a generator of inert gas.

The tanks with nitrogen must ensure a need for nitrogen during the round trip. Two tanks with nitrogen must be installed in the ship.

The nitrogen evaporator must ensure that inert gas is generated with a view to fill the cargo tanks and the vicinity of the tank spaces in case of emergency or while under repair works.

The gases must correspond to the following composition:

O_2 0,5%, $CO + H_2$ 1%

O_2 10 parts for million;

$CO + H_2$ 100 parts for million;

Dew point - 55 C;

Soot - 0.

A system of releasing of safe-valves must ensure the receiving of gas through the safe-valves and removing it in the atmosphere.

The system must be connected with a system of gas-removing pipes.

Each cargo tank must be supplied with 2 safe-valves.

Insulation space between barriers must be supplied with safe-valves.

The parts of pipelines of cargo system, cut off by the valves, must be fitted with safe-valves.

The safe-valves must be adjusted for pressure that does not exceed the pressure acceptable for the secured room.

Living systems.

Systems of water supply, sewage system, systems of conditioning and ventilation, the heating system and system of cooling of food chambers.

A system of water supply will consist of a system of potable water and separate water system for washing purposes. The potable water will be stored in a reserve tank, made of stainless steel, and washing water - in hull tanks. The water will come from shore and replenishment of the reserve tanks from a distiller must be available.

Sewage waters will be collected in special tank and treated in the unit of sewage waters treatment of physical-chemical type. The treated sewage waters will be removed overboard, and in the zones of sanitary protection - in the nearest to engine room ballast tank.

For the living, social and service rooms a double-channel, medium-speed air conditioning system shall be provided. In other rooms - a system of natural or artificial ventilation.

The rooms which are not operated by the air conditioning system and where heating of air is necessary, are operated by a system of steam heating or by heating pads.

The system of cooling of food chambers must be operated by two piston compressor-condenser units, using freon-22.

All living systems must correspond to the requirements of Classification Society and Sanitary Rules for the ships of marine fleet.

All-ship systems.

This systems include the drain, ballast, fire extinguishing systems and system of open deck scuppers.

The drain system provides ballasting of fuel by pumps, receiving and removing of ballast by gravity.

There are the following systems in the ship: a system of water fire extinguishing, which except of its main purpose provides functioning of system of upper deck watering; a system of powder fire extinguishing to extinguish fires in the area of cargo tanks and in the rooms with cargo system equipment; a system of carbon-dioxide fire extinguishing for fire extinguishing in the engine room, paint locker, mufflers and spark extinguishers.

The use of the powder fire extinguishing system to extinguish fires in the area of cargo tanks and in the rooms with cargo system equipment is stipulated by the requirements of IMO Code for the gas carriers.

All above mentioned systems must satisfy the requirements of Classification Society, International Conventions and IMO Code for the gas carriers.

2.3. The operating conditions, modes and organization of work.

Stable work of methane carriers for LNG transportation depends on hydrometeorological conditions and ice situation in the south-eastern section of the Barents Sea and in the south-western section of the Kara Sea and on availability of assisting icebreakers allowing one to ensure positive motion of the ships with certain safe speed for various ice types of Arctic navigation.

A typical climatic peculiarity of the Western Arctic is a highly variable behavior of hydrometeorological elements, high speed of air and moderate temperature. In November, the formation of an area of low pressure is finished over the Northern Atlantic, which generally remains during the whole winter till April. The cyclones, forming here with a frequency of 4-6 times per month, move in the Eastern direction. Depending on the area of motion of the cyclones, the features of prevailing winds are displayed. A recurrence of motion of the cyclones in areas is characterized by Table 2.3.

Table 2.3.

NN	An area of cyclones passage	Recurrence %
1.	Iceland-Spitsbergen-FIL-Kara Sea	20 - 25
2.	Iceland-Central Section of Barents Sea-Novaya Zemlya Island-Beliy Island	50 - 60
3.	Iceland--Northern Coast of Eurasia	10 - 20

With the cyclones passing over the northern and central areas, the western, south-western and southern winds accompanied by heat transfer, are prevailing and the cyclones of mainland routes give rise to the eastern, north-eastern winds accompanied by cold transfer from Siberia. Such background of winter synoptic situation is prevailing for the areas of the Barents and the Kara Seas.

Against the background of this common situation, some of winters are distinguished for strong cyclonic activity over the northern Atlantic, and some winters - for very weak cyclonic activity close to complete fading. In the first case in the Barents and Kara Seas, a most favorable ice situation is formed, and in the second - heaviest one. A recurrence of favorable situations is 2-3 times per decade and unfavorable - 1-2 times.

Thus, 30 years of observations give the heaviness of ice conditions in winter-spring period characterized by the data of Table 2.4.

Table 2.4.

NN	A nature of navigation ice conditions	Recurrence %
1.	Favourable	30 - 35
2.	Unfavourable	10 - 15
3.	Medium	50 - 60

Depending on ice conditions, the speed of the tandem/Icebreaker NORILSK, Icebreaker SEVMORPUT/ confirm a possibility of stable navigation even in the complicated winter-spring periods of navigation. Proceeding from the experience of work of the MSC's ships on the line Murmansk-Dudinka, the following average indices of speed have been got (See Table 2.5.):

Table 2.5.

NN	State of Navigation Conditions	Speed, knots
1.	Light	13 - 14
2.	Medium	8 - 10
3.	Heavy	5 - 7

Such wide range of speeds depending on versions of winter-spring navigation is determined by dynamic variability of weather and ice conditions in one or another areas of the route: along the Barents Sea, the Straits Zones of the south-western section of the Kara Sea, action of surface currents, tidal occurrences in the Kara Gates and the Yougorsky Shar Straits.

The ice-covered routes of methane carriers are chosen proceeding from the location of Novaya Zemlya ice massif, state and size of Amderma, Yamal and Western Novaya Zemlya ice glade clearings or, in other words, polynyas (areas of open water). In this report, 3 main routes of the movement are considered and evaluated in terms of length and state of ice cover, and degree of risk:

1. Harasavey-Kara Gates Strait-Cape Nordcap-Wilhemshafen;
2. Harasavey-Yougorsky Shar Strait-Cape Nordcap-Wilhemshafen;
3. Harasavey-Cape Zhelanya-Cape Nordcap-Wilhemshafen.

State of ice condition (light-heavy) is affected also by location and state of the Novaya Zemlya ice massif. It's formation in the Kara Sea is finished in February, in the Barents Sea - in March, and ice in the massif reaches a maximum thickness in the end of April-May. On average, a thickness of ice in the massif is at 30-50 cm. less than of the land floe ice owing to its continuous renewing when a center of the massif moves to the North.

During the years of active cyclonic activity, a drift value is doubled and is 150-250 miles. During unfavorable years, there is no drift and ice situation becomes the heaviest.

With long blowing of the moving apart wind of one direction with frequent recurrence, an over land floe glade clearing is formed near the lee side coast. In first half of the winter, a recurrence of over land floe glade clearings is higher, this fact may be well explained by prevailing moving apart winds near the western coast of the Yamal Peninsula and Amderma coast and by potential capability of wind to reduce area of the massif owing to ice hummocking process.

In accordance with average multi-years data, the glade clearings in different sections of the Kara Sea and the Barents Sea are mostly observed in January-March and are characterized by the data of Table 2.6.:

Table 2.6.

NN Name of glade clearing	Probability of appearance %
1. Yamal	50
2. Amderma	70
3. Eastern-Novaya Zemlya	30-40
4. Western-Novaya Zemlya and approaches to the Novaya Zemlya Straits	40-50

In April-May in connection with the seasonal changing of the prevailing wind directions and moderation of the wind force, a probability of occurrence of the glade clearing in all areas is decreasing to 30-40% , but the earlier formed zones of first-year ice are remained in its place, being of less thickness than in the massif.

The dangerous occurrences of the Southern Section of the Kara Sea and South-eastern section of the Barents Sea, which can interfere with the uninterrupted motion of the ships(methane carriers), include the following:

a) an occurence of a high speed ice drift in a narrow stripe of the solid massif - "ice flows". A breadth of such "ice rivers" is from 10 to 60 miles, a length is a few tens and hundreds of miles with a speed of drift from 2 to 5 knots. A nature of the motion in the "ice flow" is like steady solid flow or pulsating impulse motions. At the borders of flow along a drift shed line, a powerful barrier belt of hummocks is formed, which are hard to pass even for nuclear ships in autonomous navigation. The most frequent occurrence of "ice flow" is in the area of narrow passages - in the Kara Gates Strait, in the area of Cape Harasavey, at western approaches to the Yougorsky Shar Strait. A probability for 'ice flow' to occur usually increases in the areas of reverse currents in the period of springs and after long action of wind of one direction with increasing air temperature. A duration of the occurrence is 6-12 hours;

b) the tidal compression of ice in the period of springs in over a land floe area near Cape Harasavey and surrounding islands in the Kara Gate Strait. The time of the beginning of compression is 3 hours before high water, the time of rarefying is 3 hours before low water. Duration of the occurence is from 4 up to 6 hours;

c) hummocking in the zone of a canal that has been made by icebreaker in time of the formation of stable land floe. A border of land floe is developed consequently in accordance with growing ice thickness along the isobaths of 5,10,15,20 meters with the formation of ice barriers at the stage borders;

d) packing (stratification) of ice up to the bed in the area of shallow water under an effect of the pressing winds, the periodical breaking of land floe and displacement of enormous hummocked fields to canal, folding of approaching canal;

e) displacement and grounding of fragments of background rubbles when forming and breaking land floe in areas of shallow water of canal;

f) hummocking at icecovered routes of the Novaya Zemlya ice massif.

Probability of ice compression is very high during navigation in the winter-spring period. A length of route with the compression is about 60% of length of close ice routes.

A length of the ice routes (in miles) depending on the winter-spring navigation and the development of one or another glade clearing in south-eastern section of the Barents Sea and south-western section of the Kara Sea in various areas will be as follows (Table 2.7.):

Table 2.7.

NN A version of the choosen route	Nature of ice condition		
	Light	Medium	Heavy
1. Harasavey-Kara Gates Strait	180	210	250
Kara Gates Strait-Kolguev Island	180	180	300
2. Harasavey-Yugorsky Shar Strait	210	210	230
Yougorsky Shar Strait- Kolguev Island	180	180	300
3. Harasavey-Cape Zhealanya-Cape Nordcap	595	595	850

The time of passing ice route in a round trip Harasavey-Nordcap-Harasavey under various ice conditions and proceeding from average speeds of motion in different areas of the route in the Kara Sea and Barents Sea, is shown in Table 2.8. (in hours):

Table 2.8.

NN	Chosen route of sailing	A version of winter-spring navigation, hours		
		Light	Medium	Heavy
1.	Harasavey-Kara Gates-Kolguev Kolguev-Kanin-Kolguev-Kara Gates-Harasavey	54	70	132
2.	Harasavey-Yougorsky Shar-Kolguev-Kanin-Kolguev-Yougorsky Shar-Harasavey	60	70	126
3.	Harasavey-Zhelanya-Kanin-Zhelanya-Harasavey	92	120	200

Accepting 15% average reduction of the maximum speed of gas/methane carrier under hydrometeorological conditions in the round trip when sailing in ice-free water, we will obtain the following time delays for the passage of the methane carrier along ice area (Table 2.9. in hours):

Table 2.9.

NN	Chosen route of motion	Versions of winter-spring navigation, hours		
		Light	Medium	Heavy
1.	Harasavey-Kara Gates-Kolguev Kanin-Kolguev-Kara Gates-Harasavey	6	18	58
2.	Harasavey-Yougorsky Shar-Kolguev-Kanin-Kolguev-Yougorsky Shar-Harasavey	8	18	55
3.	Harasavey-Zhelanya-Kanin-Zhelanya -Harasavey	16	40	86

An analysis of time losses in the round trip shows that the Kara Gates and the Yougorsky Shar Straits may be recommended as the main routes for sailing. Since the export of LNG from the Yamal Peninsula is considered on the yearly basis with rhythm of departures from the port of Harasavey being 1-4 days, the delays of arrival-departure have not to exceed 2-4 days. Therefore taking into account a possibility of influence of navigational risks because of extreme conditions during ice navigation, the necessary volume of the LNG storage is chosen (Table 2.10.).

Table 2.10.

Indices	1	2	3	4
Volume of LNG production, mil cu m per year	1Î.32	2Î.64	3Î.967	46.45
Volume of production of LNG, th cu. m per day	31273	62545	93839	14Î758
Intervals of arrival of the methane carriers, days				
NGM-79À	2.4	1.3	0.9	0.6
NGM-135À	4.2	2.1	1.4	1.0
Possible increasing of interval of arrival in heavy ice navigation, days				
NGM-79À (through the straits)			0,3-2,3	
NGM-135À(Around the Zhelanya Cape)			0,7-3,6	

It is most preferable and purposeful for near perspective to use, in the transport technological system, the gas / methane carriers with the ULA class of the RF Register, which have quite powerful power units and are equipped with a pneumowashing device as a minimum.

