170K Arctic ARC7 Icebreaking LNG CARRIER

12th ASEF FORUM

2018. 10. 23.

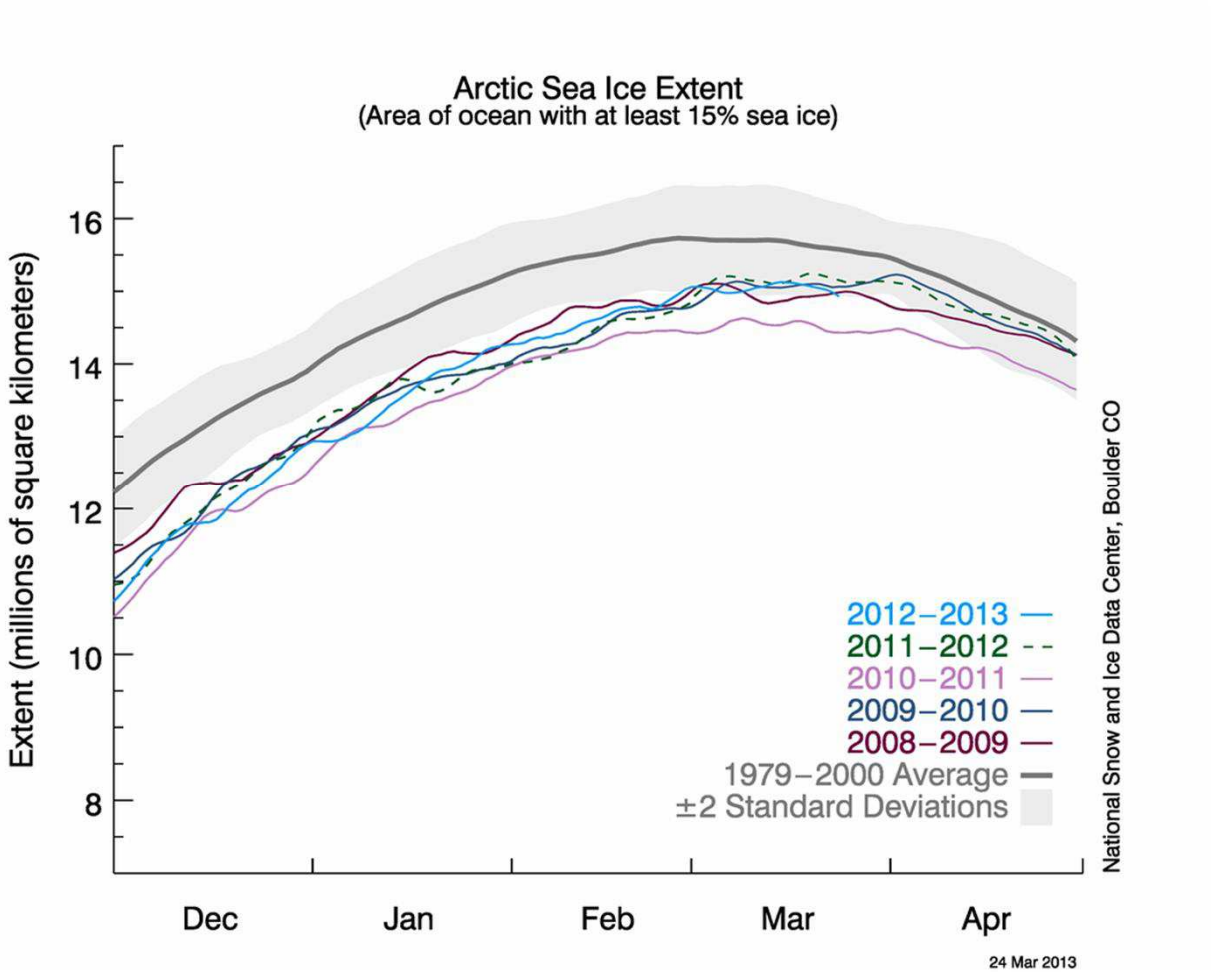
Daewoo Shipbuilding & Marine Engineering, Co., Ltd.

Contents

- Northern Sea Route(NSR) and Arctic Resources
- YAMAL LNG Project & Arctic LNG Carrier
- Ice Trial

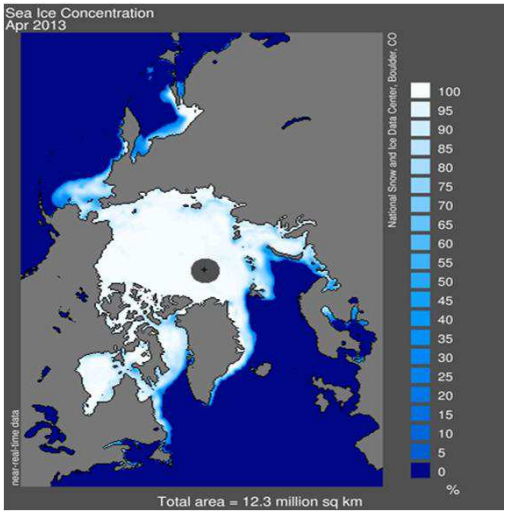
- **Northern Sea Route(NSR) and Arctic Resources**

Ice Extent in Recent 5 years

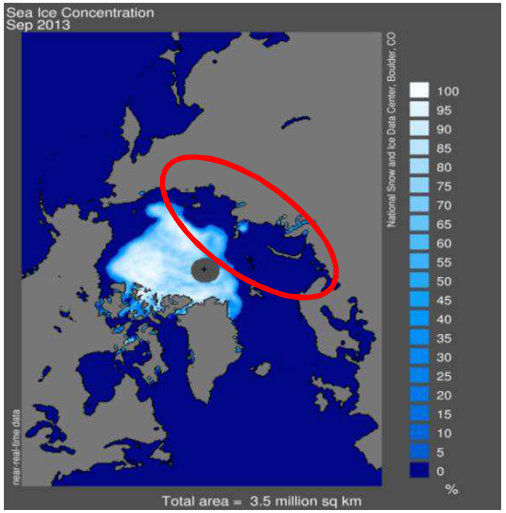


Source : National Snow and Ice Data Center

Max. ICE concentration around Apr.



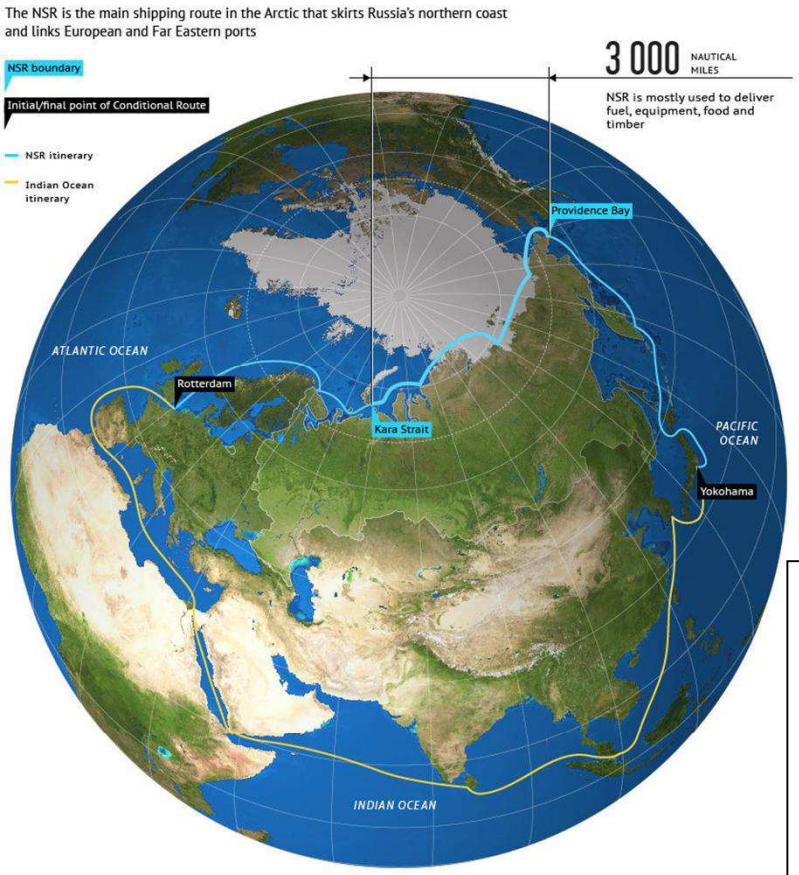
Min. ICE concentration around Sep.



