PART IV

INNOVATIONS APPLICABLE TO THE ARCTIC

11. A Fibre Optic System for Canada's Western Arctic

Michael Aumond

This article describes the rationale, design, and implementation strategy for a high-speed fibre optic system connecting Canada's Western Arctic to the Southern Canada fibre optic telecommunication grid. The article describes the Mackenzie Valley Fibre Link (MVFL) project and addresses:

1. The project objectives, focusing on the Government of the Northwest Territories (GNWT) public good objectives of providing high-speed delivery of social services programing, health care, education and outreach services and of providing a high-speed fibre-optic telecommunications "enabling" infrastructure to support economic diversification for the region by connecting relatively small rural and remote communities to the national and international marketplace.
2. The economic and technological challenges of providing fibre-optic communications in Canada's North, and the decision by the GNWT to strategically invest in a long haul backbone system, providing telecommunications transport facilities from northern communities to an existing southern location on Canada's existing fibre grid.
3. The private public partnership (PPP) chosen for the execution and long-term operation of the system, and the risk profile assumed both by the private sector partner and by the government.
4. The requirement for a robust business model for the government's investment in the MVFL, and the benefit of an existing satellite receiving station in supporting both the long term revenue base of the MVFL and the government's economic diversification objectives in the region.

PROJECT LOCATION AND OBJECTIVES

Canada's Northwest Territories (NWT) extends from the northern boundary of Alberta to Canada's high Western Arctic. The NWT is approximately 500,000 sq miles, and has a population of 43,000 located in

33 communities. The largest community is Yellowknife, with a population of approximately 20,000. The southern Canada fibre optic grid extends to Yellowknife and communities in southern NWT. Northern communities are served either by satellite or by terrestrial microwave communications systems. Both of these technologies result in higher prices, limited capacity, and in some cases, slower connection speeds.

Figure IV-1. Canada's Northwest Territories

The difference in telecommunications technologies used to provide telecommunications service to our northern communities translates into a disparity in services that can be delivered to our communities. Modern government services, including health care, education, social outreach programs, and government administrative services rely on the ability to deliver these services in an efficient and cost-effective manner. They often use high-speed Internet services as a key transport element of the services delivery component. Without access to high-speed and affordable Internet services, communities may not have access to needed, modern government services. Additionally, in an increasing competitive global economy, the ability to attract high-quality investments in the north, leading to jobs and value-added services, is often contingent on access to modern, high-speed, reliable communications systems.

The GNWT has, as two key priorities in this area:

a) Improved delivery of GNWT public services to northern communities
b) Creating an environment to attract economic activity in the NWT and regional economic diversification.