Existence of the pneumowashing device will permit one to ensure high ice going capacity when sailing autonomously in ice, to protect from sticking the hull when compressing, to improve vessel's maneuverability when mooring. Bow part of the ship must be reinforced by the additional framing and equipped with a device for towing ship closely behind the icebreaker if such necessity arises.

It is known that when the transport proceeds behind an icebreaker in solid ice and especially under conditions of compression, a breadth of a ship is usually assumed to be two meters more than a breadth of the icebreaker. However as it was known from the operation experience of SEVMORPUT nuclear icebreaker on the line Murmansk-Dudinka, when a lighter carrier followed the ARCTICA icebreaker, including ice passages in the Kara Sea in winter-autumn period under the adverse ice conditions, there were no problems with delays, although the breadth of the carrier at CWL was three meters more than the breadth of the icebreaker. Therefore the chosen type and size of the gas / methane carrier NGM-79A for the TTS Harasavey-Europe with the breadth of 38 meters is quite justified, and one icebreaker of YAMAL type will be enough for escorting.

But when conducting a gas carrier of NGM-135A type in the complicated areas , the difficulties can arise if the ship itself can not overcome the ice of windward edge of canal. In this case, an assistance of two icebreakers sailing in ledge will be needed.

The routes of sailing of gas-carriers must be equipped with all kinds of means of navigational equipment, the regular hydrometeorological and synoptic prognoses must be supplied both by satellite systems and by aviation.

The icebreakers which work on the route and provide piloting for gas-carriers, must have helicopters on board for operative-tactical reconnaissance, satellite and other reliable communications.

A detailed and reliable information obtained by a ship, will assist to navigator to choose an optimal version of motion and protect the ship from facing an unforeseen-critical navigational situation.

Servicing TTS by two nuclear icebreakers of YAMAL and TAIMYR types when working on the routes and the TAIMYR type icebreaker - at the approaching canal, will ensure reliable stable work on the line, permit to reduce the risks of delay of the ships when sailing in winter-spring period even under difficult icely navigations.

Other navigational risks can arise from a force-major and are not subject to quantitative evaluation because of lack of appropriate observations.

The transport schemes of cargo delivery to Yamal and export of hydrocarbon raw materials are developed in a composition with an operative scheme of carriages by the marine fleet in the Western Section of the Arctic by the unified methods with use of computer. Its development has certain difficulties because of impossibility of independent sailing of transport ships in ice areas. Therefore, when planning Arctic carriages, it is necessary to take into account both work of transport ships and icebreakers which ensure its sailing in ice.

To solve this task, a simulating model of planning (drawing of motion graphs) of fleet work in the Arctic is used. With this, the graphs are drawn as a machine timely realization of process of carriages in accordance with the accepted planning decisions. The planning process is divided into two stages:

- distribution of the icebreakers and determination of working tactics of the transport fleet;
- development of the graphs of fleet and port operations.

To distribute the icebreakers, the methods of optimization are used, basing on consecutive analysis of the versions for light, medium or heavy kind of ice navigation.

A task of selection of economically optimal versions of fleet work in the Arctic is solved by means of computer on the basis of the fixed list of participation of icebreakers and transport ships in Arctic operations. On the basis of the developed norms and standards, the computer distributes the icebreakers into the working areas and determines an optimal composition of ship convoys in accordance with the criteria of optimization.

The plan targets for transport fleet are realized in the form of assignment to every ship or type of ship participating in cargo carriages, of direction of work, which are characterized by the points of loading/unloading, areas of sailing and terms of execution of transport operation. The operations of conducting the ships by icebreaker and the operations of sailing of the transport ships in ice under escort which are combined with the operations, are determinative for the graph of work of icebreaker and transport fleet. The typical graphs of work of NGM-135A ship in winter and summer periods of navigation are shown in fig.8 (a, b), the typical graphs of loading of these ships in the port Harasavey are given in fig. 9 (a, b). One can see from fig.9 that demand for berths is 2 units with regular work of the ships according to time-table. Fig. 9 shows that demand for berths is 2 units with regular work of the ships according to time-table. Fig. 9 shows that demand for berths is 2 units with regular work of the ships according to time-table.

Fig. 8(a) Typical scheme of ship's (NGM-135) proceeding in winter season.

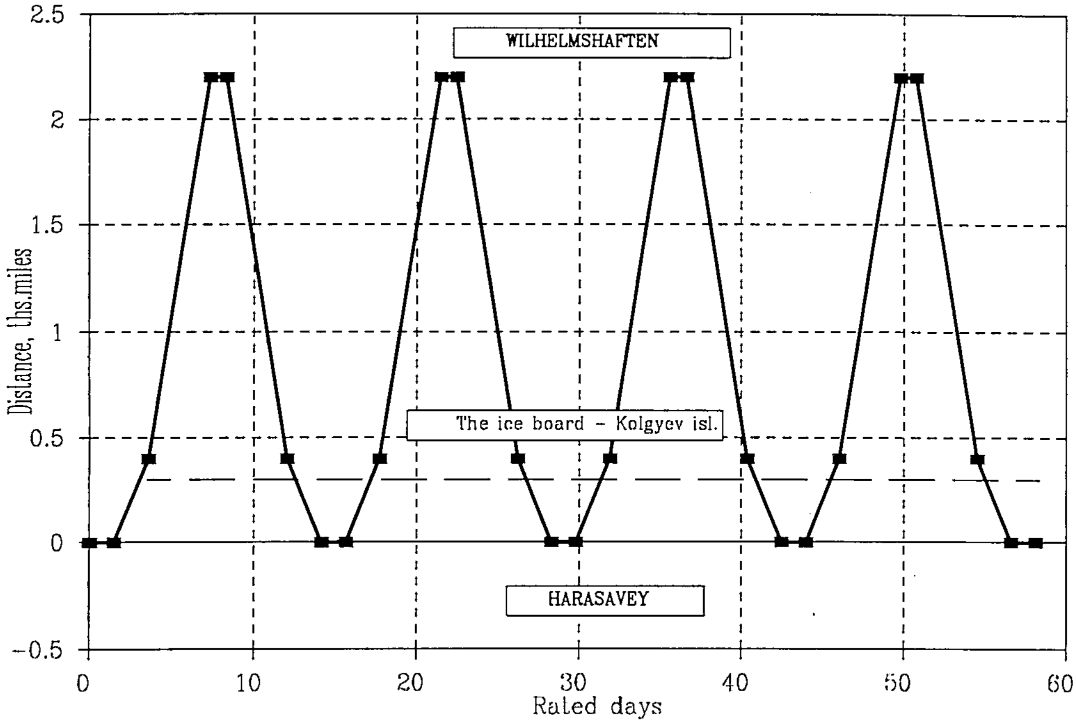


Fig. 8(b) Typical scheme of ship's (NGM-135) proceeding in summer season.

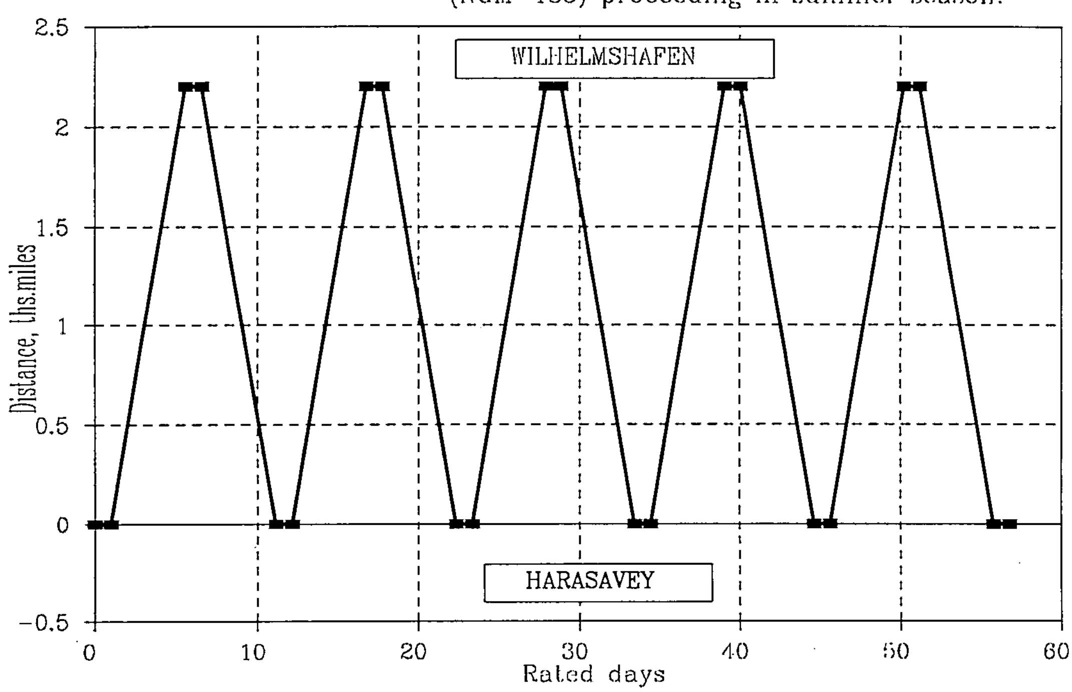


Fig. 9(a) Typical scheme of loading (p.Kharasavey) in winter season.

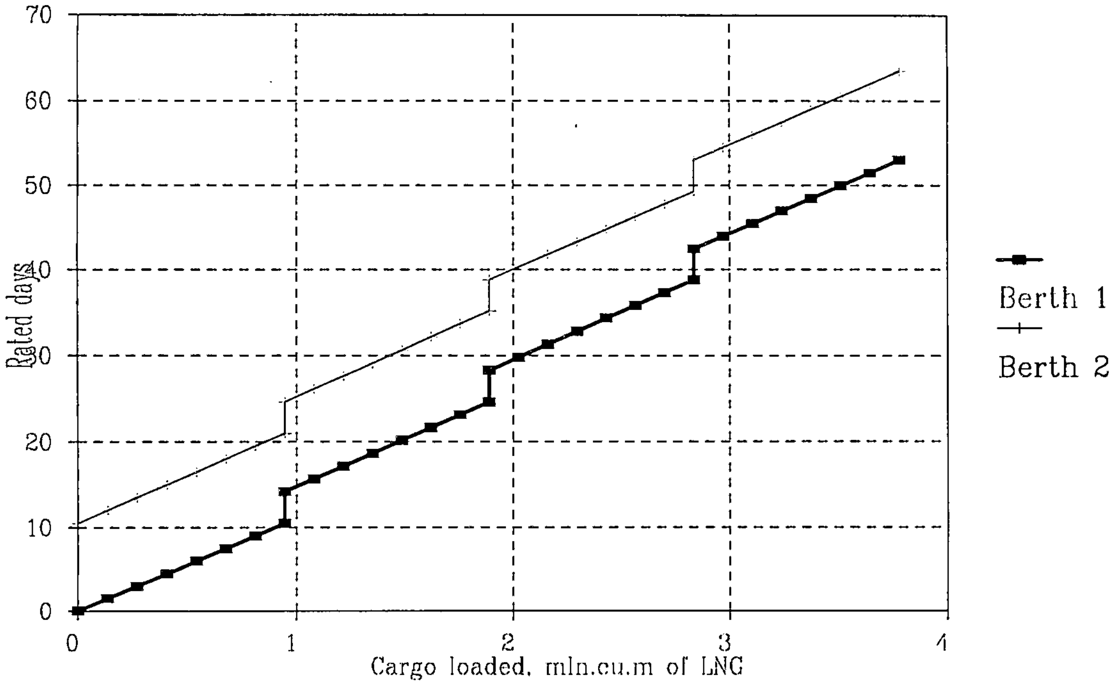
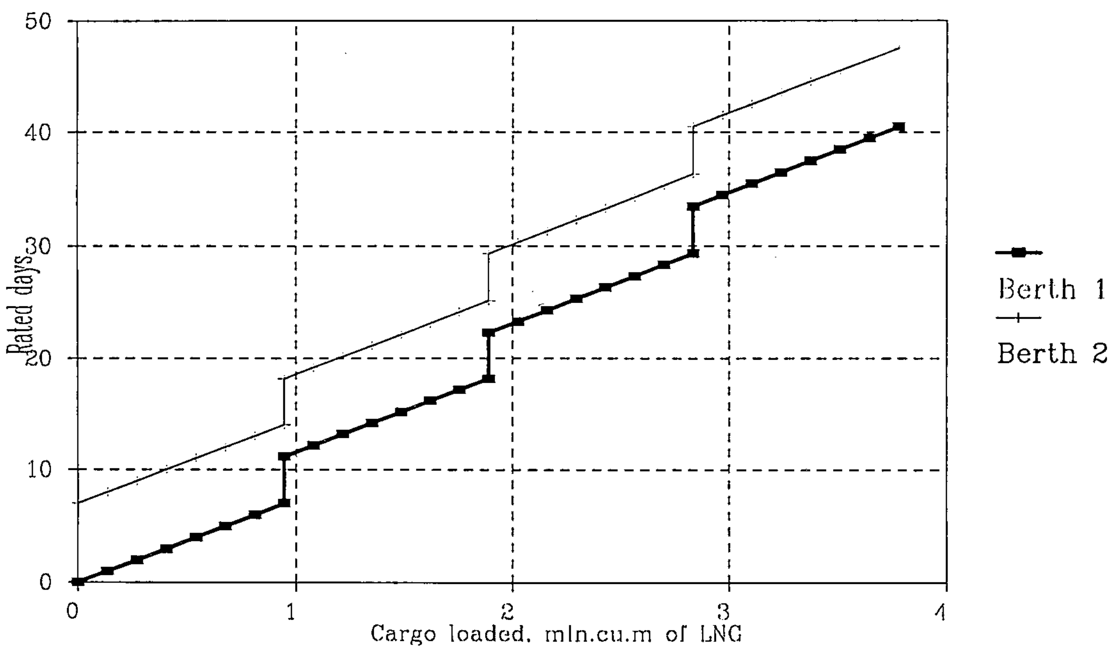


Fig. 9(b) Typical scheme of loading (p.Kharasavey) in summer period.