Northern Sea Route(NSR)

- NSR is running through Kara, Laptev, East Siberian and Chukchi seas.
- Arctic environment is changed due to an effect of Greenhouse gas
  ☞ Arctic ocean to be open to regular maritime traffic
- Increasing shipping demand for Northern Sea Route (NSR)
- Increasing resource development in Arctic area(Oil & GAS)

Advantages of using NSR



- NSR is attractive to shipping companies
  - ☞ Cut fuel consumption & CO2 emission

Main advantages

1 Reduced freight costs due to shorter distance and travel time:

DISTANCE (NAUTICAL MILES) / TIME (DAYS)

7 300/20

11 200/33

2 Lack of sea piracy threat

Main disadvantages

1 Icebreaker guidance required

2 Crews have to be trained for operations in the Arctic

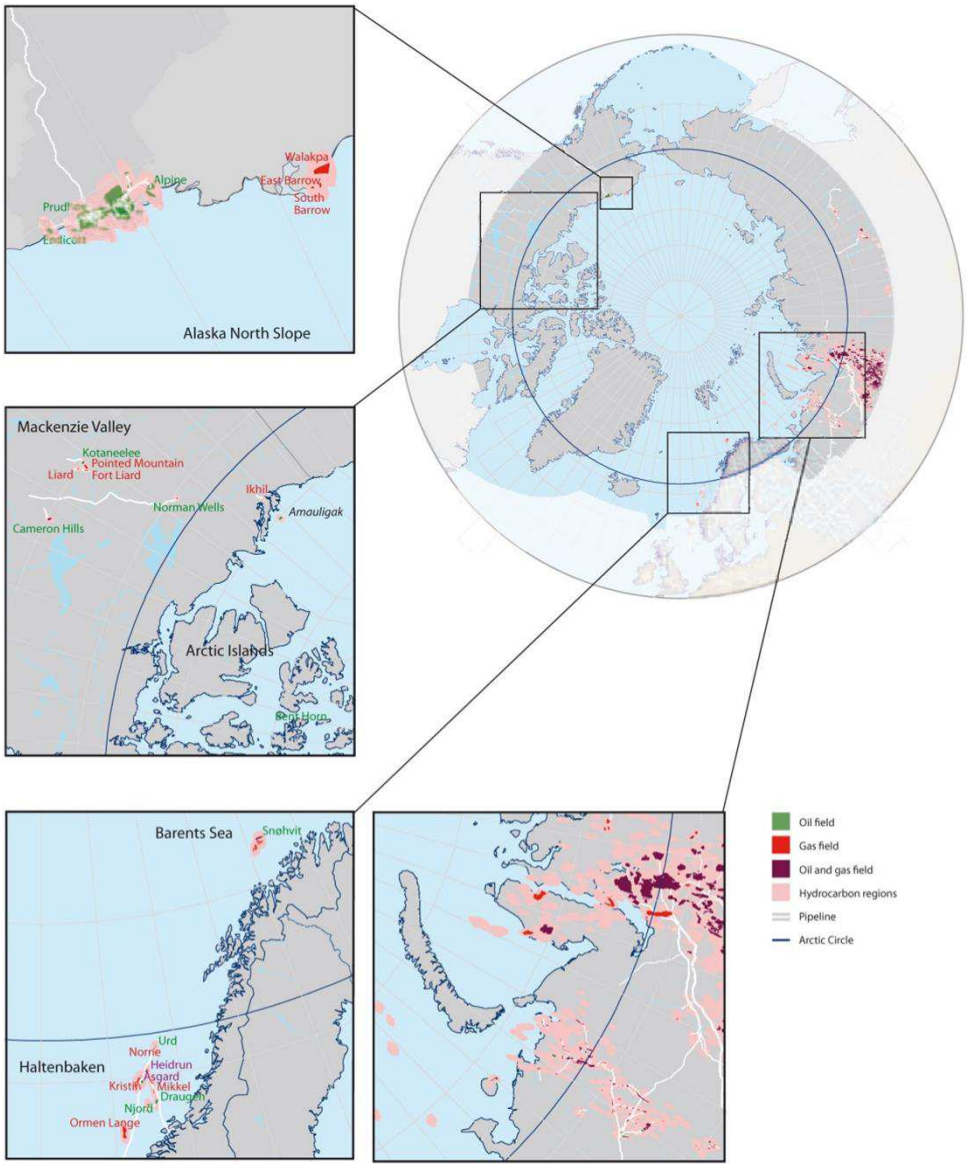
3 Short navigation period: 2-4 months per year

Arctic Resources

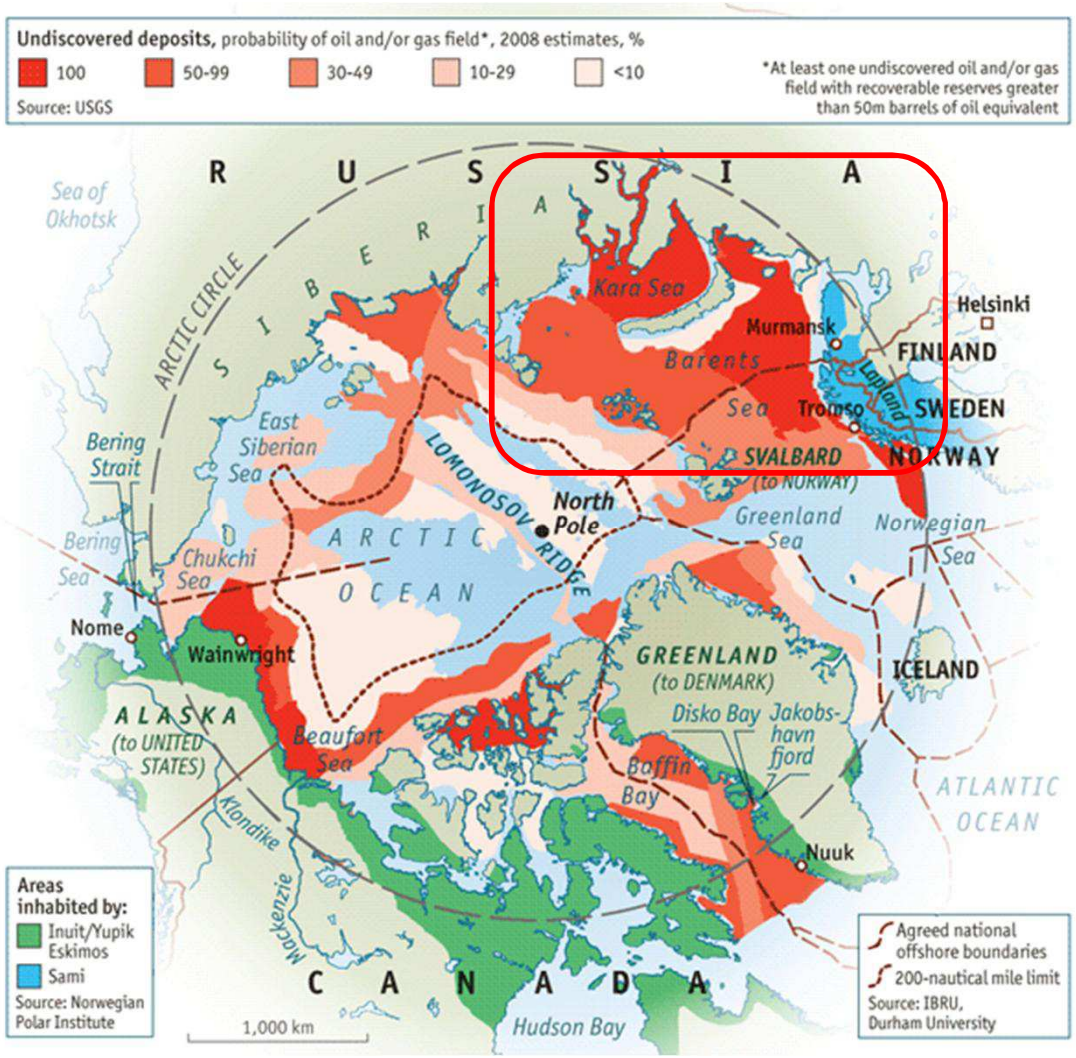
- **Approx. 61 large oil and natural gas fields** are located in the **Arctic Circle** in Russia, Alaska, Canada's Northwest Territories, and Norway

- **43** of the 61 large Arctic fields are **located in Russia**

- **35** of these large Russian fields (33 natural gas and 2 oil) are located in the **West Siberian Basin**



Arctic Resources - Potential



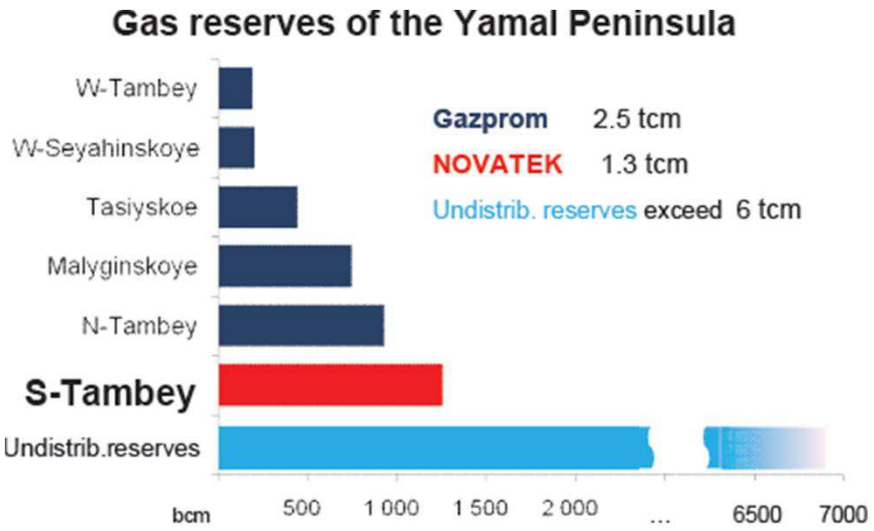
Arctic Mean Estimated Undiscovered Technically Recoverable, Conventional Oil and Natural Gas Resources By Arctic Province, Ranked by Total Oil Equivalent Resources