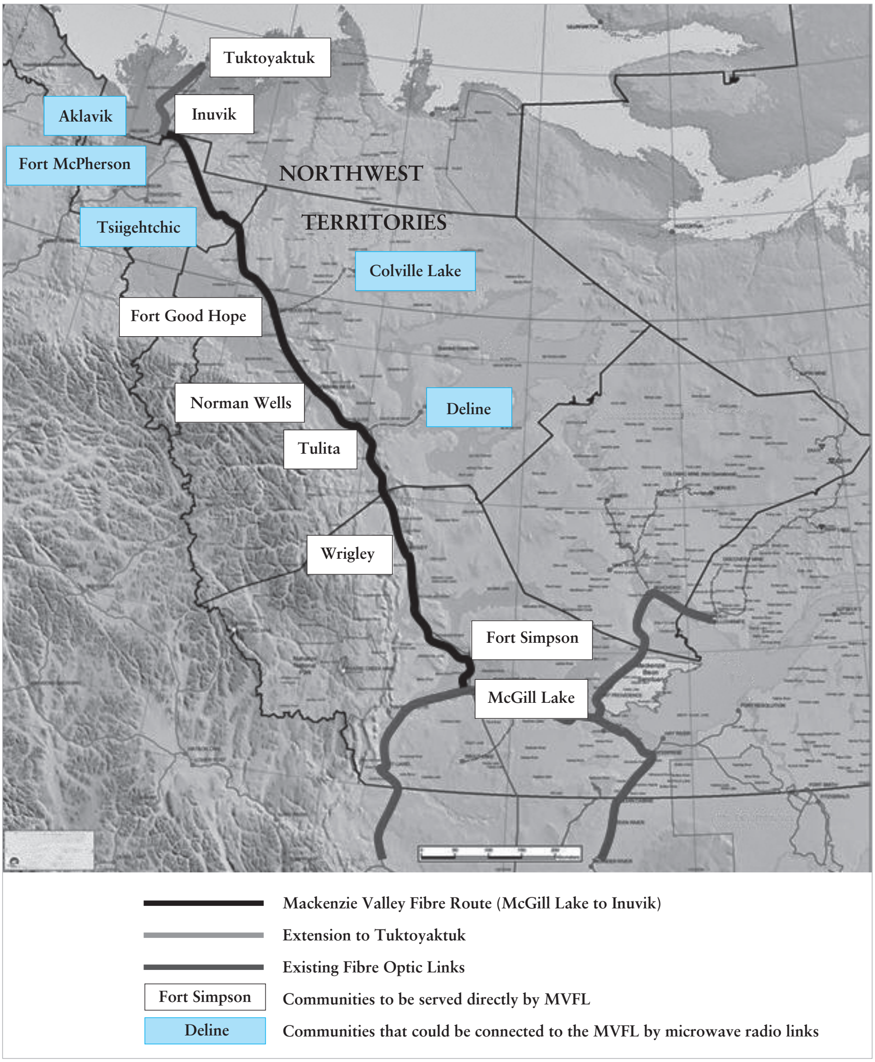


Figure IV-2. *MVFL route*

The purpose of the Mackenzie Valley Fibre Link Project is to realize both of these priorities in the Mackenzie Valley region of NWT and to improve overall connectivity. The system extends from the southern Canada fibre grid at McGill Lake in southern NWT to Tuktoyaktuk on the shores of the Beaufort Sea. Six communities will be served directly on the fibre route, and an additional four communities could be served in the future by short microwave connecting systems from communities located close to the MVFL, but not directly on the fibre route. Inuvik is the largest community, with a population of 3,500, and the region has a total population of 10,100. The distance from McGill Lake to Tuktoyaktuk is approximately 1,200 km.

ECONOMICS OF NORTHERN TELECOMMUNICATIONS SYSTEMS

Telecommunications systems can be classified broadly into three major components, as shown in the diagram below:

In the north, distances between communities are typically much larger

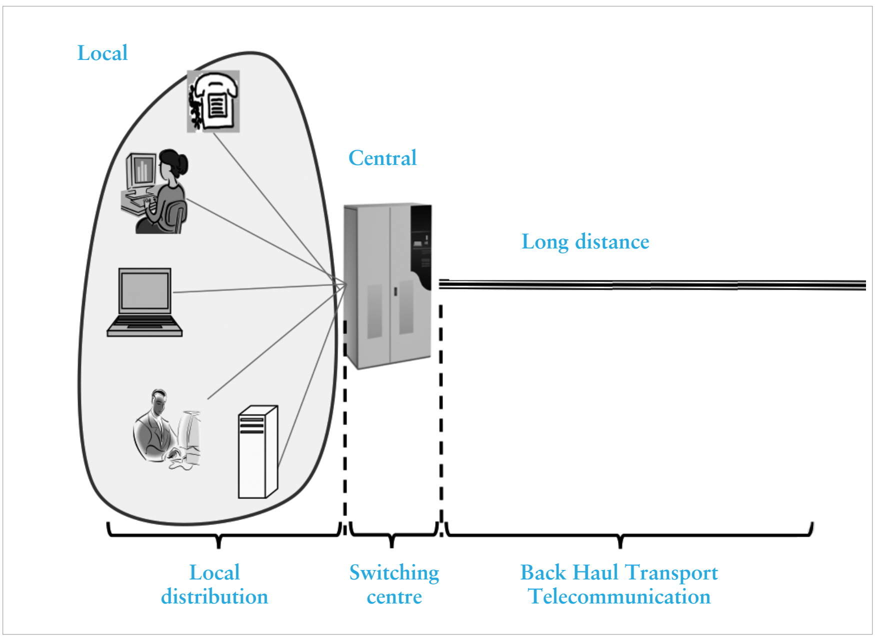


Figure IV-3. Three major components of telecommunications systems than in southern Canada, and the communities themselves are much smaller. Conversely, the communities in the north tend to be more compact than in rural areas in the south or in peri-urban areas. These differences have a profound effect on the economics of providing modern, high-speed telecommunications services to northern communities at an affordable cost.

In typical southern Canadian networks, the cost of providing local loop services in rural areas is the dominant cost. In general, the cost of the backhaul system is a relatively minor component on a per-customer basis.

In northern networks, the situation is reversed. The cost of the backhaul networks is almost always the single most significant cost component. The provision of local service to northern customers in the relatively compact communities is not, by comparison, a large cost component. Technology is providing alternative ways of providing relatively inexpensive local loop alternatives (for example, wide bandwidth cellular distribution systems). Additionally, the cost of switching systems, including ancillary elements such as building space and power consumption, has fallen significantly.