In accordance with the proposed conception of formation of the Arctic sea transport system, it is necessary to consider the following rated versions:

Version 1. Carriages from the port of Harasavey to an intermediate port at the Kola Peninsula are carried-out by methane carriers NGM-79A with a cargo capacity of up to 80 thous. cub. m and with ice-strengthened hull for ULA class of the RF Register. The carriages between the port of the Kola Peninsula and the port of Wilhemshaven are carried-out by methane carriers NGM-165 with a cargo capacity of up to 160 thous. cub. m at the first stage and NGM-200 with a cargo capacity of up to 200 thous. cub. m without ice reinforcement of hull - for foreseeable perspective.

Version 2. Carriages from the port of Harasavey to the port of Wilhemshaven at initial stage are fulfilled by methane carriers NGM-79A with a cargo capacity of up to 80 thous. cub. m with changing-over, after accumulation of experience, to the type and size NGM-135A with a cargo capacity of up to 135 thous. cub. m., with the hull strengthened up to the class ULA of the Register of the RF.

2.4. A number of ships recommended to build.

A calculation of demand for the ships has been carried out by two versions separately for summer and winter periods of exploitation. As the initial data for execution of such calculation, the following assumptions are accepted:

- Phased commissioning of natural gas liquefying plant in accordance with quantity of technological lines - 2,4,6,8 with a corresponding increase in annual volumes of LNG export production - 11,61; 23,32; 34,83;46,45 mill. cub. m. It is accepted by an order of the head developer - VNIIGAS.

- working period of the methane carriers at a transport scheme - 365 days, including winter one - 245 days, summer one - 120 days;

- a length of the round trip - 4300 miles including 800 miles in ice in winter period; the factors of cargo capacity and vessel speed of rated types and sizes of the ships are accepted according to data of the main technical and operating characteristics (See Table 1.2-1.5);

- a stowage factor of the methane carrier is accepted as 0.98 - according to information of foreign companies; - a coefficient of speed performance in ice-free water is accepted as 0.85 - from data of statistical analysis; - an average operational speed in ice is accepted as average monthly (quantity of the trips in every month) and is equal to 10 knots;

- a port time during the trip has been determined as average statistical data by means of analysis of the indices of international LNG carriages and are accepted to be 2.0 ship-days in summer and 2.5 ship-days in winter for NGM-79A. The indices of port time in a round trip for NGM-135A are accepted to be 2.5 and 3.0 ship-days; for NMG-165, which ensures carriages between non-freezing ports, the port time during the round trip will not exceed 2.0 ship-days;

- an operating period of methane carriers is determined taking into account the losses of time for repair and technical service and is 330 ship-days per year for NGM-79A, 340 - for NGM-135A, 200-345 - for NGM-165 and NGM-200.

The time of round trip and quantity of trips, have been calculated by accepted data are as follows:

	Winter	Summer
1. NGM - 79A (Main waterway - feeder)	7.6/32	6.0/20
2.NGM - 165 (Main waterway - feeder)	9.8/25	9.8/12
3.NGM - 200 (Main waterway - feeder)	8.5/29	8.5/14
4.NGM - 97A (Main waterway)	15.6/16	14.0/ 8
5. NGM -135A (Main waterway)	11.1/22	13.3/ 9

Annual carrying capacity for a ship is:

1. NGM - 79A (Main waterway - feeder) - 4043 thous. cub. m of LNG;
2. NGM - 165 (Main waterway - feeder) - 6120 thous. cub. m of LNG;
3. NGM - 200 (Main waterway - feeder) - 8033 thous. cub. m of LNG;
4. NGM - 79A (Main waterway) - 1866 thous. cub. m of LNG;
5. NGM -135A (Main waterway) - 4190 thous. cub. m of LNG.

By means of the indices of annual carrying capacity, a quantity of ships required to cover rated carriage volumes for every stage (phase), is presented in Table 2.11. NGM-200 shipbuilding is not stipulated at this stage since it is necessary to carry out more deeper technical economic studies regarding readiness of the shipbuilding base and availability of port complexes.

In the summer, transportation demand for calculated cargo volumes decreases by 1 - 3 pcs that enables us to provide ships repair without disturbing transportation process in a round year regime.

Table 2.11

Calculated transportation volume ths cu m of LNG	Main feeder TTS			Main TTS	
	NGM-79À	NGM-165	Total	NGM-79À	NGM-135À
11610	4/3*	2	6/5	7/6*	4/3*
23220	7/5*	4	11/5	-	7/6*
34830	11/7*	6	17/14	-	11/8*
46450	14/11	8	22/19	-	14/11*

Reference: * - winter/summer

The main feeder TTS has favorable prospects regarding an increase in capacity of the non Arctic going methane-carrier, if transferring from 165 000 cu. m to 200 000 cu. m.

In studying the working organization of the main feeder TTS, it should be expected that a distance of transportation scheme might increase, as experience shows, in the summer (by NGM-165 vessels to the Dolgaya Bay on the Vaigach Peninsula). In addition, the volume of summer transportation is realized by NGM-165 vessels, and demand for feeder NGM-79A vessels decreases to 6 pcs, and other vessels may be repaired or carry additional commodity.

Potential advantages of the main feeder TTS should be attributed to the broad possibilities on operative change of the working organization of heavy tonnage methane carriers of both the existing stock companies and those being established on the international market without any fall of transport economic figures.

2.5. Technical and economic feasibility study

Specific character of world gas industry resides in that international natural gas trade is being performed under long-term contracts basing on the state guarantees. In accordance with contract's terms, transportation expenses, as a rule, are included in the final product price, and are divided by certain ration agreed before between the sides.

Due to high LNG sea transportation technology, the technical and economic feasibility study of a single methane carrier became unreasonable, and the leading international companies came to the substantiation of technological transportation systems (or, giving a more precise definition, an industrial-transportation system in the composition of the cycle : extraction-production-transportation-consumption).

For the decision of LNG transportation problem from the field to consumption regions, transportation fleet plays a key role and influences the characteristics of cargo handling terminal and composite productive modules of LNG production plant. For this reason, specialized technological transportation systems (TTS) are being projected including the following elements as regards Harasavey field:

- LNG production plant;
- loading terminal and LNG storage plants;
- arctic going methane carriers;
- other methane carriers;
- transportation schemes-routes;
- supporting fleet - liner icebreakers, port icebreakers and tugs;
- reception terminal of consumer with regasification module and NG storage park connected through pipe lines. There is considered, as a sub-task, the reception terminal in the port of Wilhelmshafen (Germany).

Technical and economic feasibility study has been conducted for four calculated versions of organization of carriages; an initial basis of the organization is presented in sections 1.1, 2.3, 2.4.

1. Main - on the basis of NGM - 79A methane carriers of up to 30.000 cu m of capacity; quantity - 7 pcs, Russian built, ULA class , average series cost USD 170 mil each and transition to NGM -135 A of 135.000 cu m LNG; quantity - 11 pcs, ULA class, at a cost of USD 235 mil. per each vessel.

2. Main feeder - on the basis of NGM - 79A feeder methane carriers; capacity 79.000 cu m of LNG, 14 pcs, ULA class; USD 170 mil each cost. NGM - 165 without ice-class vessels are considered in the project - 165.000 cu m LNG, 8 pcs and at an average series cost of USD 250 mil. An alternative is economic evaluation of the main feeder TTS with use of prospective type of the main methane carriers - NGM 200 not ice classified, up to 200.000 cu m LNG, 6 pcs, at an average cost of USD 310 mil. per each vessel.

Important aspect when studying, is a correct choice of contract terms of the vessel construction that below research indicates.

The question is an influence of vessel construction cost on economic efficiency of the operation.

Realization conditions and scale of the taken project do not permit to accept cash funds for the vessel construction.

In this connection, a question of special significance will arise in relation to: a ratio according to which the vessel construction finance will be performed, actual dynamics of cash flow stipulated by one or another credit conditions and influence of these conditions on financial results of the vessels' operations.

Loan at 40 - 60 % of the project cost is the most typical for modern shipbuilding practice and, as a rule, the vessel become the guarantee of loan return and after passing tests and registration, she is rendered to the operator under bareboat charter conditions.

Loan at 80-100% takes place in modern financial practice on large industrial projects guaranteed by the state that due to especially huge volumes of the investments and great state importance of the project might be accepted as most suitable to this case.

Calculation and comparison of the potential versions of ordering the vessels have been executed for the construction of NGM-135 vessels on the basis of the following initial data:

1. Calculated contract cost of the vessel USD 235 and 310 mil.

2. Credit return is on standard conditions of the financing - by equal shares during 8,5 years being installed once half a year. Credit rate is within 8-10% a year and two years of the payment deferment.

3. Loan varies within 60-100% of the vessel's contract cost.

For the first two versions, the operator (future owner) remits remaining part of the contract cost in advance as a banking deposit on account of the bank-creditor executing stage by stage vessel's construction.

Basic final factors of economic efficiency of capital investments under the versions are presented in table 2.12.

Depreciation is calculated basing upon construction cost of the vessel and assuming 15 years depreciation period from the moment of putting the vessel into operation without regard to the remaining cost.

Absolute figures of depreciation for the vessels of USD 235 and 310 mil come to USD 15,67 and 20,67 mil a year, respectively.

Table 2.12.

Full credit cost on standard financing conditions

Factors	Absolute figures of the factors under the credit conditions		
NGM- 135 À			
Vessel's cost USD mil	235.0	235.0	235.0
Loan, % cost	60	80	100
Banking rate, %	8	8	8
Loan, USD mil	141.6	188.8	235.0
Own capital, USD mil	94.4	47.2	0
Credit price, USD mil	50.76	67.68	84.60
NGM - 135 LL			
Vessel's cost, USD mil	310.0	310.0	310.0
Loan, % cost	60	80	100
Banking rate, %	8	8	8
Loan, USD mil	186.0	248.0	310.0
Own capital, USD mil	124.0	62.0	0
Credit price, USD mil.	66.96	89.28	111.6
NGM- 135 À			
Vessel's cost, USD mil	235.0	235.0	235.0
Loan, % cost	60	80	100
Banking rate, %	10	10	10
Loan, USD mil	141.6	188.8	235.0
Own capital, USD mil	94.4	47.2	0
Credit price, USD mil	63.45	84.60	105.75
NGM - 135 LL			
Vessel's cost, USD mil	310.0	310.0	310.0
Loan, % cost	60	80	100
Banking rate, %	10	10	10
Loan, USD mil	186.0	248.0	310.0
Own capital, USD mil	124.0	62.0	0
Credit price, USD mil	83.7	111.6	139.5

A lot of applied questions remain beyond the framework of this research and require detail substantiation when studying economic efficiency of the final version of the examined TTS, particularly:

- whether the deprecation should be considered as a separate article of operational expenses or only as operator's income part without any taxation;

• how will economic factors of the vessel and TTS, on the whole, change in case of using different scheme of faster depreciation;

• how will these factors change in case of accounting for disposal and deprecated vessel's costs and some other special issues, which need comments of professional economist and knowledge of the commercial specific aspects in both Russian and international practice.

In any case it is obvious that under any conditions of financing, the ship's owner receives the same amount of depreciation money for 15 years which under other equal terms might serve as an argument in favor of maximum loan sum.

The calculation of capital investment return dynamics utilized in the present section, doesn't take into account the taxes privilege for the depreciation granted by the majority of governments as one of the directions of domestic shipbuilding support program and priority branches of national economy which could considerably decrease the actual level of capital expenses.

High technology of methane carrier construction is naturally responsible for high construction expenses which involve the redistribution of specific expenses with regard to the hull and ice strengthening of the hull, propulsion, cargo space and cargo handling systems.

Increased specific weight of cargo holds and systems in the cost of methane-carrier results in the necessity to reconsider technological requirements to the selection of propulsion output and in the possibility of increasing the speed.

Another feature of fleet organization is a full use of natural gas for the main engine and no bunkering with fuel whilst necessary emergency reserve is available.

Another distinctive feature of the fleet organization is a reasonable consideration of Arctic transportation process and selection of rational size and type of vessels as well as rational technological transportation scheme.