USGS Petroleum Province Name	Crude Oil (billion barrels)	Natural Gas (trillion cubic feet)	Natural Gas Liquids 1/ (billion barrels)	Total Resources, Oil Equivalent 2/ (billion barrels)
West Siberian Basin	3.66	651.50	20.33	132.57
Arctic Alaska	29.96	221.40	5.90	72.77
East Barents Basin	7.41	317.56	1.42	61.76
East Greenland Rift Basins	8.90	86.18	8.12	31.39
Yenisey-Khatanga Basin	5.58	99.96	2.68	24.92
Amerasia Basin	9.72	56.89	0.54	19.75
West Greenland-East Canada	7.27	51.82	1.15	17.06
Laptev Sea Shelf	3.12	32.56	0.87	9.41
Norwegian Margin	1.44	32.28	0.50	7.32
Barents Platform	2.06	26.22	0.28	6.70
Eurasia Basin	1.34	19.48	0.52	5.11
North Kara Basins and Platforms	1.81	14.97	0.39	4.69
Timan-Pechora Basin	1.67	9.06	0.20	3.38
North Greenland Sheared Margin	1.35	10.21	0.27	3.32
Lomonosov-Makarov	1.11	7.16	0.19	2.49
Sverdrup Basin	0.85	8.60	0.19	2.48
Lena-Anabar Basin	1.91	2.11	0.06	2.32
North Chukchi-Wrangel Foreland Basin	0.09	6.07	0.11	1.20
Vilkitskii Basin	0.10	5.74	0.10	1.16
Northwest Laptev Sea Shelf	0.17	4.49	0.12	1.04
Lena-Vilyui Basin	0.38	1.34	0.04	0.64
Zyryanka Basin	0.05	1.51	0.04	0.34
East Siberian Sea Basin	0.02	0.62	0.01	0.13
Hope Basin	0.002	0.65	0.01	0.12
Northwest Canadian Interior Basins	0.02	0.31	0.02	0.09
Total	**89.98**	**1,668.66**	**44.06**	**412.16**

Source: U.S. Geological Survey, "Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle," USGS Fact Sheet 2008-3049 Washington, DC (2008), Table 1, page 4.
Note: The column totals do not equal the sum of the rows due to rounding. USGS website URL is: http://pubs.usgs.gov/fs/2008/3049/. The relative location of these provinces is identified in Appendix B.
1/ Natural gas liquids are composed of ethane, propane, and butane.
2/ The USGS uses a natural gas to oil conversion factor in which 6 thousand cubic feet of natural gas equals 1 barrel of crude oil.

- **YAMAL LNG Project & Arctic LNG Carrier**

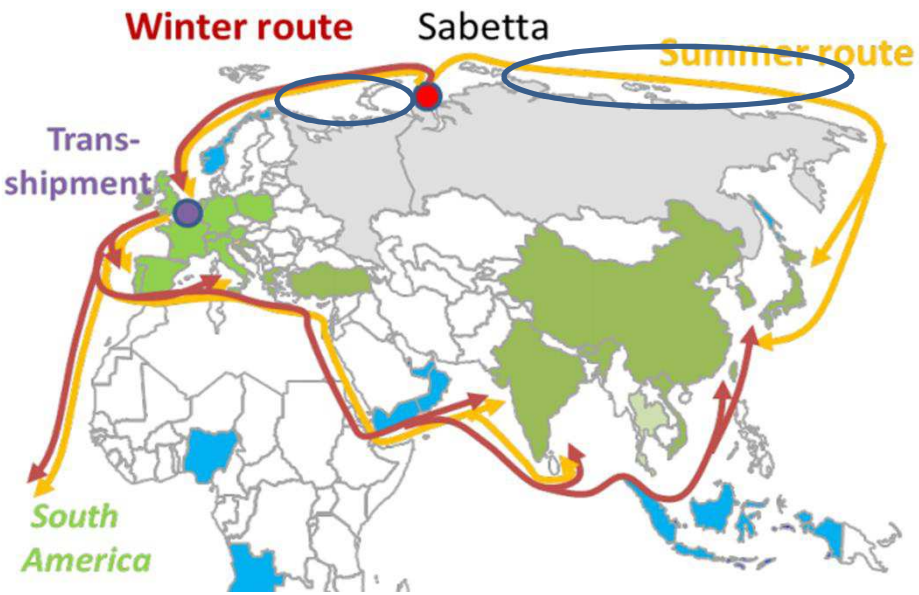
YAMAL LNG Project



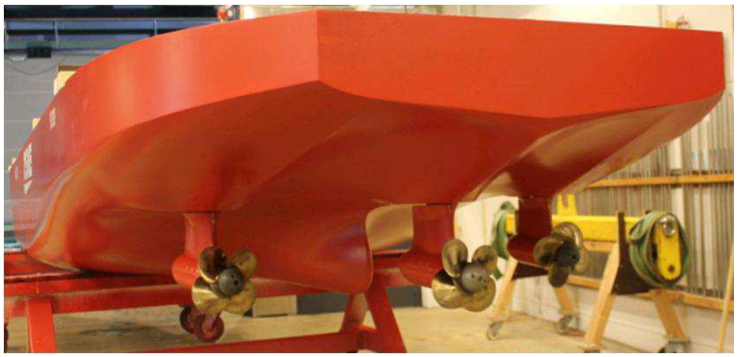
- **1.3 TCM Yamal South-Tembey Field Resources Base**

- 16 mtpa, LNG Production
- 1 mtpa, Condensate Production
- Drilling of more than **200** wells
- Construction of **3 LNG trains**
- **With 15 Icebreakers (LNG Carrier)** ➡ DSME

Design basis for Yamal Arctic LNG



3 PODs propulsion



Principal Particulars	
Length O.A	299.0 m
Length B.P	283.1 m
Breadth, mld	50.0 m
Depth, mld	26.5 m
Designed draft	11.76 m
Cargo capacity	172,600 cbm

Design concept	
Ice strengthening	Ice class Arc7
Service area	Sabetta ↔ Murmansk ↔ Europe/India Sabetta ↔ NSR ↔ Korea/Japan
Independent navigation	
Northern sea route during summer/autumn	
All year round navigation in the Kara sea	

Design basis for Yamal Arctic LNG

Ice class (Arc7)

- Summer / Autumn season : independent navigation
- Winter / Spring season : icebreaker escorted navigation may be required

Ship category	Permitted type and thickness of ice	
	Winter/spring navigation	Summer/autumn navigation
Arc4	Thin first-year	Medium first-year up to 0,9 m
Arc5	Medium first-year up to 0,8 m thick	Medium first-year
Arc6	Medium first-year	Thick first-year up to 1,5 m
Arc7	Thick first-year up to 1,8 m	Second-year
Arc8	Multi-year up to 3,4 m	Multi-year
Arc9	Multi-year	Multi-year

N o t e . The classification of ice adopted according to the "Sea Ice Nomenclature" of the World Meteorological Organization (WMO):

Ice type	**Ice thickness**
Multi-year	> 3,0 m
Second-year	> 2,0 m
Thick first-year	> 1,2 m
Medium first-year	0,7 — 1,2 m
Thin first-year	< 0,7 m

Overview

▶ Video

YAMAL Arctic LNGC Technologies

Ice Performance

Double Acting System (DAS)
Hull form development
- Bow/Stern Ice Shape
- Hull Form Optimization
- Ice Hull Interaction

Winterization

Heating & Thermal Insulation
Semi-enclosed Mooring Spaces
Anti-icing provisions
Totally enclosed Bridge
ER Cooling Water System

Arctic LNGC
Key Design Characteristics

Strength & Safety

Fwd. & Aft. Ice Belt
LNG CCS in Ice condition
Hull Load Monitoring
ER Double Hull

POD Propulsion

POD Hull Design
POD Electric Solutions

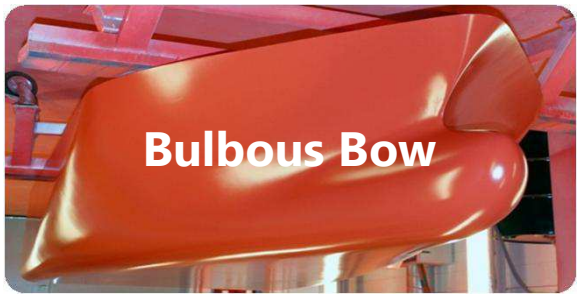
YAMAL Arctic LNGC Technologies

Ice Performance

Extensive hull form development for Double Acting System(DAS) throughout various hull form alternatives

Double Acting System (DAS)

VS.