In economic terms, the high cost of backhaul systems in the north means that telecommunication service providers have little choice but to charge significantly higher prices to serve these communities. This has the effect of generating a systemic disadvantage to northern communities both in terms of the effective and efficient provision of public good services to local residents and in attracting firms to provide jobs and economic opportunities for northern communities.

Government of Northwest Territories (GNWT) Investment Strategy for the Mackenzie Valley Fibre Link

The GNWT developed an investment strategy specifically to address the high-cost backhaul segment of northern telecommunications systems. The government has no interest in operating a broader telecommunications service, or in becoming a telecommunications service provider, other than the facilitation of important government services to residents and businesses. For those areas where the telecommunications market functions well, the government has no interest in intervening.

The GNWT strategy has two basic components:

a) Limiting investment to the backhaul portion of the network from Tuktoyaktuk to McGill Lake, which is the closest point in the southern Northwest Territories that has an existing high-speed fibre system.

b) Establishing a PPP business arrangement to design, build, finance, operate and maintain the MVFL system. The term of the contract is for a period of 20 years from the service commencement date.

Technology Challenges of the Mackenzie Valley Fibre Link (MVFL)

The route of the MVFL, extending from McGill Lake in the south to Tuktoyaktuk in the north, is characterised by a rapid change in environmental conditions. From the sporadic permafrost in the subarctic region in the south, to continuous permafrost in the polar north, the MVFL has been designed to meet the challenges of operating in a hostile, and changing, northern and Arctic environment. Specific challenges unique to the MVFL environment are:

Climatic and Environmental Conditions and Route Geography

The southern end of the MVFL at McGill Lake is located in a subarctic climatic region, and the route extends to a polar climatic region at Tuktoyaktuk in the north. The route is divided into four sections:

This section can be installed during the summer/fall seasons using a traditional cable plough.

1) An all-weather gravel road section from McGill Lake for approximately 320 km to Wrigley.
2) A winter road section from Wrigley for approximately 475 km to Fort Good Hope, close to the Arctic Circle,
3) A section from Fort Good Hope to Inuvik (a distance of approximately 360 km), along the proposed route of an extension of the NWT's Mackenzie Valley Highway. This is the most challenging section of the route and requires the use of mobile crew camps.
4) The final section from Inuvik to Tuktoyaktuk, following the all-weather Dempster Highway that is currently under construction.

Permafrost

Permafrost along the MVFL route ranges from sporadic, to discontinuous, to extensive discontinuous. Permafrost consists of three layers: an active layer, which is subject to a freeze-thaw cycle every year, a permanently frozen layer, and a transition layer, which resides between the active layer and the permanently frozen layer, and can contain "bubbles" of water and/or ice and an area called an ice lens when frozen. When this layer melts, the ground above sometimes gives way in a process called "slumping."

Permafrost is a problem because, in summer, the active layer of the permafrost becomes similar to a wet land swamp and is unable to support the weight of installation equipment. Winter is the only season when installation can occur, and contractors have to wait until the ground is frozen to the point that transport and installation equipment can be safely moved.

Permafrost has three important impacts on the MVFL installation and operation.

Permafrost:

a) Limits the installation for the northern two-thirds of the MVFL to the winter season, lasting typically from early January to early April.

For these sections of the route, the cable is installed directly in a trench, in the active layer of the permafrost

b) Affects the installation techniques to be employed and the fibre optic cable. The MVFL uses a marine-type cable for the northern two-thirds of the route because of its superior tensile and crush-resistant strength characteristics

C) Limits the options for cable replacement in the event of a cable break. For parts of the year when the route is inaccessible, repairs will be completed using a temporary cable which will be laid directly on the ground. As soon as conditions permit, a permanent repair cable will be installed underground.

As the route progresses northwards, the depth of the active layer decreases. The route design takes this into consideration and the depth of the trench changes accordingly.

Forest Fires

Forest fires in the Northwest Territories are typically left to burn unless property or people are affected. For the MVFL project, this means that aerial construction outside of community locations represents a long-term risk to the cable.

Tundra Fires

Tundra fires can occur at locations along the entire MVFL route. These fires can travel horizontally underground and can last for years. Typically, tundra fires do not penetrate at depths lower than approximately 1-1.5 ft below cleared ground level. As a result, the depth of the fibre cable trench is typically below 1.5 ft to mitigate the risks of the effects of tundra fires, but still within the permafrost active layer.