In this connection the above questions are necessary to study in detail.

2.5.1. Issue of choice of propulsion plant output

The operation experience shows that ice-going capacity of vessel generally depends on main engine's output, weight of a certain vessel, thrusters, shape of bow structure. The rules of the Russian Register states a minimum output of the main engines for ULA vessels and the ice-going capability is verified in view of economic operational factors relevant to the region of operation.

The minimum output of ULA carrier engine is lower than calculated on the basis of the existing methane carrier of close capacity and of the same architectural constructive type but the latter could be economically feasible for the vessels designed for such purpose.

The estimation whether it is advisable to increase the operational speed of Arctic going methane carriers within TTS, has been made on the basis of the following data:

- cargo quantity per voyage :135.000 cu. m. LNG
- methane carrier construction cost: USD 235 mil.
- annual transportation volume: 46,45 mil. cu. m. LNG
- distance of transportation: 2150 miles
- length of ice passage: 400 miles

- summer period 125 vessel-day
- winter period 240 vessel-day
- operation period 355 v-d-/year
- total berthing time per voyage: summer -2 v.-d. winter - 3 v. d.

Proposed analytical graph in fig. 10 (a, b) shows the ratio of changing average annual transportation capacity of one assumed vessel and a required number of similar type vessels to changing operation speed.

Analytical calculation shown in fig. 10 (a, b) enables us to make the following estimation:

- increase in operation speed from 18 to 20 knots makes it possible to reduce the need for fleet for the examined TTS by 1 vessel;
- increase in operation speed from 18 to 23 knots enables one to reduce the need for fleet by 2 vessels;
- increase in operation speed from 18 to 27 knots gives the reduction by 3 vessels.

The estimation of changes of the main engine cost as well as fuel expenses with increase in engine output and speed is given in fig. 11.

Final analysis of reasonability of the faster methane carriers construction for TTS of methane export with a volume of 46,45 mil. cu. m. a year is presented in table 2.13.

Table 2.13.

Economic evaluation of reasonability of increased speed shipbuilding for methane export TTS

Increase in speed to base point of 18 kn	Decrease		Expenses on growth		Investment difference
	N of vessel, pcs	Investment USD men	engine cost USD men	fuel USD men	operation expenses
2 kn	1	235.0	73.7	41.6	161.3 41.6
5 kn	2	470.0	149.6	217.4	320.4 217.4
9 kn	3	705.0	332.3	494.7	372.7 494.7

Fig. 10(a) Results from Alternation of Operation Speed.

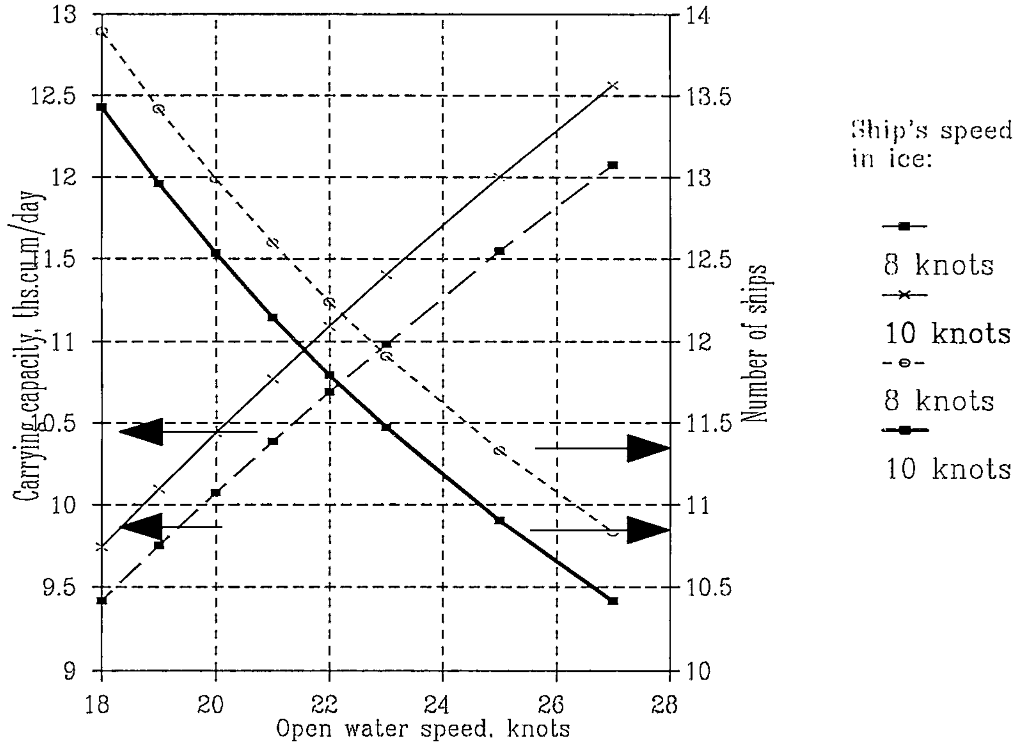
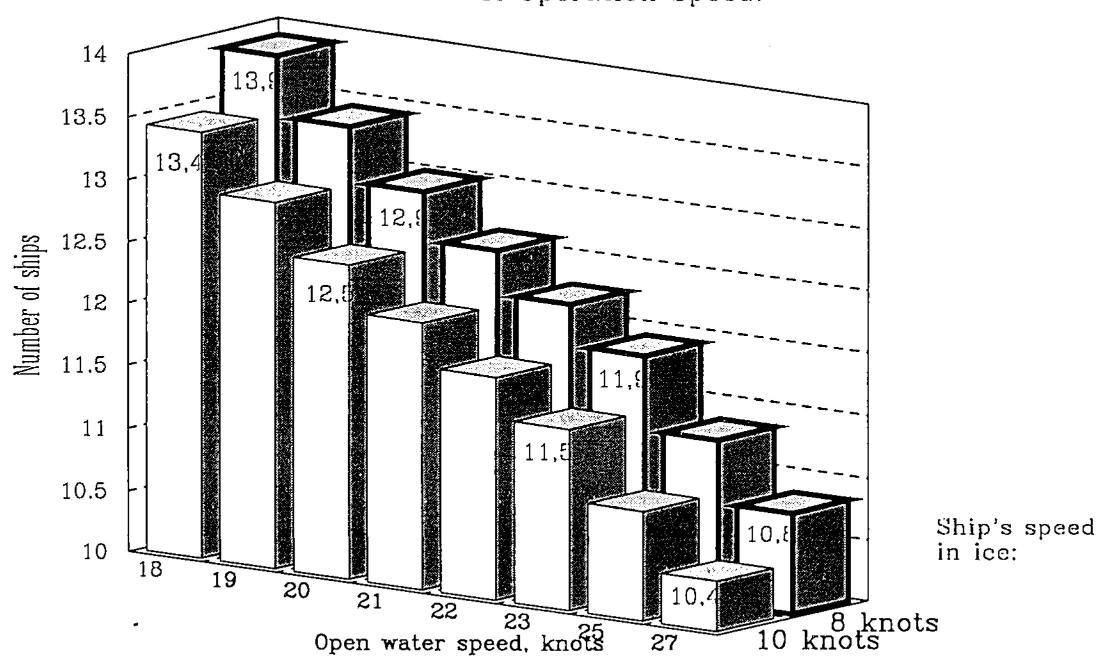


Fig. 10(b) Results from Alternation of Operation Speed.



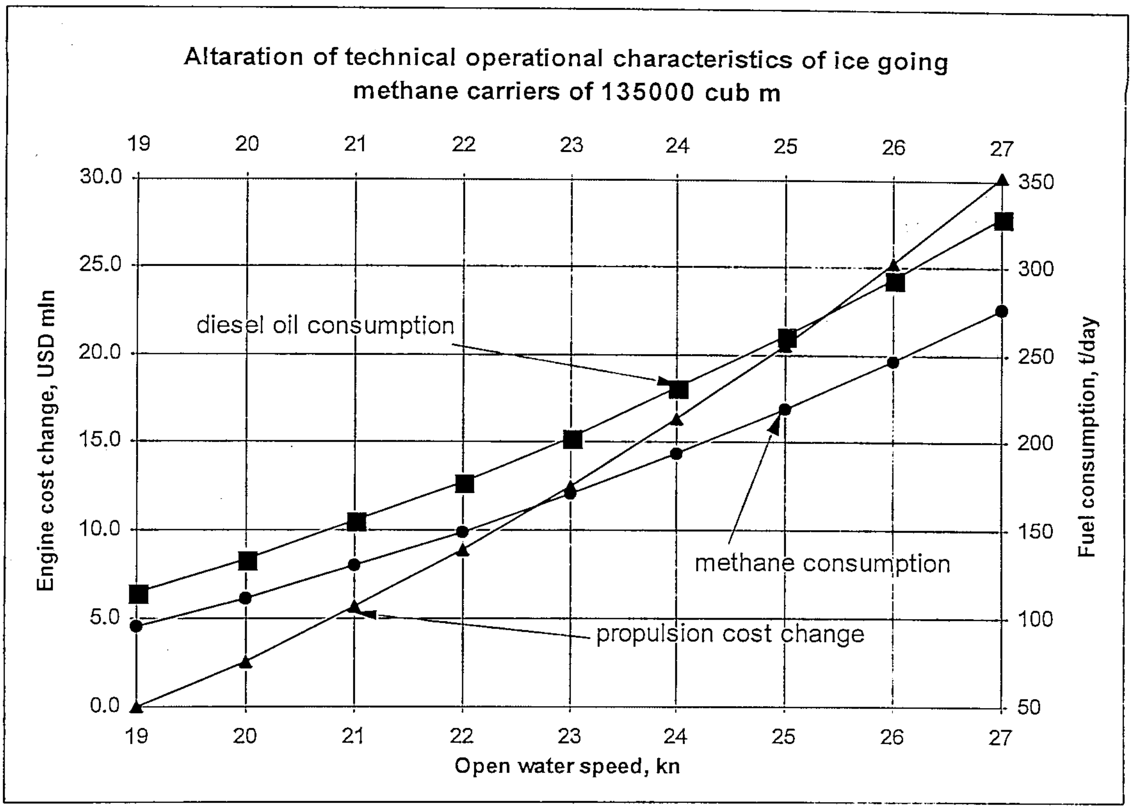


Fig. 11

Expert estimation made for the construction of increased speed methane carriers confirms such a reasonability if the increase in speed is equal to 5 knots. Under the rate of investment return EH = 0,15, additional existing fuel expenses exceed an economy of capital investments to the vessels when the increase of speed ranges from 23 to 27 knots.

2.5.2. To the question of using only natural gas as a fuel for vessel's engine

In the work of "Drewry Shipping Consultants" executed by order of UNIDO in 1980 it is indicated that heating power of 250 cu m of LNG as a fuel for the engine is equivalent to 130 t Ne (1300 mil. kilo calorie).

It was assumed there that 1 t Ne was corresponding to 1,18 t. of fuel in term of the heating power.

Therefore, we come to the following:

- 1 ton of fuel has a heating power appr 8.5 mil. Kc or 33.7 mil. BTE
- 1 cu m of LNG has a heating power appr 5.2 mil. Kc or 20.6 mil BTE - 1 ths cu m LN has a heating power appr 8.6 mil. Kc or 34.3 mil. BTE.

The cost of fleet fuel 380 sSt in Rotterdam in mid of 1995 came to about 110 USD/t. including delivery to the side of ship ("Cockett Marine Oil" data) and analysis of its absolute alterations for the last 5 years is presented in fig. 6 of section 1.4.

It is obvious from statistical review, that although the values at present time come to two-years-ago level, a considerable fall in bunkering price seems to be improbable for foreseeable future.

The port of Rotterdam has been accepted as a base port in relation to fuel cost, moreover, this port is a typical port in the aspect of level and costs of port services within the studied LNG delivery region.

In particular, the bunkering price in Rotterdam is one of the lowest in European ports. Creation of bunkering base on Jamal for known reasons will considerably increase the cost of bunkering which, as predicted, would be on the world level or close to it in Russia.

Calculated expenses on natural gas as a fuel for the engine might be assumed on the level of conventional FOB price (gas price at the valve of LNG production plant + liquefaction price) that, proceeding from the world analogs, will come up to not more than USD 70/ths cu m NG.

Thus, the price of the question might be clearly shown by way of example of calculations the results of which are given in table 2.14.