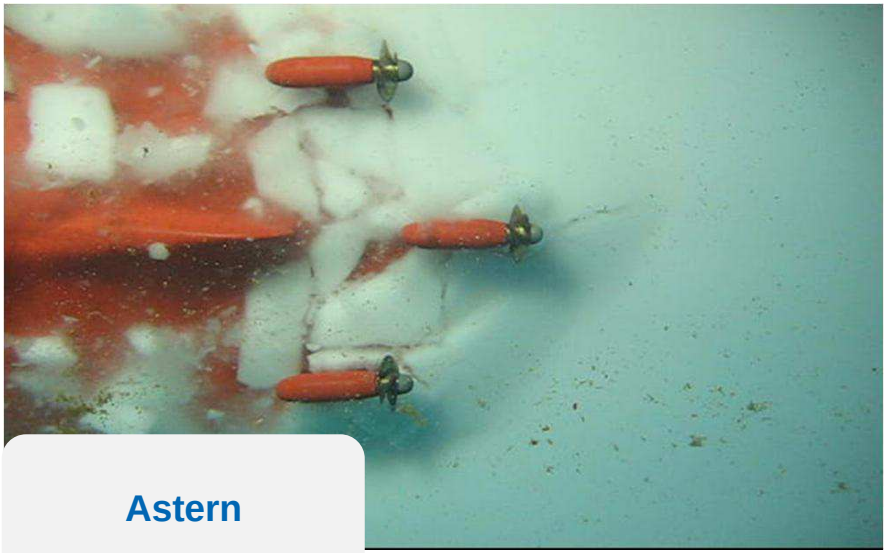


Open water & ice performance

YAMAL Arctic LNGC Technologies

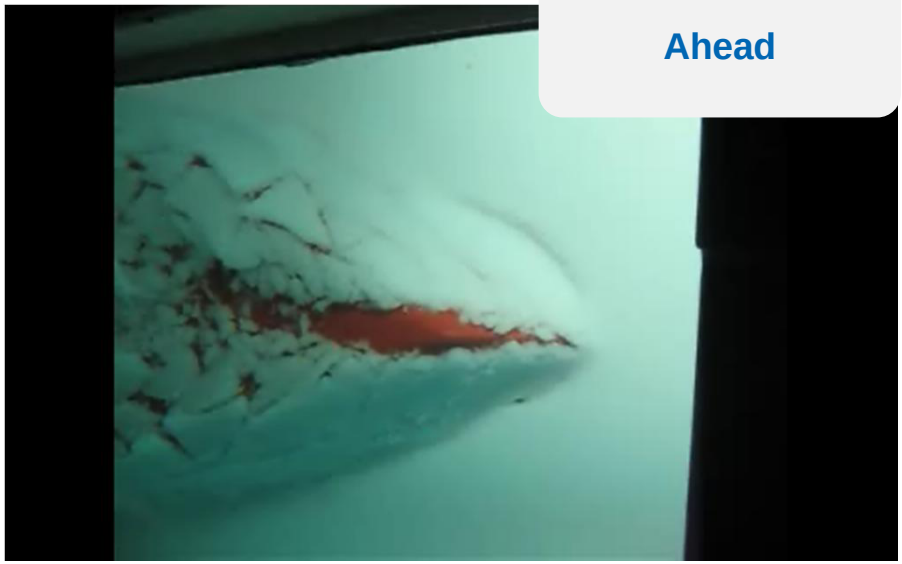
Ice Performance

Extensive researches and model tests

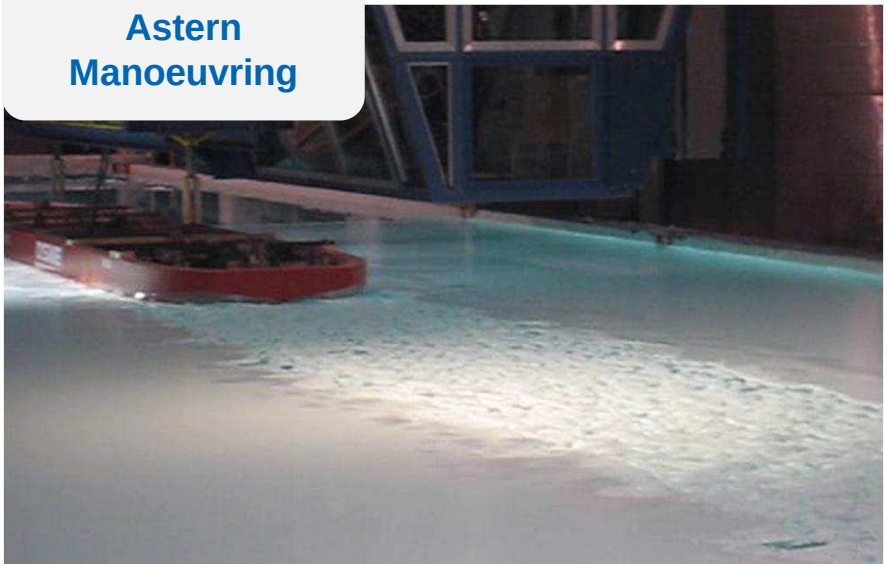


Astern

Ahead



Astern Manoeuvring



YAMAL Arctic LNGC Technologies

Ice Performance

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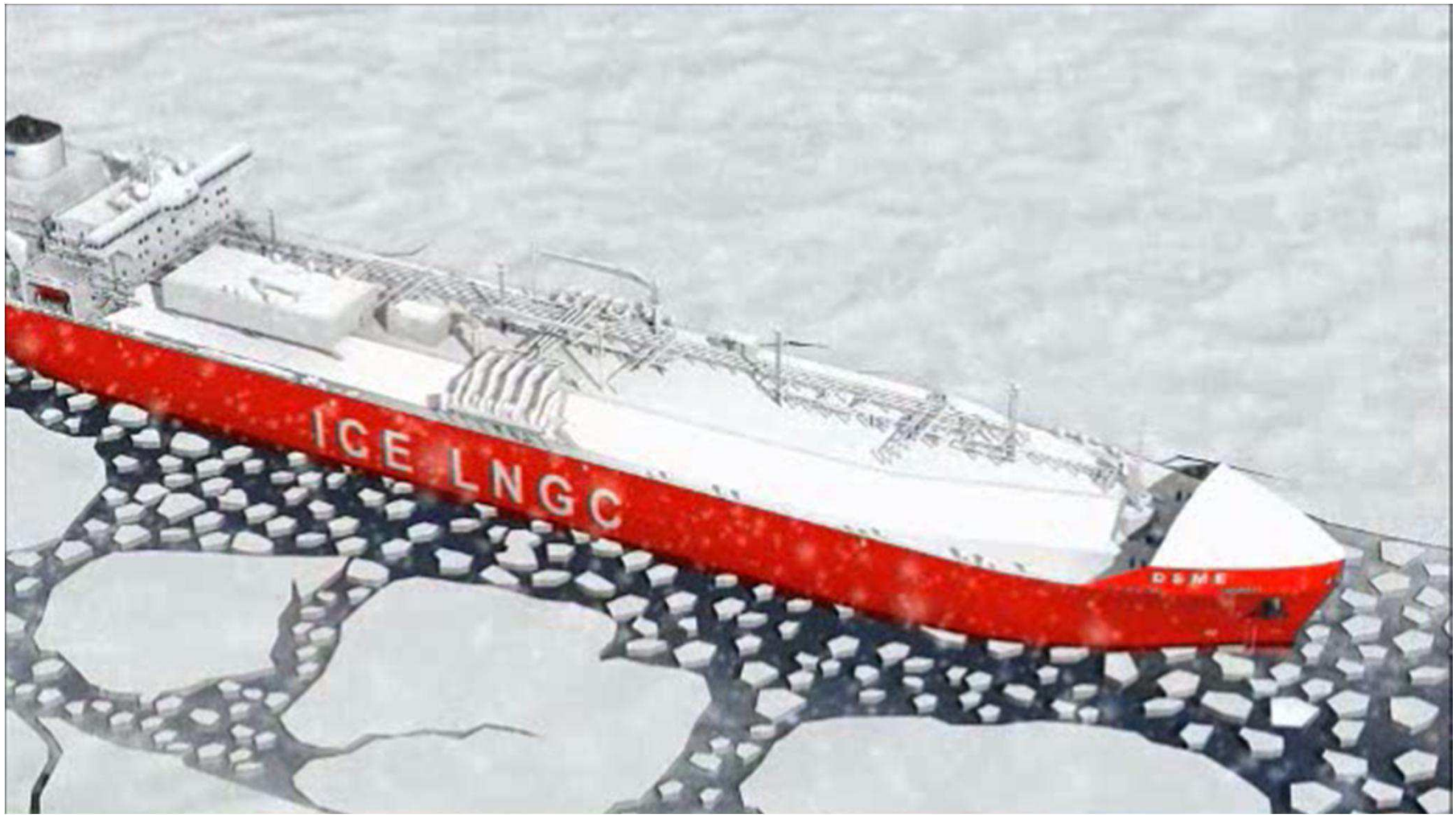
Winterization