Major River Crossings

There are four major river crossings along the MVFL route. The largest of these is the crossing of the Mackenzie River north of Fort Simpson, with a crossing length of over a mile. All these rivers have experienced significant spring flow rates with accompanying large sections of ice propelled down the river, which renders any cable on the river bed vulnerable to ice scouring. As a result, the fibre cable installation will use horizontal directional drilling (HDD) techniques for each major crossing.

Crossing Minor Rivers and Creeks

Environmental regulations along the MVFL route permit trenching of the fibre cable across minor rivers and creeks provided that the river/creek is fully frozen to the river or creek bed. In those instances where flowing water remains, horizontal drilling techniques will be employed.

Bridge Crossings

Where bridges exist, the fibre cable will be installed in ducts attached to the bridge structure. This poses additional temperature constraints on the cable, as outside temperatures in winter can drop below -40 degrees C, and summer temperatures can reach above + 30 degrees C.

MVFL SYSTEM ARCHITECTURE

The MVFL system is equipped with terminal equipment at either end, and intermediate sites equipped with reconfigurable add-drop multiplexers (ROADM) which are configured as MVFL, publically accessible points of presence (PoP) locations. Local service providers can access the MVFL at any intermediate point, and their traffic is delivered to the southern Canadian grid carrier of their choice. The system is configured to provide equal access to any local telecommunications provider in the MVFL communities, and at the southern end of the system, equal access to any of three southern grid carriers. The MVFL provides power, equipment rack space, and a controlled equipment environment for local service provider's equipment necessary to connect their customer's traffic to the MVFL at every PoP along the route.

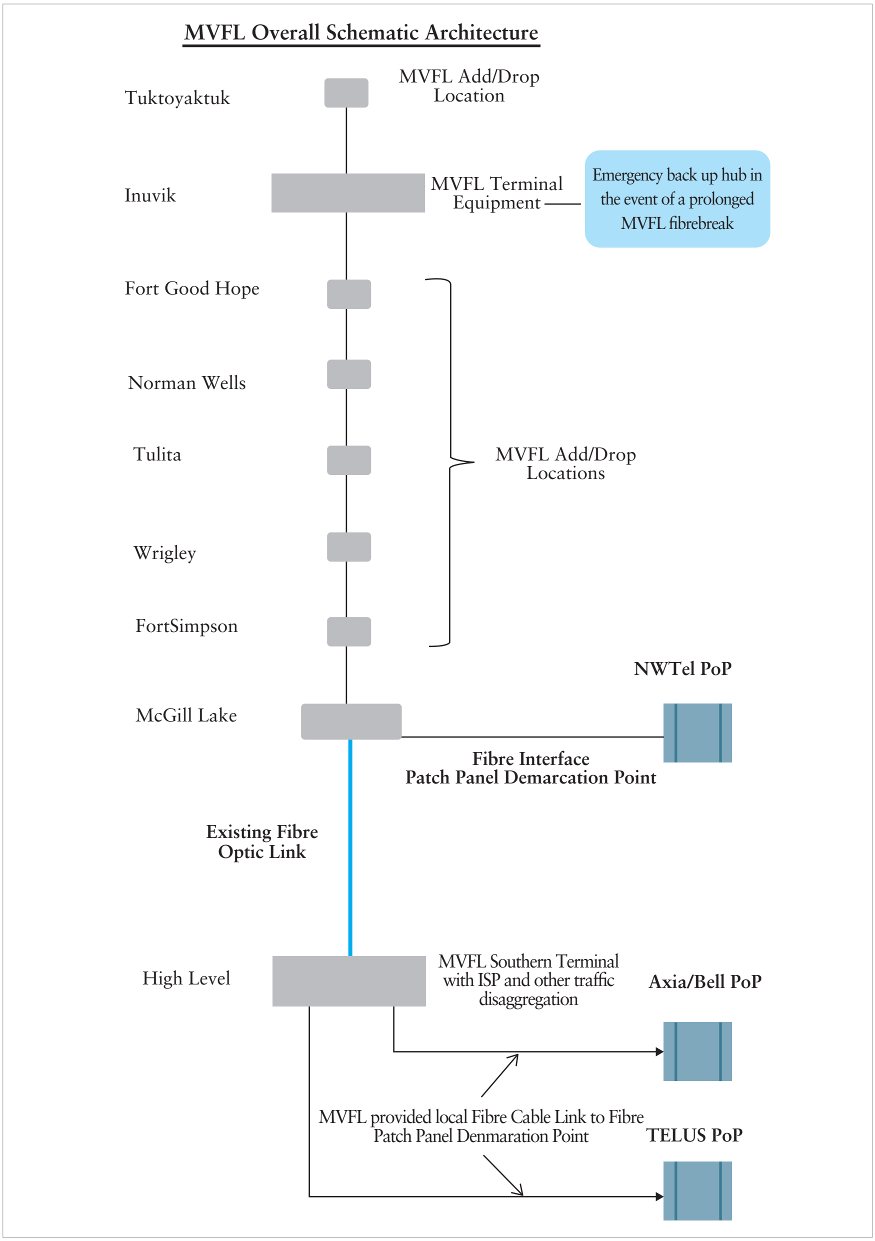
The system has a design life of 30 years. Although the demand for capacity is increasing at an exponential rate, the fibre cable capacity of 48 high-capacity fibres has been sized to meet the 30-year demand.