Table 2.14

Fuel consumption and its price per one vessel

Factors	Vessel's type*			
	NGM-135À		NGM-135 LL1	
1. Capacity LNG (100/98 %) ths. cu. m	**137,900/135, 150**			
2. Class	ULA		LL1	
3. Main engine type	SSD**	ST***	SSD**	ST***
4. Output, ths kW	31,0	28,0	73,0	66,0
5. Fuel consumption t/vessel-day				
Calculated speed , kn.	18,3	18,4	19,0/ 23,7	19,0/ 23,5
5.1. at sea (FO)	114,0	209,0	145,2/268,1	260,4/491,0
5.2. at berth (DO) with LNG boiling - off	30	30	30	30
5.3. at sea (FO)	0	91,0	27.0/141.0	143,0/373,0
5.4. at sea (NG)	0	76,6	22,8/126,2	120,3/313,8
6. Fuel expenses ths USD (v-d)				
6.1. at sea (FO)	12,5	23,0	16,0/29,5	28,7/54,0
6.2. at berth with consideration of LNG boiling-off	4,5	4,5	4,5	4,5
6.3. FO	0	10,0	3,0/15,5	15,7/41,0
6.4 NG	0	6,2	1,8/10,1	9,6/25,1
7. Calculated average annual fuel expenses, ths USD				
7.1. FO and DO	283	3219	1164/4834	4892/12320
7.2. NG and DO	283	2103	811/3248	3101/7652

The following comments to this table should be done:

* vessel's type according to the classification of CNIIMF

1 - capacity according to the theory /theoretical maximum cargo quantity;

4 - maximum theoretical output and rated operational output for steam turbine.

5 - theoretical fuel consumption calculated by CNIIMF

5.1. Theoretical fuel (FO) consumption by the main engine on the open sea without use of LNG.

The calculations assume that vessel runs through ice at less speed but with the same operational output and fuel consumption.

5.2. - at berth with cargo handling, without cargo handling operations - 6 t of fuel a day for each version.

5.3. - quantity of boiling gas which might be used as a fuel is 99,2 t a day for each version.

5.4. - additional LNG quantity which might be used instead of oil fuel (where it is necessary).

6. - articles 6.1 - 6.4 are corresponding to appropriate positions 5.1-5.4.

7. - calculations are made basing on operational period 355 v-day/year and average annual coefficient of utilizing voyage time Kg - 0.827

** Low revolution engine

*** Steam turbine

Main conclusions:

1) The version of ULA class vessel and low revolution engine is the most effective version in terms of fuel expenses.

2) Calculated fuel expenses with due account for boiling cargo is 7,4 times lower than in steam turbine version of oil fuel.

3) In icebreaker variant, an increase in operational speed by 4-5 knots leads to growth of fuel expenses of about 4 fold according to the version of low revolution engine and - of 2,5 fold as for steam turbine,

4) Economic advantage of gas is out of question for the problem under consideration.

Calculated LNG expenses are 1,4-1,6 times as low as the fuel expenses in all the versions.

Missed profit of cargo owner

The version of using the cargo as a fuel for the main engine among all advantages and disadvantages decreases the quantity of the cargo delivered.

It is obvious that technologically the boiling methane seems reasonable to use as a fuel. However, full substitution of fuel by methane is not considered as profitable. Therefore, it will be logical to estimate the whole possible spectrum of losses in this version from the point of view of cargo owner.

For this purpose according to the data available, assume the price interval (fuel 380 sSt) as lying within the limits of changes according to the statistics for the last 5 years, i.e. from 80 to 110 USD/t., and for estimation of overall volume of missed profit of cargo owner, three levels of calculated prices for natural gas are assumed:

1. USD 70/ths cu m NL - approximate FOB price including extraction, delivery to LNG production plant and liquefaction of natural gas.

2. USD 95/ths cu m NG - approximate CIF price on the level of 1993/94 for the West Europe market.

3. USD 120/ths cu m NG - possible retail price of natural gas when selling to the final consumer.

These three price levels as supposed, include a certain profit rate on the incurred expenses, including transportation, and it is logical to expect the increase in overall cargo owner profit volume as the commodity is delivered to consumer under common conditions.

Results of computer analysis of version calculations are shown on diagram, fig.12.

It is clear that within the adopted price intervals, the change-over from fuel oil to LNG could be economically effective with allowance for FOB price or at fuel oil price higher than USD 100/t.

Consolidated LNG transportation factors for the complete project development depending on variants of the main TTC are given in table 2.16 . and those of the main feeder TTC are given in table 2.17.

Fig. 12. Prices Ratio of Heating Power Among Methane & HFO.

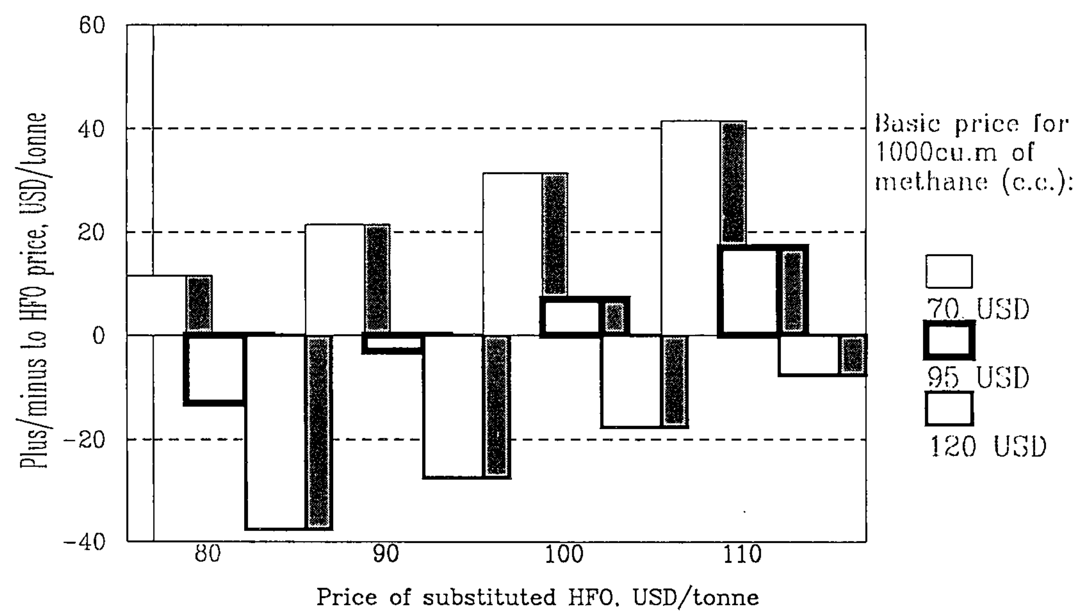


Table 2.16.

Consolidated LNG transportation factors depending on variants of the main TTS fully developed

Factors	I stage NGM-79A	II stage NGM-135À	Total	NGM-135À
Calculated transportation volume, mil cum	11.61	34.84	46.45	46.45
Required number of the vessel's, pcs	7	10	17	14
Capital investment, USD mil	1190.0	2350	3540	3290
Operational expenses, USD mil, including:	58.5	177.5	236.0	250.9
methane carriers	51.9	167.2	219.1	234.0
icebreakers	6.6	10.3	16.9	16:9
Crew number, persons	340	683	1023	956

Table 2.17

Consolidated LNG transportation factors depending on variants of the main feeder TTS fully developed

Factors	NGM-79À	NGM-165	Total	NGM-79À	NGM-200	Total
Calculated transportation volume, mil cum	46.45	46.45	46.45	46.45	46.45	46.45
Required number of the vessels, pcs	14	8	22	14	6	20
Capital investment, USD mil	2380.0	2000.0	4380.0	2380.0	1860.0	4240.0
Operational expenses, USD mil,	120.6	106.0	226.0	120.6	103.5	224.1
including: methane carriers	103.7	106.3	210.0	103.7	103.5	207.2
icebreakers	16.9	-	16.9	16.9	-	16.9
Crew number, persons	680	547	1227	680	410	1090

Analysis of factors of the above alternatives enables us to note the advantage of the main TTS over the main feeder TTS consisting in amount of capital investments into transport fleet (29-33%) with small increase in the existing operational expenses (4-11%) which will have to be compensated by additional expenses on the transshipment at an intermediate port.

Estimation of commercial conditions of the project realization made through the use of tables 2,16-2,17 with participation of some domestic and foreign investors permits us to select the two main versions of possible division of transportation means and investments for its construction. It should be expected that variants of the main TTC development will be performed on an equal basis with the fleet construction and operation due to the development of transport composing a certain income article in any production.

Development versions of the main feeder TTS make it possible for the Russian side to hope for acquisition and operation of Arctic fleet by its own funds creating additional working places and receiving the right to collect depreciation charges on the renovation of transportation means. Besides, only part of transportation means which provides carriages from ice free port, will be distributed between the project partners.

Possible distribution of transportation means and capital investments on the versions under consideration could be characterized by the following numbers (pcs/USD mil):

	Main feeder	**Main**
Russian partner	18/3380	7/1649
Foreign partner	4/1000	7/1645
Total	22/4380	14/3290

Thus, the main feeder TTS realization enables the Russian side to expect the main income to be earned from transport leg.

2.6. Economic efficiency estimation of the starting stage of the LNG export project realization on the basis of methane carriers of up to 80.000 cu m.

Determination of the realization efficiency of LNG export investment project and preparation of the road transfer terminal in the port of Harasavey for operation have been carried out aiming at preliminary evaluation of necessary financial means for investments and commercial reasonability of the creation of stock company for this purpose.

Methodology basis of commercial efficiency calculations on the considered investment project includes:

a) conceptual assumptions of financial analysis of investment efficiency utilized in foreign practice, particularly, UNIDO edition - W.Behrens, P.M. Hawranek. Manual for the Preparation of Industrial Feasibility Studies. Newly revised and expanded edition, November 1991;

b) domestic publications on this question including " Methodical recommendations for investment project efficiency estimation and project selection for financing " Moscow, 1994.

In accordance with the adopted methodology, the evaluation of commercial efficiency of the investment project was made by means of scale modeling cash flows from investments, productive and financial activities of stock company within the assumed 12 years period including starting stage of the project realization by means of methane carriers of up to 80.000 cu m.

Calculations were executed on the basis of data presented in other sections of the present feasibility study using the formed (basic) prices in USD. The following factors were calculated to evaluate the project's efficiency:

a) Integral effect -э,

$$э = sum\ э(t) * a(t), \qquad (1)$$

where э (t) - net cash flow in year t (annual effect)

$t = 0,1,...,T-1,$

$$э(t) = P(t) - K(t) \qquad (2)$$

P (t), K (t) - results of productive and investment activities of stock company in year t;

T - calculation horizon, T = 12 years;

a (t) - coefficient of discount in year t at rate of discount E = 0.1,

$$a(t) = 1/(1+э) \qquad (3)$$

b) Profitability index - PI

$$PI = э/K + 1 \qquad (4)$$

where K - discounting investments

$$K = K(t) * a(t). \qquad (5)$$

c) Internal rate of income - Ec equals such rate of discount Eb when

$$\sum_{t}^{t} э(t)/(1 + Eb) = 0 \qquad (6)$$

d) Period of investment return - Tr - is defined by minimum time interval from the starting period beyond of which the limits of integral effect become and remain not negative.

Besides, the investment project is considered to be effective, if:

a) Integral effect э>0 or profitability index PI>1.

b) Internal income rate Ec>E

Period of return Tr allows us to conduct the analysis of accepted length of the calculation period which must be not less than Tr, i.e. T>Tr .

The results of the calculations are presented in table 2.18 and 2.19

Table 2.18

Investments into basic capital and injection of basic funds

Factors	yearly figures, USD mil						Total
	0.00	1.00	2.00	3.00	4.00	5.00	USD, mil.
1.Total investment, USD mil	600.00	770.00	954.00	376.00	376.00	0.00	3076.00
including:							
LNG production plant	440.00	430.00	430.00	0.00	0.00	0.00	1300.00
Fleet	0.00	190.00	374.00	376.00	376.00	0.00	1316.00
Port	160.00	150.00	150.00	0.00	0.00	0.00	460.00
2.Putting basic funds, USD mil including:	0.00	0.00	1125.00	1199.00	376.00	376.00	3076.00
LNG production plant	0.00	0.00	660.00	640.00	0.00	0.00	1300.00
Fleet	0.00	0.00	188.00	376.00	376.00	376.00	1316.00
Port	0.00	0.00	277.00	183.00	0.00	0.00	460.00

Investments into basic capital (table 2.18) are to be made during 5 years and would be expected to come up to USD 3076 mil, including fleet - 4 years at USD 1316 mil (42,8%).

In table 2.19, the effect from the product realization (line 2,2) was calculated by multiplication of annual volume of transportation carried out by methane carriers which had been put into service, by the price CIF "Katar-Italy" accepted by "Eurogas" project.