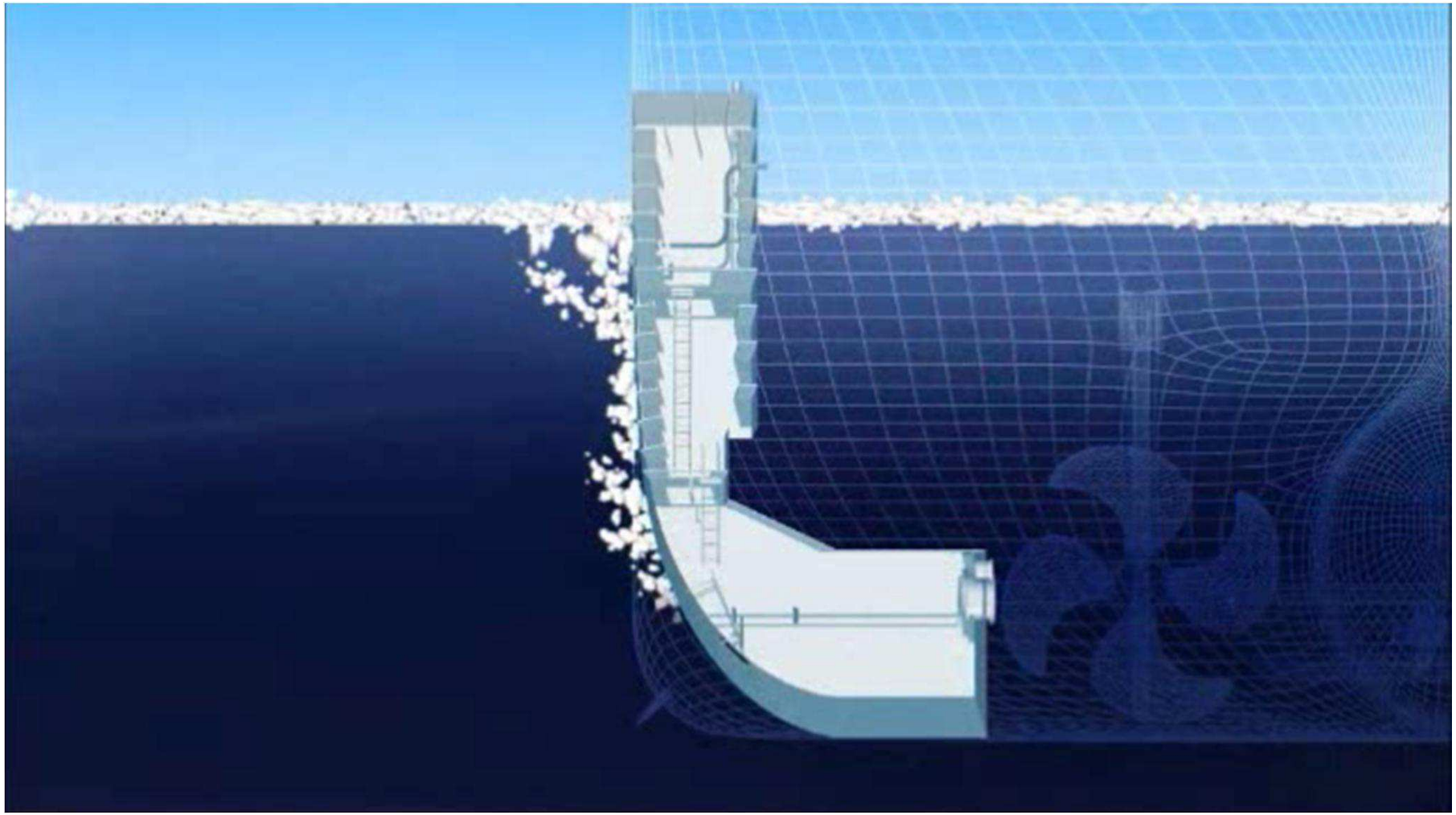


YAMAL Arctic LNGC Technologies

Winterization

YAMAL Arctic LNGC Technologies

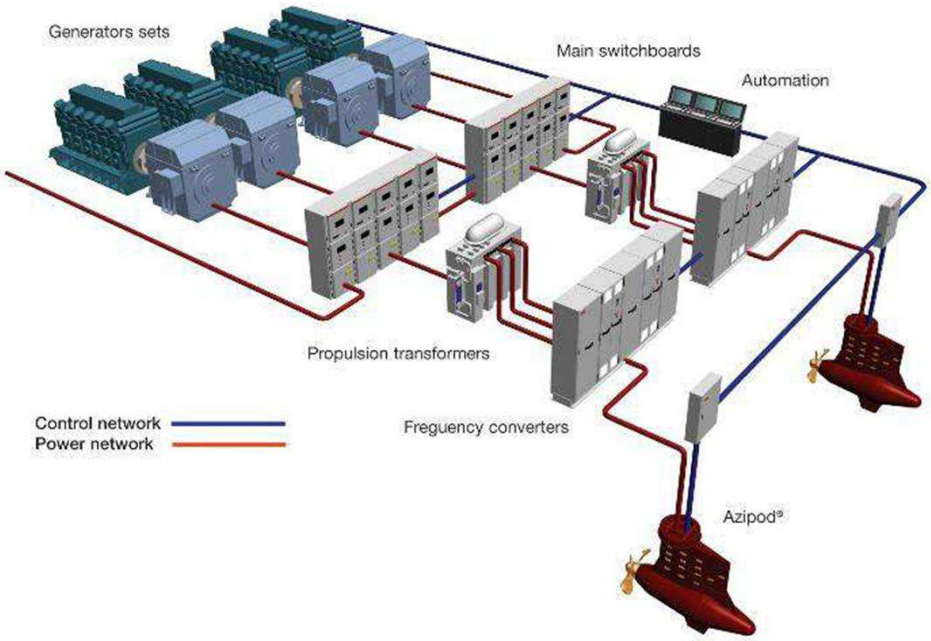
Winterization

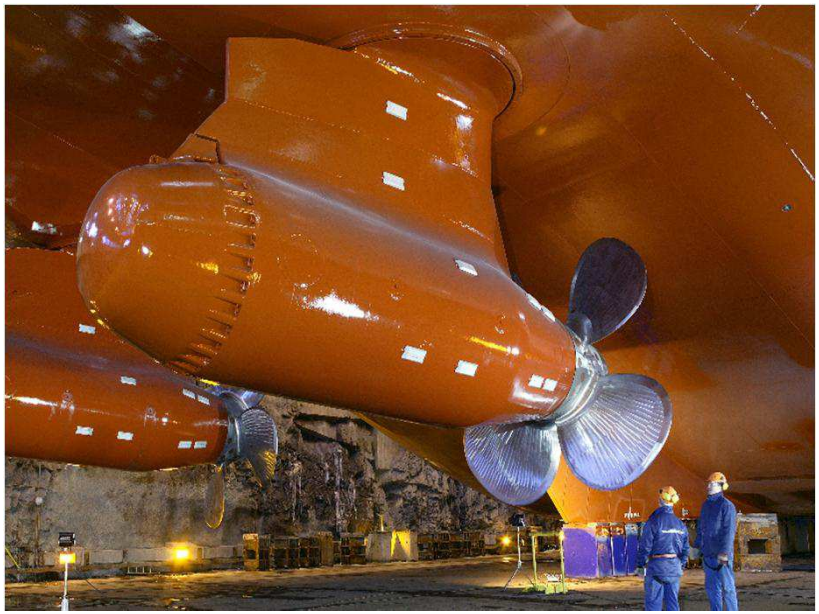


YAMAL Arctic LNGC Technologies

POD Propulsion
World's first/largest 15MW class Arc7 POD system

- Propulsion motor : 15,000 kW x 3 sets
- Propulsion frequency converter : Three(3) sets, one(1) for each propulsion motor
- Propulsion transformer : Six(6) sets, two(2) for each propulsion motor
- High voltage(6.6kV) main SWBD : 2sets
- Main generator(6.6kV) : 11,250 kW x 4set + 8,450 kW x 2 sets





YAMAL Arctic LNGC Technologies

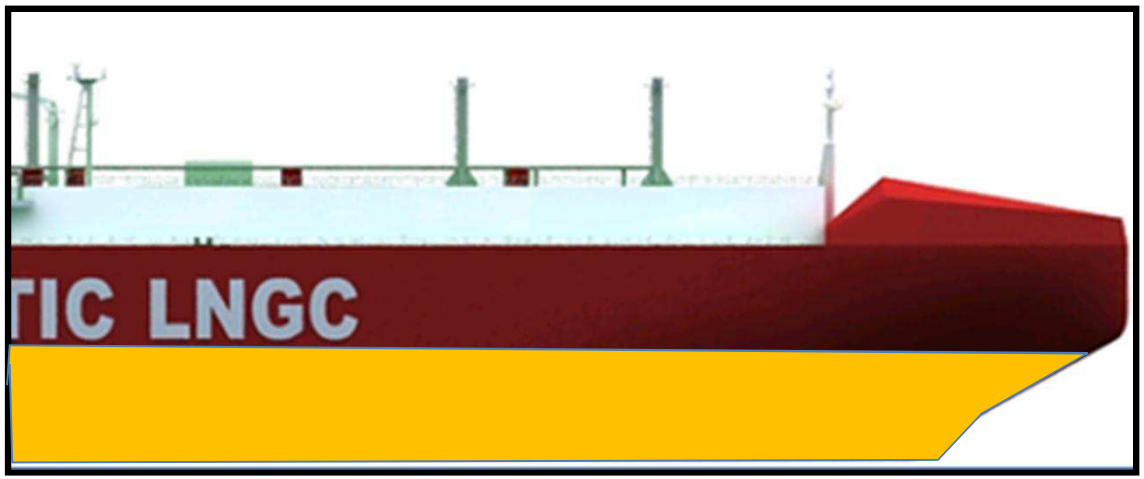
World's first/largest 15MW class Arc7 POD system

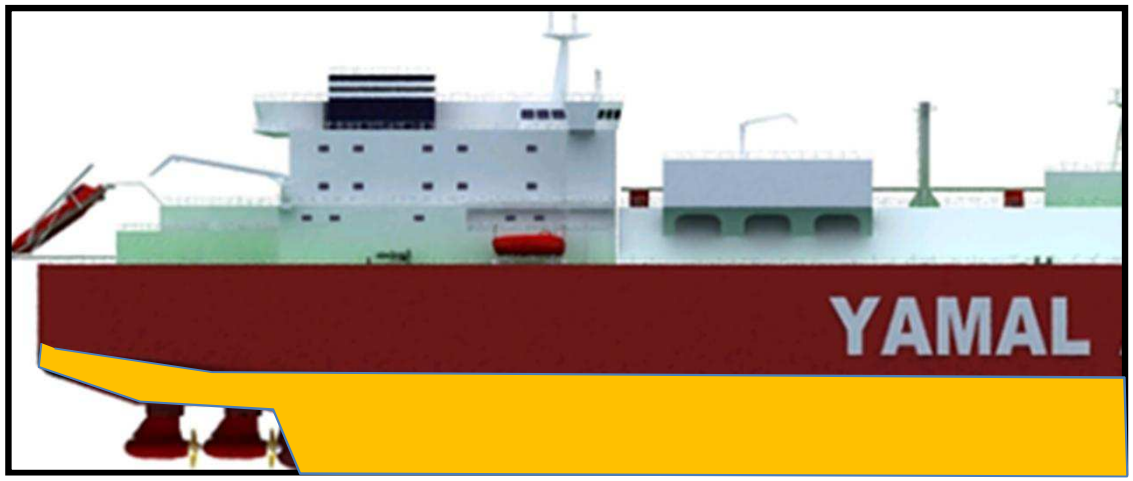
YAMAL Arctic LNGC Technologies

Strength & Safety

- Ice region based on RS requirement
- In consideration of DAS(Double Acting System)