Table 2.19

Factors on investment project of LNG export by methane carriers of NGM - 79A type and preparation of technological terminal in the port of Harasavey for service

Factors	Figures on years of construction and operation											
	0	1	2	3	4	5	6	7	8	9	10	11
1.Investments,USD mil including:	600.0	770.0	960.0	380.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1.Investments in basic capital	600.0	770.0	954.0	376.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2.Investments in working capital	0.0	0.0	6.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.Production, USD mil, including	0.0	0.0	142.0	227.5	587.8	817.5	846.4	875.4	904.3	933.3	962.2	991.2
2.1.Putting basic funds	0.0	0.0	1125.0	1190.0	376.0	376.0	0.0	0.0	0.0	0.0	0.0	0.0
2.2.Effect from realization on the product	0.0	0.0	262.0	786.0	1308.0	1629.0	1629.0	1629.0	1629.0	1629.0	1629.0	1629.0
2.3.Current expenses without depreciation	0.0	0.0	51.4	85.0	99.8	114.6	114.6	114.6	114.6	114.6	114.6	114.6
2.4.Depreciation	0.0	0.0	75.0	155.0	180.1	205.1	205.1	205.1	205.1	205.1	205.1	205.1
2.5.Financical result	0.0	0.0	135.6	546.0	1028.1	1309.3	1309.3	1309.3	1309.3	1309.3	1309.3	1309.3
2.6.Taxes	0.0	0.0	68.6	234.7	410.5	516.0	516.0	516.0	516.0	516.0	516.0	516.0
2.7.Net profit	0.0	0.0	67.0	311.3	617.6	793.3	793.3	793.3	793.3	793.3	793.3	793.3
2.8. % on credit	0.0	0.0	0.0	238.8	209.9	180.9	152.0	123.0	94.1	65.1	36.2	7.2
3.Finans, USD mil,												
Factors	0	1	2	3	4	5	6	7	8	9	10	11
3.1.Stock capital	600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.2.Long-term credit	0.0	3076.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.3.Credit return	0.0	615.2	0.0	289.5	289.5	289.5	289.5	289.5	289.5	289.5	289.5	144.8
4.Reserves of funds, USD mil	0.0	1690.8	-818.0	-442.0	-81.7	528.0	556.9	585.9	614.8	643.8	672.7	846.4
5.Year end balance, USD mil	0.0	1690.8	872.8	430.8	349.1	877.2	1431.1	2020.1	2634.9	3278.8	3951.5	4798.0
6.Annual effect, USD mil	-600.0	-770.0	-818.0	-152.5	207.8	817.5	846.4	875.4	904.3	933.3	962.2	991.2
7.Coefficient of discounting effect USD mil	1.0	0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	0.5132	0.4665	0.4241	0.3855	0.3505
8.Integral discounting effect USD mil	-600.0	-1300.0	-1976.0	-2090.5	-1948.6	-1441.0	-963.2	-513.9	-92.0	303.8	674.7	1022.2

Taxes (line 2.6) include income tax (35% from financial result) and property tax (2% from remaining cost of basic funds and total investments into the working capital)

line 1 = line 1.1 + line 1.2

line 2 = line 2.4 + line 2.7 - line 2.8

line 2.7 = line 2.2 - line 2.3 - line 2.4 - line 2.6

line 3 = line 3.1 + line 3.2 - line 3.3

line 4 = line 2 + line 3 - line 1

line 5 = line 5 (t-1) + line (t)

line 5 (0) = line 4 (0)

line 6 = line 2 - line 1

line 7 = formula (3)

line 8 = line 8 (t-1) + line 6 (t)* x line 7(t)

line 8 (0) = line 6 (0)* x line 7(0)

It is seen from this data that in order to establish a stock company under the accepted policy of attracting loan, it is necessary to have one's own (stock) capital in the first year of the calculated period to the tune of USD 600 mil., which provides positive balance of collected cash flows to the end of each year with the following figures of efficiency:

Integral effect (formula 1) - USD 1022 mil

Profitability index (formula 4) - 1.39

Internal income rate (formula 6) - 0.17

A period of the return is 9 years from the moment of construction started, and 3 years after bringing up the project to full capacity. Presented factors show commercial efficiency of the starting stage of the LNG export project carried out by methane -carriers of up to 80.000 cu m. The accepted investment conditions enable us, in the second year of construction, to send more than USD 800 mil for reconstruction of the building site at Sevmashpredprijatie with a view to make productive preparation for the construction of series of methane-carriers of 125.000cu m each. Besides, the stock company established at the expense of credit and its own funds is in a position , starting from sixth year of the project realization, to come to financing the second stage of its technical and material bases developments and to complete their construction by the tenth year increasing annual LNG export by a factor of 2 , that is, from 10,32 to 20,64 mil cu m.

Further research in this sphere must be directed at detailed evaluation of not only commercial but also economic and budget efficiencies of this project considering its development for the future. The main focus of interest must be on the problem of foundation of the stock company and optimization of its financial activity.

3. SUPPORTING FLEETS

In the system of transportation supply of the high-latitude regions, an icebreaker fleet is of great significance. According to its tasks, the icebreaker fleet is divided into liner and port fleets.

List of liner icebreaker fleet of Russia consists of nuclear "Arktika" type vessels of 75.000 horse power. Utilization of nuclear energy in icebreaker building could be explained by necessity to provide maximum autonomous capability of icebreaker operations in Arctic conditions where the regular supply with oil fuel is connected with high expenses. Calculations show that the scope of competitive capacity of diesel engine as compared with nuclear one, lies within 35-40 Mw. Such an output, with the use of the last achievements in design of hull shape, is able to provide ice going capacity of icebreakers close to 2,5 m. Besides, the problem of increasing of the autonomous sailing ability is still remaining.

To provide stable and guaranteed escort of vessels in shallow Arctic regions, icebreakers "Taimyr" and "Vaigach" were built in Finland (draught 8 m). These icebreakers are equipped with domestic mechanisms which proved itself fit to work in difficult Arctic conditions (nuclear reactor, main and auxiliary turbines etc.). Steel characterized by high strength and stressing viscosity under low temperatures, is utilized in hull composition. The main engine of icebreaker consists of two turbo generators which provide maximum continuous output of 50.000 horse power that enables the icebreaker to pass through the ice of up to 2 m thick and to provide effective icebreaker operations at temperatures to - 50 C.

At present, nuclear icebreakers play the leading role in icebreaker fleet operations and have a direct bearing on the reliability of Arctic transportation links. The experience acquired by icebreakers' personnel, shipbuilding specialists and researchers of Russia shows that success of escorting of transport vessels depends not only on power of an icebreaker but also on optimal course in ice and knowledge of ice going tactics.

Operating limitations were chosen in consultation with MSE, thus, to ensure stable work of the TTS from the port of Harasavey in the winter season, one icebreaker of ' Arktika' type and one of 'Taimyr' type must be available. Total icebreaker charter time assumed in the calculations comes up to 240 vessel-day for each icebreaker.

The composition of other types of supporting fleet include sea tugs, pilot boats, oil & garbage collecting vessel, vessels for processing waste, floating bases, passenger boat, road diving boat and other crafts the characteristics of which are presented by Lenmorniiproject in the section "Technical and economic substantiation of development of LNG technological complex the Harasavey cape region of the Jamal Peninsula".

4. ELABORATION OF QUESTIONS OF TOWING TECHNICAL SUPPLIES TO THE PORT OF HARASAVEY (6).

The technical supplies for a liquefying plant consist of:

- 8 pontoons with main dimensions 92 x 56 x 10 m each;
- 3 floating LNG storage barges with main dimensions 74 x 74 x x 10 m each.

More complete information concerning supply of pontoons and floating storage barges is not available at this stage, which does not permit us to formulate in detail their characteristics as objects of towing. Therefore, in the section an economical evaluation of operating questions of towing technical supplies from the assumed port Severodvinsk (SEVMASHPREDPRIYATIJE) to the port of Harasavey has been elaborated and introduced as follows:

- determination of necessary traction for towing;
- requirements to tugs, a method of towing;
- supply of towing operations;
- a route and calendar period of towing operations;
- economic indices of expenses on towing.

It was recognized that for deeper development of the project of movement (in particular, concerning selection of certain tugs, carrying out calculation of tow lines, discovery of peculiarities of object behavior when towing etc.) it is necessary to carry out the purposeful technical projecting, with simulation of towing process included in its program.

The peculiarities of towing of pontoons and barges.

The technological installation is an engineering structure and is intended for an assembly of the processing line for liquefying NG and temporary LNG storage .

The technological installation is non self propelled structure, therefore its movement from one place to another must be performed by towing.

The hull of this object is to be built on a caisson principle, thus, it has rectangular form without any fairness of lines. A buoyancy can be provided by constant tanks and ventilated ballast tanks located between the walls of caisson.

Taking into account that on a route of a passage to be made, there are few chances to meet heavy swell and these chances can be additionally reduced by operative control while sailing, so we consider it is possible to tow vessels with a draught not more than 7 m.

Large size and form of the hull of a flowing technological installation having no fairness of lines, will produce strong resistance of water when moving. The high speed of towing in spite of the powerful tugs used, will be impeded by this circumstance. The practice of long distant towing of floating docks (the objects which are comparable as to their towing characteristics with the floating docks) shows that really available speeds lies within 3-5 knots. One can believe that real speeds of towing technical installation will be 3.5-4.5 knots in ice-free water, even with an optimal selection of tugs.

In marine practice the cases are known, when for the purpose of improvement of the fairness of lines, the temporary structures designed as a bow streamlined structures were mounted. As to the above objects, such possibility, in our opinion, is excluded because of their large dimensions; such structure must have large dimensions and weight which will cause serious troubles involving durability and fastening the structure to the hull of caisson.

Taking into account that the technical installation (object) has no rudder gear and side thruster, all changes of movement direction must be carried out only by the tugs itself. With this, an execution of the turn becomes a difficult task because of significant inertia of the object. This circumstance forces one to look for a possibility of moving along straight extent stretches and makes it necessary to use the stern tug assistance when turning.

A necessity of using of the second tug may be also explained by a large windage area of the installation which may contribute to significant drift when strong beam winds are blowing. In these cases, a stern tug must compensate the drift, keeping the object on the course. The stern tug will be in need also to damp the inertia and help to hold the object in place when the caravan stops.

The hydrometeorological conditions of sailing for a NSR route can often and quickly change. These circumstances as well as slow speed of the caravan can be attributed to the necessity of:

constant correction of real and predicted conditions of navigation in the area of the caravan movement (within the range of about 200 miles);

fast connection to the caravan of an additional tug support to provide security of the installation (object) in tow.

Choosing route of caravan

The average periods favorable for towing object along the transport scheme Severodvinsk-Harasavey, correspond to a period of navigation from the third decade of July until the first decade of September.

A length of the transport scheme changes from 850 to 900 miles with allowance for passage through the straits of Kara Gates and Jugorskij Shar. The selection of a route is carried out with due account of location of the nearest shelter port, at a distance of not more than 100 miles from the route. The operative plans of passage along separate legs are worked out here:

Severodvinsk - Morzhovets island - 160 miles;
Morzhovets island - cape Kanin Nos - 130 miles;
cape Kanin Nos - Kolguev(Bugrino) island -160 miles;
Kolguev island - Matvejev island - 200 miles;
Matvejev island - cape Chirachy - 50 miles;
Matvejev island - cape Yarosel - 50 miles;
cape Chirachy - Harasavey - 140 miles;
cape Yarosel - Harasavey - 190 miles.

The slow speeds of caravan and its vulnerability in respect of hydrometeorological and, probably, ice conditions will require one to find out more details of situation in order to take an appropriate decision in due time:

- for correction of general route;
- in respect of places of shelter;
- in respect of other practical decisions.

Since more reliable data about sea condition, including possible ice conditions, are coming through air reconnaissance, then it is necessary to provide practically daily flights within the range of 150 - 200 miles from the caravan, but not less than 1 time per 2 days and for reconnaissance of more distant areas for the purpose of prognosis of changing sea conditions - not less than 1 time per 4-5 days.

To ensure safe towing, it is necessary to organize continuous control of technical state of the object in tow, which must be done by its crew proceeding from a necessity of executing general productive functions when moving. These functions are:

- dead reckoning, watch-keeping, communicating, supervision for situation, signaling;
- ensuring normal work of mechanisms, units and life-supporting systems, which must be in service when towing;
- control for state of hull during towing, necessary actions taken to provide proper damage control;
- ensuring the presence of persons on the object in tow. The number of crew members necessary for carrying out the main productive functions is defined to be 16 persons.

A choice of towing caravan and method of towing

As was pointed out above, at the moment of development of the feasibility study, the available initial data do not contain information concerning towing and mooring equipment, some constructive special features of hull and superstructures etc. But without knowing such details as well as without experience of long towing of similar objects in Arctic conditions, it is practically impossible to substantiate not only an acceptable method of towing (including the calculation of towing lines and its components, the ways of fastening and casting off the hawsers etc.) but also to determine a certain type of towed ships. This task in our opinion can be positively decided only by way of carrying out a special technical project ''Substantiation of a method and technical calculation of towing of an object''.

As for towing of an object it should be noted that in main composition of a caravan, except of the object in tow there are some traction tugs, which ensure advancing movement along the route and a stern tug, which ensures the control of the object and assistance when changing motion. It is wise to keep the same tugs during all time of towing from the beginning to the end.

Additional tugs may be used to provide additional towing forces for passing the straits, increasing speed of towing or sailing in the open pack ice. Using additional tugs has an episodic character when deciding emergency tasks.

The main tugs are required:

- to provide necessary traction forces;
- to be capable to work effectively in the towing regime for a long time;
- to be classified at least as UL -type ships i.e. having ice hull strengthening (UL-classified ships are increasingly more capable).