Forward Region





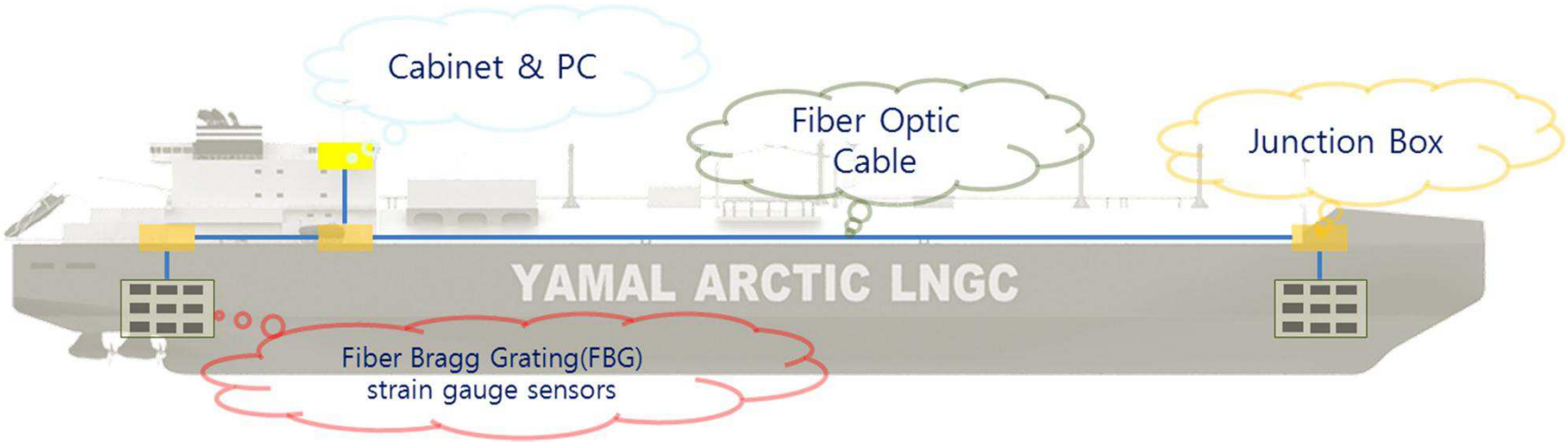
After Region

YAMAL Arctic LNGC Technologies

Strength & Safety

- **Real time Hull Stress/Load monitoring by Ice breaking**

. Real time monitoring and log data.
. Hull stress monitoring system + Ice load Monitoring
. Sensor installation at Fwd, Amid, Aft
. Fiber Optic sensor which are against Arctic Temperature
. Monitoring of Navigation data(speed etc) and POD propulsion data(power etc)



YAMAL Arctic LNGC Technologies

Strength & Safety

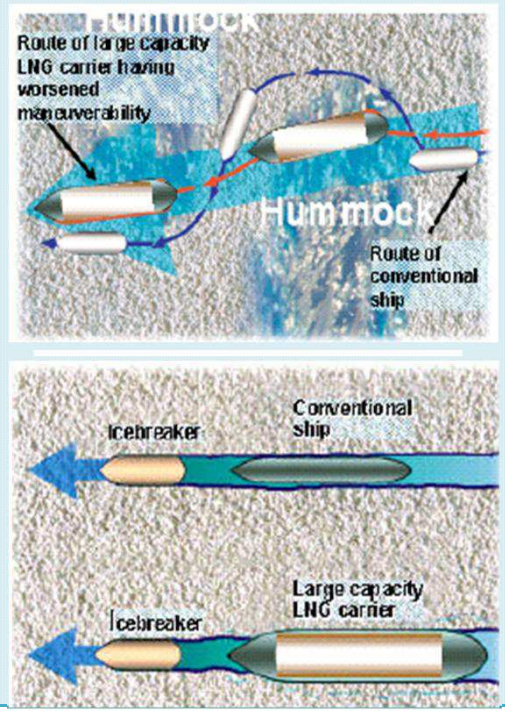
YAMAL Arctic LNGC Technologies

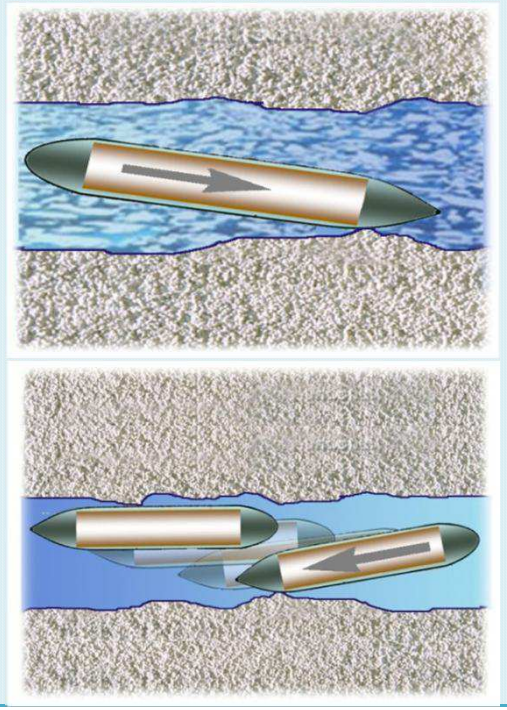
LNG Cargo Containment System

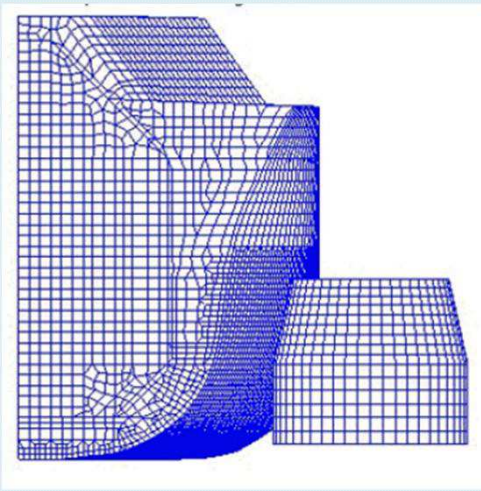
Ice collision safety analysis for CCS in multiple scenarios

- FEA calculations with ice channel sides
- FEA calculations for shoulder loading in maneuvering in ice
- Iceberg collision

Standard Scenario	Non-Standard Scenario	Ice Collision







YAMAL Arctic LNGC Technologies

CCS flexibility in Ice/Arctic operation NO96

YAMAL ARC7 LNGC
ICE TRIAL

The Arctic Area for Ice Trial

- Ice Trials were carried out

1. 2017. 02.18~03.08 (CHRISTOPHE DE MARGERIE)

2. 2018. 02.24~03.11 (VLADIMIR RUSANOV)

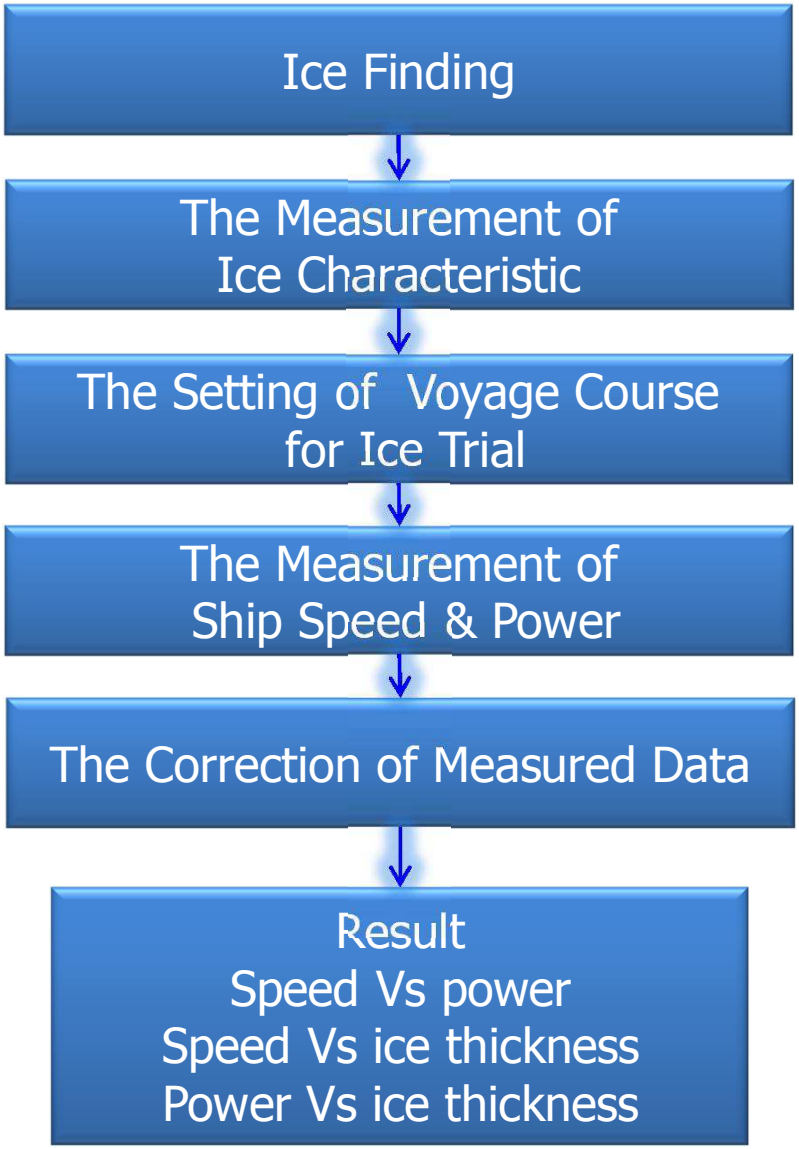
The purpose of Ice Trial

Verification ship's performance on ice field

Major demonstration items

- Speed performance (astern/ahead)
- Turning ability
- Vibration & Noise Measurement
- Function test of various equipment in Low Temperature