In principle, such requirements are best of all met by icebreakers and ocean tugs and tug-salvage ships having appropriate ice class. Using transport ships in spite of the main traction tugs is undesirable since their engines and propeller complexes are not adapted to a continuous work in traction regime and in this respect their work will be ineffective.

When selecting tugs by their power, one should take into account that a value- N of this power must satisfy the following condition:

$$N=N1+N2+N3$$

where: N1 - a power, that provides traction at hook.

From the experience of towing of the similar objects, a value of traction for translation must be not less than 100 t and for controlling the object - not less than 40 t;

N2 - a power, ensuring its own motion at a fixed speed (4 knots); it is determined in reference to certain type of tug;

N3 - a reserve of power, recommended by marine practice for the cases of towing in ice (up to 30-40%).

Taking into account these requirements, in our opinion, it is reasonable to use ice breaker with a power of about 12-15 ths. h. p. as the main traction tug and as a stern tug - a tug classified as S1 ice class and having a power of 4-4.5 ths. h. p.

At a stage of preliminary consideration, a question about method of towing remains uncleared, and a problem is conditioned by the characteristics of objects, particularly by form and size of the hull.

So, almost rectangular configuration of the hull provides two versions of towing - with an angle of square being moved forward and with a side of square -forward; both versions have their advantages and restrictions when sailing in open water and in open pack ice. In addition, while deciding the main question - which version ensures best speed with less efforts and provides best capability in ice - the next not less important questions arises, for example: determination of optimum diagram of exerted powers, length and composition of the towing lines, character of behavior of object when towing (yawing etc.). These tasks have not ordinary numerical solutions and answers in our opinion can be obtained as a result of modeling the process (mathematical model with use of computer or natural model in experimental basin).

An analysis of composition and technical characteristics of icebreaker and the towing fleet, permits us to recommend the icebreaker Kapitan Sorokin with a nominal stress on hook equal to 60 t as a bow tug. The salvage ship "Agat" with a power of 6 ths. h. p. is recommended as a stern tug.

In ensuring of successful conduct of caravan along the NSR route, a leading role belongs to effective air reconnaissance flights in the areas from Kolguev island to the port of Harasavey , the need for which is restricted by 10-12 hours.

A total time spent for an escort of one caravan is 10-12 days.

Cost evaluation of towing of technical objects

It is reasonable to carry out such calculations at the international price level when evaluating operation cost in hard currency, and at level of internal prices as well when such price is introduced in rubles. A price level is defined as a value of a lease rate (in hard currency or in rubles) per unit of time, which is spent for carrying out towing operations.

Lease rates of certain technical equipment according to data of the Planning Department of the Murmansk Shipping Company as of 1994 are shown in table 4.1.

Lease rates in hard currency has been examined by MSC when organizing an international shipping in the Arctic. Lease rates in rubles are established in accordance with active instructive and normative documents of the Transport Ministry of the RF as of second half of 1994.

On the basis of this data (table 4.2), calculations have been made to obtain the cost of towing of technical installation (object) for two levels of prices.

Table 4.1

The lease rates of towing for use of Russian technical means

Technical means	Rent rates per day	
	Hard currency (am.doll.)	Ths.roubles
A/I ARCTICA	45000	65000
A/I TAIMYR	35000	43400
I/B KAPITAN SOROKIN	20000	41700
S/S AGAT	9000	13900

Table 4.2

Costs of towing of technical object to the port of Harasavey

Technical means	Ship-day, un.	Lease rate		Costs of towing	
		ths. $ USA	mil. rubl.	ths. $ USA	mil. rubl.
I/B KAPITAN SOROKIN	10	20	41,7	200	417
S/S AGAT	10	9	13.9	90	139
Aviation reconnaissance	0.5	24	15.0	12	7.5
TOTAL:				302	563.5

The cost of towing of 11 units of technical supplies will be 3322 thousand US $ or 6198.5 mil. rubles. When making a decision concerning the towing of technical object, one should be guided by detailed technical project for such towing, agreed with corresponding departments of safe navigation services.

5. MAIN REQUIREMENTS TO ENVIROMENTAL PROTECTION

Northern and Arctic areas occupy more than 60 % of Russian territory. There are located numerous strategic reserves of natural resources, which determine the long- term prospects of economic development of Russia. Besides, further possibilities of this region will depend upon quality of environment and change in ecological situation.

Natural complexes of the North and Arctic, due to the extreme climate, are especially vulnerable and unsteady against outside impact. They have low ability to regenerate and clean itself. Therefore, the activities aimed at environmental protection of the North and Arctic regions against pollution, are important in all cases including organization of shipping. The existing and new vessels, operating in the Arctic must meet the whole complex of constructional and operational requirements specified by "Rules to prevention of the pollution from vessels" RD 31.04723-94 and "Rules on prevention of the pollution from vessels" of the RF Register.

CONSTRUCTIVE REQUIREMENTS REGARDING EQUIPMENT OF VESSELS

Vessel should be equipped with the following protecting devices, required by MARPOL 73/78 and the law of Russia:

- plant for filtering oil (15 mil-1),
- indicator of oil content less than 15 mil-1,
- automatic bolt device for stopping discharge of oil water when oil concentration becomes more than 15 mil -1;
- standard join for pouring out oil water;
- system of pumping, delivering and discharging oil water, including tanks;
- equipment designed for ventilation of cargo spaces, device for handling and disinfecting water, including prefabricated reservoir with standard discharge connection for delivering polluting water to shore receiver;
- containers for separate collection of garbage (metal, paper, dust etc.);
- device for pressing and burning garbage.

OPERATIONAL REQUIREMENTS ON SEA POLLUTION PREVENTION WHEN GOING IN ICE CONDITIONS

1) Preparation of the vessel for sailing in ice:

- for sailing in ice where danger to face hard ice exists continuously as well as possibility to damage the hull, it is necessary to use ice-strengthened vessels and meet the requirements of MARPOL 73/78 and "Regulations of navigation along the NSR passage" published in Notices to Seamen;

- the vessel, designed for navigating in ice, should held appropriate certificate;

• when such a certificate is absent, the captain inform the Administration (the Committee of sea Operations) immediately about the fact;
• responsibility for permitting such vessel to join a caravan of ice support, rests with the Committee of Sea Operations;
• before entering ice, particularly, as far as the loaded tanker is concerned, all openings after and for peak, fuel tanks must be closed, all doors and portholes should be locked;
• all water protecting rooms must be kept closed when going in ice because in case of damage of the hull it might maintain ship's sailing characteristics, prevent or reduce oil pollution;
• it is recommended to have on board a few hoses and cargo pump, in case of emergency this equipment will allow one to transfer oil from a damaged tank or vessel to another ;
• before entering the ice it is recommended, if possible, to pump fuel oil from bow tanks into fuel tanks of middle and stern parts;
• training exercises are recommended before voyage as established in the Muster List.

Officers of a vessel are obliged to know well all the items of the ship's damage control plan and, particularly, in what tanks and what way cargo might be pumped in case of emergency.

2) Ice going:

The captain sailing along the NSR and through the adjacent areas is to keep the systematic contact to the Sea Operation Committee in the navigating area and to follow in strict accordance with recommendations received;

Entering the ice and further passing through ice are permitted only by the port whose area the vessel is crossing, or by the head of ice operations in navigating area. It is prohibited to enter the passage of the NSR and adjoining areas without permission of the head of ice operations;

In absence of safe navigation conditions favorable to passing through the ice (especially in storm) from open sea side, the enter is prohibited and the master has to expect for weather permitting , staying at safe place (distance) and informing the port's captain or the head about it;

Before approaching the edge of ice, it is necessary to reduce inertia down to the lowest speed. Ice going speed is chosen with respect to the strength of the hull, kind of cargo and ice conditions in order to prevent break of hull tightness and pollution resulted from this damage;

Vessel in ice should avoid sharp turning because stern and bow parts, where fuel spaces usually allocated, could have dangerous contact with ice edge and submerged ice parts;

Fuel and water pumps and saving equipment are to be in full readiness during all time of voyage;

It is necessary to carry out observations of oil level in fuel tanks as well as sea surface by ship's side and keel water line;

In all cases of oil pollution, the master of damaged vessel must act according to the ship's damage control plan concerning actions in emergencies and to notice immediately the NSRA and the captain of the nearest port and take all possible measures to prevent marine pollution and to liquidate the spillage of oil.

3) Action in case of emergency:

According to Rule N 26 of Appendix 1 of MARPOL 73/78, each vessel has to get "Plan of vessel's urgent measures against oil pollution", which includes the following sections:

• action in accordance with the regulations of item 8 of MARPOL 73/78, which should be performed by captain or other person responsible for vessel in the case of an accident resulting in oil pollution;
• list of organizations or persons to which the contact should be kept;
• detailed measures descriptions, which should be immediately taken by crew aiming at the reduction of pollution;
• procedures and contact with local authorities for coordination of measures for preventing the pollution;
• actions of vessel aimed at environmental protection, taking into account that the most suitable vessel for liquidation of the spillage of oil in the Arctic seas is the icebreaker, so she has to get on board:
• blocks of the strengthened type;
• autonomous cargo pumps designed to transfer oil from damaged tanks;
• removable autonomous equipment of "Foksteil" type for removing oil out of water surface in ice;
• elastic volume for storing removed mixtures oil-water.

4) Prevention of the waste water and garbage pollution at sea:

The vessels going in the Arctic seas have to meet more strict requirements, regarding prevention of the pollution at sea, than produced by MARPOL 73/78.

The waste of unprocessed water is prohibited for the Arctic seas. It is allowed to discharge only water having kou-index not more than 1000. Dust, generated from the processing should be delivered to shore receivers or burnt.

The vessel should accumulate and make preliminary processing of the garbage on board. Combustible part must be separated and then liquidated on board the ship, and another part might be pressed and handed in to a shore receiver.

5) Prevention of the pollution of atmosphere:

In connection with the supposed introduction in 1998 of new appendix to MARPOL 73/78 concerning protection of the atmosphere, new designed vessels must meet the following requirements:

1. Waste of nitric oxide shouldn't exceed for propulsion:

less 130 rotations per min - 17 g/kW/h,

130-2000 - 45*n-0.2 (n - rotations),

more than 2000 - 9,84 g/kW/h;

waste of volatile organic combinations (methane, for example);

2. Measures to prevent emission into the atmosphere both with handling and transport operations

3. Emission of ozone destroying materials

4. It is allowed to use only components indicated by the Montreal protocol for preserving ozone belt of the Earth.

CONCLUSIONS

The present section of tanker fleet development for LNG export coming up to 46.45 mil cu m is prepared in accordance with the requirements of normative document OST 5.0064-84 "An order of elaboration, coordination and confirmation of the vessels' project" and contains elaboration of the special questions of methane-carrier substantiation, including;

- designation and application sphere of the vessel;
- desirable parameters and characteristics of the vessel;
- operational conditions, regimes and vessel's working organization;
- number of the vessels recommended to construct;
- technical and economic feasibility study for the vessel;

The inculcation of progressive technology of LNG export transportation under modern conditions is of great state importance for Russia. Large reserves of hydrocarbon raw material in the Extreme North regions and on the shelf of the Arctic seas are reliable basis to ensure economic and social activity of northern peoples for long term prospects.

From a technical standpoint, the proposed transportation technology is recognized in the world and proved by considerable experience for a period of 30 years. Under these conditions, the feasibility study is based on achievements of scientific and technical progress in combination with the world shipbuilding practice of construction of icebreaker and transport fleets and operational experience in the severe Arctic seas.

Initial data for the feasibility study is accepted by the customer and includes:

- calculated annual volumes of LNG export amounted to 11.61, 23.22, 34.83, 46.45 mil cu m - are accepted under the task of the leading contractor VNIIGAS;
- assumed transportation direction: Harasavey (Jamal) - Wilhelmshafen (Germany);
- transportation period - round the year.

The following issues were elaborated when working on FS:

- analysis of the LNG transportation development in the main economic regions of production and consumption of the world and prognosis of scientific evaluation of the leading specialized firms for the prospects;
- analysis of world shipbuilding and dynamics of the world fleet development for LNG transportation;
- exploitation of increased speed methane-carriers;
- economic estimation of reasonability for gas carriers' constructions under different credit forms;

• analysis of scientific and technical progress in developing the main constructive mechanisms (main dimensions, cargo systems, spare parts etc.) of carriers depending on countries-constructors;

• technical-operational requirements to Arctic going vessels;

• hydrometeorological, hydrological and ice conditions of passages;

• evaluation of technical readiness of domestic shipbuilding industries for the construction of methane carriers and determination of the existing restrictions connected with the building berth dimensions.

• elaboration of type/size row of Arctic going methane carriers in view of coordination of their principal dimensions with operation potential of the existing and prospective icebreakers to provide the guaranteed escorting;

• technical and economic substantiation of type/size row as regards the main characteristics of certain scheme;

• choice of cargo and vessel systems and equipment for methane-carriers which are adopted by the study;

• elaboration of maker-list for domestic shipbuilding yards;

• escorting vessels during ice passages with estimation of ice conditions and timely risks of scheduled approach to Harasavey;

• estimation of demand for icebreaker supports;

• main ecological requirements to environmental protection for ice-going methane carriers;

• estimation of the project development with calculations of technical, operational and economic factors.

List of the conducted elaborations together with 1981-1983 studies enable us to summarize the following recommendations and conclusions resulted from the present feasibility study:

Marine technology of LNG export by methane carriers from the Harasavey field is competitive at the European market in terms of both the alternative version of LNG carriage from the Persian Gulf and the pipeline version from the Bovanenkovskoe field;

Calculations show that LNG transportation project realization is possible both by intensive credit development and creation of the deep Harasavey port and by means of establishing specialized stock company with participation of Russian and foreign investors, which starts the production with minimum credit resources and will provide the further project development and self-financing funds;

An optimal type and size of Arctic going methane tanker of 135.000 cu m of capacity is chosen in accordance with its economic factors from the type/size row of six tankers;

As an alternative is recommended Arctic going methane tanker of 79.000 cu m of maximum size and type, the construction of which is possible at Sevmashpredprijtie;

When choosing the construction of cargo tanks, spherical tanks are preferable in view of reliability and safety of gas transportation. Besides, when the vessel is beset by ice, these tanks will not be affected by deformation of vessel's hull. Considerable vibrations and impact loads when passing through ice, are taken into consideration.

Two low revolution diesels of B & W are recommended as the main engines. Two controllable pitch propellers are driven by engines through hydro-transformers, the hydro-transformers are bypassed when going in open water;

The calculations have shown that it is expedient to increase speed from 18 to 23 knots. Further increase, thanks to power growth of marine propulsion plant, is ineffective in view of quick rise in costs of fuel;

The calculations confirm the reasonability of using only natural gases as a fuel in the cases when oil fuel bunkering is higher than USD 100 per 1 t.

The following vessels selected from the type/size row of methane carriers are recommended for orders to be placed with:

- Arctic going methane/gas-carrier (NGM -135A) of appr. 135.000 cu m - to organize the main TTC. The demand for such vessels intended for transportation of the whole rated volume of gas is 14 pcs. Capital investments required, come to USD 3 bln;

- Arctic going methane -gas-carrier (NGM-79A) of appr.80.000cu m - to organize LNG feeder transportation to the assumed port of Teriberka (the Kola peninsula). Demand is from 10 to 14 pcs. Investments come to USD 1,7-2,4 bln. Construction of these vessels might be allocated at Sevmashpredprijtie;

- gas/methane-carrier (NGM-165) of appr. 165.000 cu m - for organization of the main transportation from the ice free port of Teriberka. Demand is 8 pcs. Capital investments are estimated at USD 2 bln.

Economic evaluation of LNG carriage transportation shows the advantage of the main TTC vs. the main feeder TTC at the expense of 29-33% reduction of capital investments.

The development versions of the main feeder TTC make it possible for the Russian side to plan an acquisition and operation of the Arctic fleet on Russia's own account using own resources, creating additional working places and obtaining rights to collect depreciation deductions to renovate means of transportation. Besides, only a part of transportation means which provides the carriage from ice free port, will be distributed between the project sides.

A possible distribution of transportation means and capital investments among the considered variants, is characterized by the following figures (pcs/USD mil):

	Main- feeder	main
Russian part	18/3380	7/1645
Foreign part	4/1000	7/1645
TOTAL	**22/4380**	**14/3290**

LNG carriage organization with the use of the main feeder TTC permits one to:

• hope that the main income volume in favor of the Russian side, will be obtained from transportation of cargoes;

• prepare a shore base for exploration of the Shtokman gas & condensate field;

• provide additional working places for skilled personnel of the Kola peninsula;

• ensure the development of industrial base for exploration of other Arctic hydrocarbon fields.

REFERENCES

1. General opinions for organization of an export by sea ships-methane carriers of liquefied gas from the deposits of Yamal/State project-research and Scientific-Research Institute of the Marine Transport SoyuzMorNIIProject ,M. 1990, 140 pages.

2. Technical and economic feasibility study for LNG export by the Marine Transport and development of technological terminal in the port of Harasavey:

scientific report, executive Isakov N.A. - 1995 -147 pages.

3. Tsoj L.G., Glebko Yu.V., Morejnis F.A. State and perspectives of the development of transport ships for ice navigation. Shipbuildings abroad N9, 1986, pages 19-40.

4. A prognosis appraisal of the development of Arctic fleet with use of heavy tonnage ships of an active non ice breaking navigation: Scientific-Research Work Report, executive Tsoj L.G. - Leningrad, 1981, 57 pages.

5. Elaboration of technical task for projecting a ship of NGM-50(125) type for program of replenishment 1976-1980 with a Feasibility Study of the main characteristics. Vol.1: Scientific-Research Work Report, executives Morejnis F.A., Naumova I.A. - Leningrad, 1974, 97 pages.

6. A computer program of calculations of the main technical economic characteristics of the gas carriers: Scientific-Research Work Report, executive Artsykova A.A. - Leningrad, 1979, 80 pages.

REVIEWER'S COMMENTS

The paper is lengthy and rich in technical detail. It provides a quite extensive techno-economic analysis of the use of methane carriers for natural gas transportation. Unfortunately, as I am not a trained naval architect or chemist, I cannot offer any comments on the accuracy of the analysis undertaken.

From the point of view of a business economist, however, I think that the paper would benefit from a number of changes and improvements.

- The improvement of the English used in the paper is absolutely necessary, as it often makes understanding of the authors comments not only difficult, but impossible.
- The paper would benefit greatly from a better structure and a clarification of the issues it attempts to tackle. While I was expecting to find a feasibility study of an LNG transportation system, I was faced with a purely technical analysis of the different types of methane carriers that the project could use.
- At the same time, the paper tries to tackle issues which, although relevant, are not properly discussed. For example, the environmental impacts of LNG carriage by sea are only hastily discussed at the end of the paper, and without any attempt to link them to the main body of the paper.
- The paper really starts making sense (for an outside reader) from section 2 (page 51) onwards. However, the investment criteria used (NPV and IRR) are described somewhat confusingly. I also question the choice of the discount rate at 10% p.a. which does not seem to be justified by the authors. Although the project might not have contractual/default risks, there are still quite a few operational risks (e.g. Arctic navigation) that would surely increase the chosen discount rate.
- The paper seems to be building on the assumptions and findings of other projects, but this is not immediately obvious to the reader. The choice of cargo flows right at the beginning of the paper, for instance, seems quite arbitrary. If the authors choose not to justify their assumptions they should at least state their sources clearly.
- The list of references seems to be rather short, with all sources being exclusively from Russia. I am sure other INSROP projects have been written on the subject and substantial research has been carried out by INSROP's sub-programme IV in the area of environmental protection. I would suggest more extensive cross-referencing, otherwise the part on environmental concerns (section 5 of the paper) should be dropped altogether.
- The main body of the paper seems to be tackling two issues: the choice of an appropriate type of methane carrier; and the deployment of an adequate number of vessels to service the LNG trade between Russia and Germany. The first issue seems to be readily addressed by the usage of an ice-strengthened methane carrier and the authors use available technical information from the shipyards specialising in the construction of such vessels. Therefore, I do not see why so much time and effort should be spent on the provision of information that is readily available. What would be more interesting to spend more time on the second issue, by describing the logistics of the whole operation, i.e. explain the choice of vessel sizes and number of voyages in more detail.

• The paper focuses on the feasibility of the purchase and operation of methane carriers, and although this is a big and expensive project in its own right, it is still only a part of the much bigger expenditure required for the construction of the liquefaction and regasification terminals. It would be useful if something is mentioned about this aspect, unless another relevant project has already been carried out.

Overall, I have to stress that this a largely technical report (and less an economic one) with a vast amount of information (sometimes only of peripheral nature). However, in order to make justice to the amount of time and effort put into it, considerable streamlining is necessary. The improvement of English is only one prerequisite; the paper needs to be reconstructed and presented in a more coherent manner. I think there is enough material there to make it very useful for people both at the technical and at the management/decision-making level.

Michael N. Tamvakis

CITY UNIVERSITY

BUSINESS SCHOOL

LONDON

AUTHORS' ANSWER

We appreciate Mr. Michael N.Tamvakis for good review and useful comments (incorrect phrases, omissions etc.) which are accepted in the row of corrections in the final edition of the working project.

Basically, in view of some notes and recommendations of the reviewer, we wish to express our special opinion.

1.We can not disagree with the reviewer regarding language difficulties especially when experts of different spheres are contacting each other, no one of which carries the English as native.

In our view, the problem consists in seeking adequate sense structures through deeper personal contact between the experts of similar speciality.

2. We also agree with the reviewer on the problem of imperfection of the report structure in relation to the technical and economic feasibility study for LNG transportation system.

It is not a secret for European specialist companies that normally the feasibility study of such level exceeds considerably total yearly INSROP fund in terms of amount and detail of input data, calculations of versions and analysis, overall volume of the final documentation, and especially finance.

In this respect, the project as accepted according to the task, is the classic version of technical and economic substantiation of methane carrier designed to operate in the Arctic seas and which broadly utilized in the Russian marine industry at the first stage of setting commercial projects.

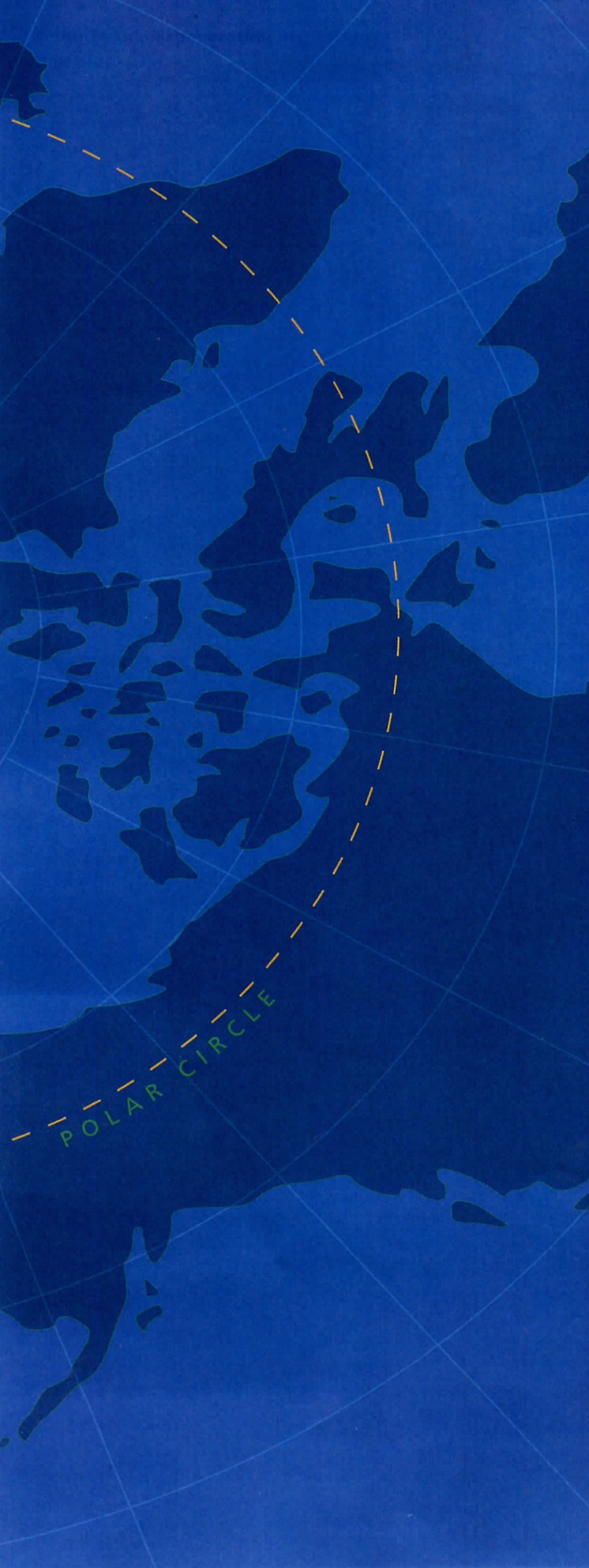
3. The question of special importance to strict indication of economic assessment method for the project is out of discussion.

It should be noted, that financial support of such projects, according to international practice, is provided only if certain long-term guarantee exists at inter-governmental level.

Information of technical, and, especially economic operational factors of the existing LNG industrial transportation systems, is almost not available. It could be seen from the example of research into LNG sea transportation conducted by "Drewry Shipping Consultants" in 1983 and 1992 or simply from statistics of "Lloyd's Shipping Statistics&Economics", "Fairplay", "Motorship", other recognized published issues.

In our view, discount rate at 10% is a recognized economic norm and it is successfully used in economic studies for container ships, bulk carriers, methane carriers and any other transport means operating our planet and between planets. The key question is absolute cost of transport means to which the discount rate is applied. This cost shows the complex operating conditions and anticipated risks.

Reconstruction of the report which would be suitable for the reviewer, leads to the destruction of the requirements of state industrial standard of Russia and revision of working goal.



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.
SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Sasakawa Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.
CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stockholding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.
FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multidisciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.