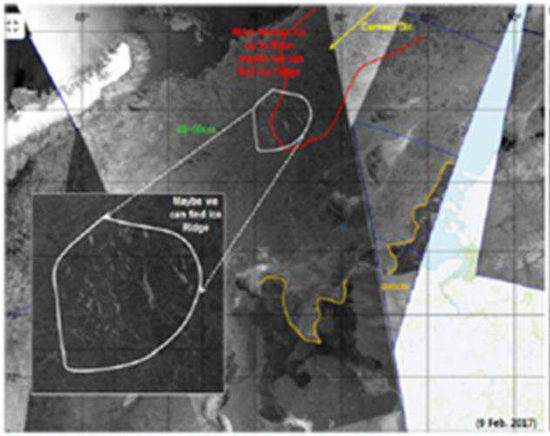
Flowchart of Ice Performance Trial

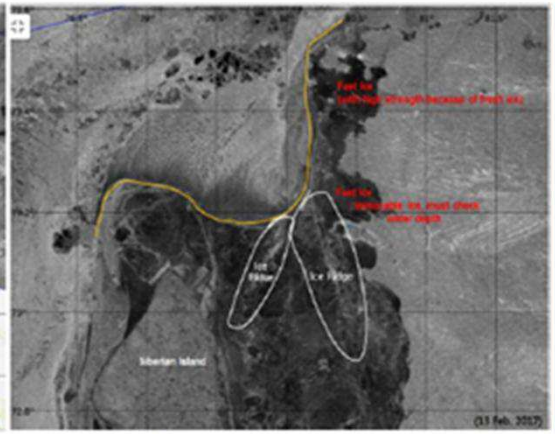


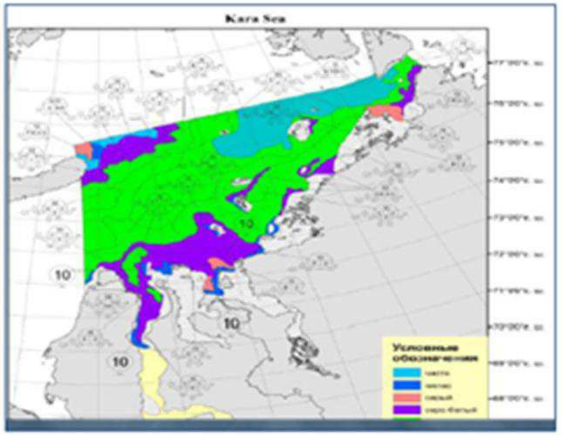
Ice Finding

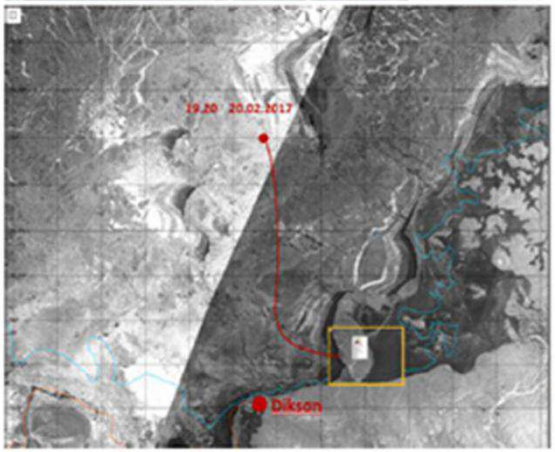
Find proper ice station to carry out Ice Trial

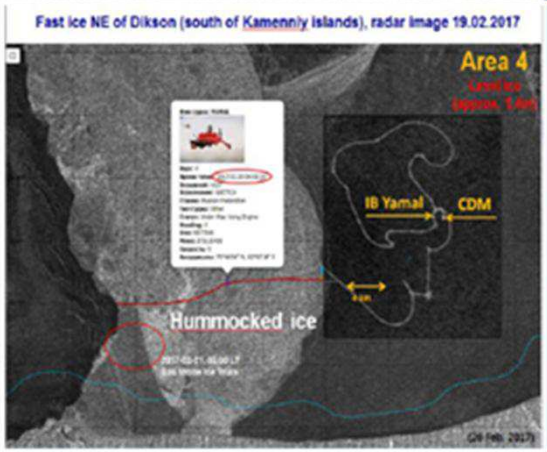
- SATELLITE IMAGE, ICE CHART
- INFORMATION FROM ICE BREAKER (ICE OBSERVER)

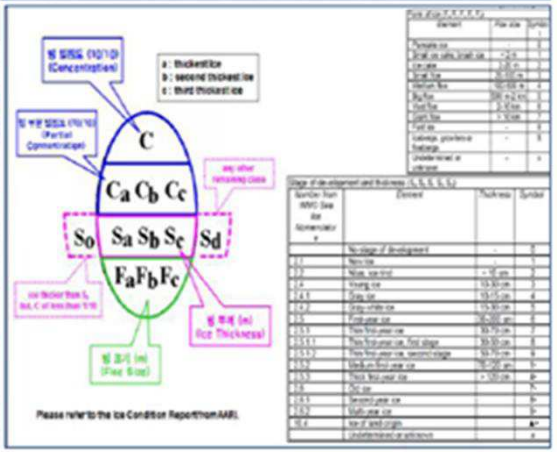












Ice Measurement (by AARI)

Measurement of ice properties

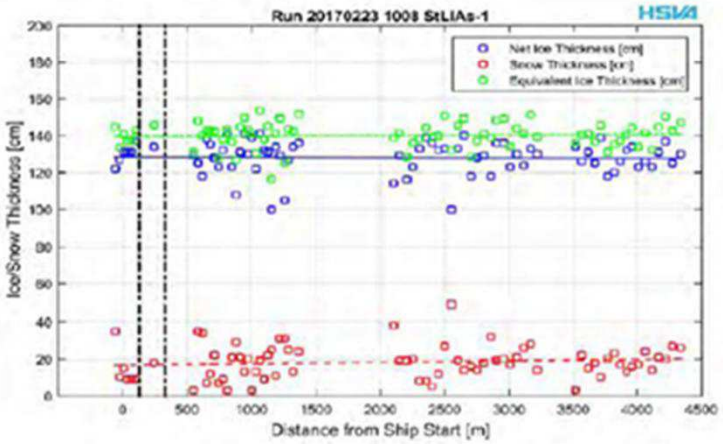
- ICE & SNOW THICKNESS MEASUREMENT, FLEXURAL STRENGTH
- ICE PROPERTY MEASUREMENT (ICE TEMP., DENSITY, SALINITY)

3.2 Ice Field Measurements

3.2.1 Level Ice Thickness

		Average	Standard Deviation
Net Ice Thickness:	H_{ice}	134.0 cm	0.0 cm
Snow Thickness:	H_{snow}	18.0 cm	0.0 cm
Total Thickness:	H_{total}	152.0 cm	0.0 cm
Equivalent Ice Thickness (f_{snow} = 0.65):	H_{eq}	145.7 cm	0.0 cm
Weighed Equivalent Ice Thickness:	$H_{eq'}$	145.7 cm	–

Table 2: Level Ice Thickness Measurements Over Selected Interval



Yamal LNG Ice Trials - Ice thickness measurement sheet

Date/Time: 2017-02-22	Test Area:		Section No.:			Group Leader:	
Bore hole No.	GPS Latitude [deg]	GPS Longitude [deg]	Distance from Start Flag [m]	Net Ice Thickness [cm]	Snow Thickness [cm]		
1	73.767	83.250	0	140	20	-	-
2	73.735	83.313	2000	135	12	-	-
3	73.748	83.362	2000	135	15	-	-

Start Flag position: Lat [deg]: 73.767, Lon [deg]: 83.250; Remarks:

Yamal LNG Ice Trials - Flexural Strength measurement sheet

Date/Time: 2017-02-22	Test Area:		Section No.:		Group Leader:
Bore hole No.	GPS Latitude [deg]	GPS Longitude [deg]	Distance from Start Flag [m]	Flexural Strength [kPa]	Method (profile = 1) (3-point = 2) (cantilever = 3) [-]	Distribution + Remarks:
1	73.7667	83.2500	0	794	2	9 samples at 3 layers
1	73.7667	83.2500	0	780	1	Core No 2201

Start Flag position: Lat [deg]: 73.7667, Lon [deg]: 83.2500

Flexural Strength based on Temperature, Salinity and Density

Air Temp. [°C]:	-20	Snow Temp. [°C]:	-	Water Temp. [°C]:	-
Total Ice Tickness [cm]:	140	Snow Thickness [cm]:	2	Salinity of Water [‰]:	-

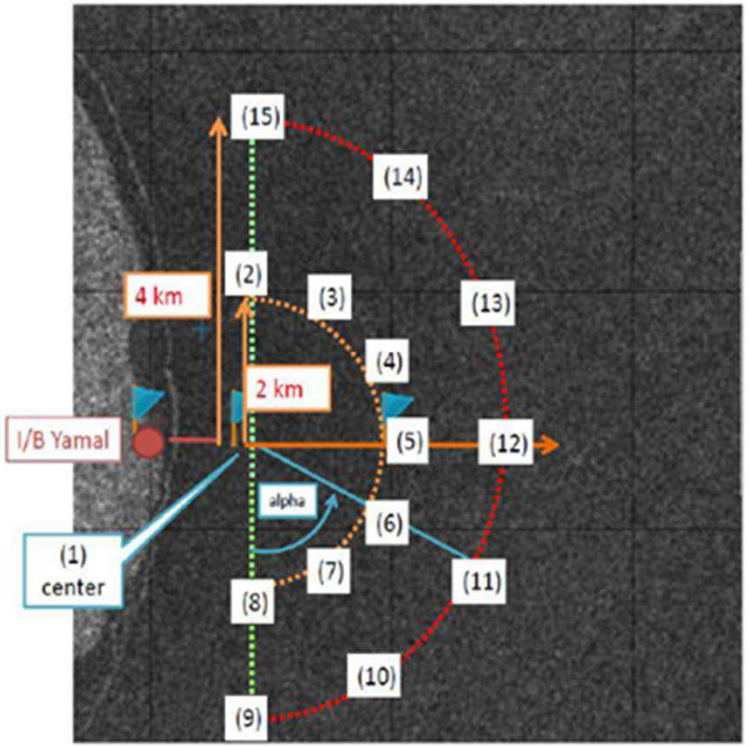
Input Data Temperature		Input Data Salinity and Density				
Z_T [cm]	T [°C]	Z_0 [cm]	Salinity [‰]	Weight [g]	Length [cm]	Diameter [cm]
10	-18.0	10	4	1323	9.3	14.2
20	-17.4	20	4	1169	8.2	14.2

Ice Measurement (by AARI)

The Setting of Voyage Course for Ice Trial

- **Judgment of Ice Thickness & Environmental condition**
- **Setting of Voyage Course**
  - ICE & SNOW THICKNESS, ICE DRIFT
  - WATER DEPTH, WIND SPEED/DIRECTION

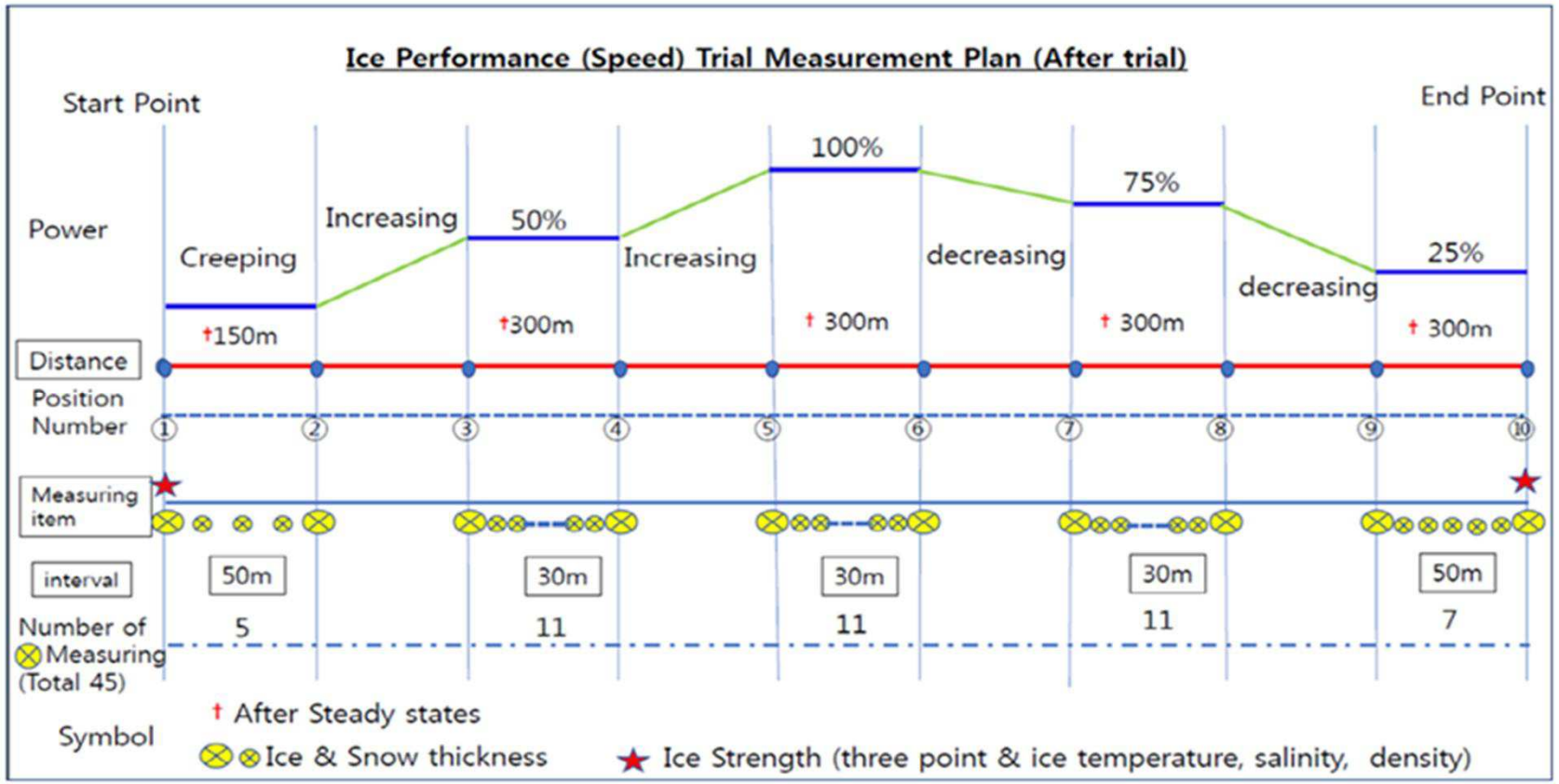
Arrangement of Measurements for possible test tracks



Yamal LNG Ice Trials - Ice thickness measurement sheet

Date/Time: 2017-02-22		Test Area:		Section No.:				Group Leader:	
Bore hole No.	GPS Latitude [deg]	GPS Longitude [deg]	Distance from Start Rag [m]	Net Ice Thickness [cm]	Snow Thickness [cm]			Start Rag position: Lat [deg]: 73.767 Lon [deg]: 83.250 Remarks:	
1	73.767	83.250	0	140	20	-	-		
2	73.735	83.313	2000	135	12	-	-		
3	73.748	83.362	2000	135	15	-	-		
4	73.767	83.378	2000	108	25	-	-		
5	73.785	83.362	2000	108	20	-	-		
6	73.798	83.313	2000	130	50	-	-		
7	73.803	83.250	2000	131	4	-	-		
8	73.785	83.250	2000	126	8	-	-		
9	73.782	83.282	4000	126	8	-	-		
10	73.775	83.305	4000	139	7	-	-		
11	73.767	83.313	4000	138	4	-	-		
12	73.758	83.305	4000	130	9	-	-		
13	73.752	83.282	4000	131	13	-	-		
14	73.748	83.250	4000	128	4	-	-		
15	73.730	83.250	4000	136	6	-	-		

The Measurement of Ship Speed & Power



Ice Performance Test

The Correction of Measured Data

● **Correct measured data & environmental condition to Requested(Contractual) condition.**

- There is no standard Ice Correction Method in the world.
- Their own empirical method is used in Ice institute(ice model basin).
- Independent correction method for YAMAL LNGC was developed.

- The activities other than ice correction method such as managing and reporting were cooperated with HSVA.

Result (Speed-Power-Ice Thickness)

Table 2 Astern Performance raw data

Average raw data without any correction					
Test Run	H_ice [cm]	H_snow [cm]	SIG_F [kPa]	V_sog [kts]	P_tot [kW]
*Run 20170223_1008_StLiAs-1**	*134.0*	*18.0*	*636*		
Run 20170223_1008_StLiAs-2	128.0	18.5	636		
Run 20170223_1008_StLiAs-4	128.7	19.5	636		
Run 20170223_1008_StLiAs-3	129.4	18.6	636		

Table 3 Astern Performance corrected data

Results of Test Runs				Average H_eq' adjustment	
Test Run	P_corr [kW]	V_ice [kts]	H_eq' [cm]	P_corr_av [kW]	
*Run 20170223_1008_StLiAs-1**			*145.7*		
Run 20170223_1008_StLiAs-2			140.7		
Run 20170223_1008_StLiAs-4			141.6		
Run 20170223_1008_StLiAs-3			141.8		
Average weighted equivalent ice thickness [cm]:			141.3		

*The results of the creeping speed are only given for reference as the acceptance criteria for the constant speed is not fulfilled and insufficient ice measurements are available.

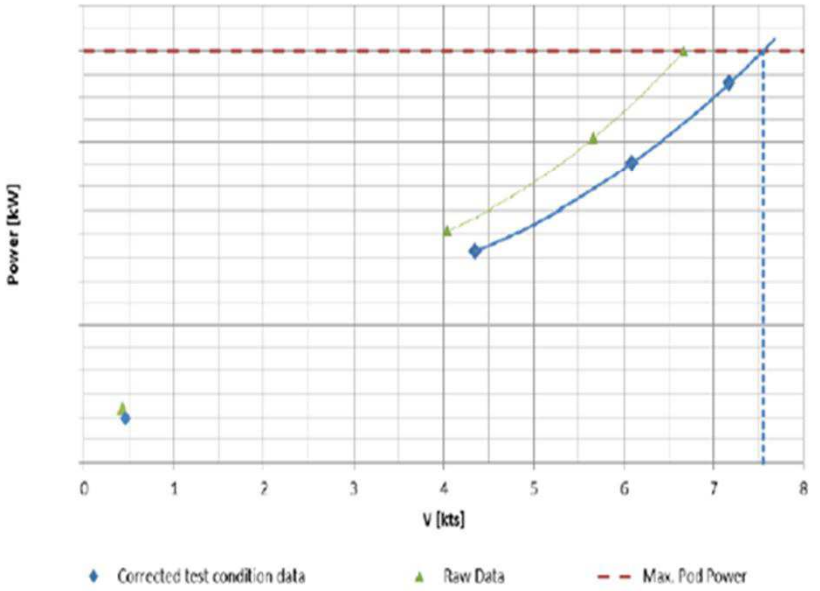


Figure 4 Astern Performance Test in 1.41m Eq. Level ice: Raw data and corrected data

Completion..!! World First ARC7 LNG CARRIER ICE TRIAL