One significant aspect of the system architecture is the configuration of the terminal equipment and the emergency backup facility. The MVFL is a linear system and is vulnerable to a cable break. The system equipment is fully duplicated using separate operating and standby fibres. This architecture protects customers from equipment failures (the standby system is always in fully operational mode, commonly called hot standby mode) and from single fibre or spice failures. However, the system remains vulnerable to a complete cable break, which may take days to repair.

The MVFL solution to this problem is to provide an emergency backup system at the northern terminal in Inuvik that provides service to hospitals/nurses stations, police and emergency services, and government administration in the event of a cable failure. For this to work, each intermediate site has been designed to work with just one terminal. In the event of a cable failure in the middle of the system, all the intermediate sites to the north of the break will operate through the emergency backup service in Inuvik, while all the stations to the south of the break will continue operating with the southern terminal.

The MVFL system performance specifications are:

a. Equipment-only availability - 99.99% (4.5 minutes per month - this can only be achieved with full equipment redundancy).



- The MVFL system utilizes an existing fibre system from McGill Lake NWT to High Level, Alberta to facilities access to two of the three major southern grid carriers. The third carrier is accessed directly at McGill Lake.
- The system is configured with both Express Channels from Inuvik and Norman Wells respectively to McGill Lake and local "festoon" channels that can be accessed at any intermediate or terminal location.
- The fibre cable consists of 48 fibres, with each fibre capable of supporting 88 independent Dense Wavelength Division Multiplexing (DWDM) channels, each supporting a maximum transmission rate of 100 Gbits/s.

b. Overall system availability - 98% (includes all failures, including cable cuts).

Private-Public Partnership Project Implementation Business Model

The GNWT decided to implement the MVFL using a PPP business model for two strategic reasons:

1) To obtain access to private sector capital.

2) To share the project risk with a private sector partner that has experience both in subarctic and Arctic infrastructure construction, and the long-term operations of telecommunication services. In the MVFL project, the private sector partners assumes the design, build, maintenance and long-term operations risk, and the GNWT assumes the project revenue risk. This PPP business model provides the prime contractor with a significant incentive to design the system for reliability and to minimize long-term operation costs, and to ensure that the design meets the operational specifications. The PPP agreement provides for a reduction in payments in the event that the performance specifications are not met, and provided the reason for the poor performance is within the responsibility scope of the project agreement signed with the contractor.

The incentive for the contractor is that monthly system availability payments are guaranteed by the GNWT, subject to the contractor meeting the agreed system performance criteria. The benefit for the GNWT is that risk associated with the design, build and long-term operations of the system is assumed by the contractor.

The GNWT initially contracted a feasibility study to assess both the technical and business viability of the MVFL system. This confirmed the viability and feasibility of the system. The next step undertaken by the GNWT was the generation of a request for expressions of interest. For the MVFL project, five firms responded, and the GNWT selected three firms, each of which demonstrated both the technical capacity and financial strength to undertake a project of this risk and magnitude.

A series of collaborative meetings were held independently with each of the selected contractors. These meetings ensured that the contractors fully understood the requirements of the project. Additionally, a number of positive technical and business suggestions were made by the prospective contractors based on their own individual experience with infrastructure projects in the north, and these proved to be valuable to the GNWT in structuring both the technical and business aspects of the project.

Following the collaborative meeting, a request for proposal was sent to the three contractors. These have been evaluated recently by the GNWT and the highest-rated proponent has been notified of its selection as the preferred proponent. The final step prior to contract execution is the financial close with the selected proponent.

MVFL PROJECT BUSINESS CASE

The GNWT undertook a rigorous business review that modelled the system costs and potential revenue for the duration of the project. The review also evaluated the value of a PPP procurement process compared to the more traditional tender process, which would have then involved the GNWT contracting out the operations and long-term maintenance.

There were five important aspects of the business modelling process:

1) The political support from the GNWT to proceed with a project focussing on improving connectivity in northern communities.

2) The result that a PPP procurement model offered the best value for the money compared to other procurement methods.

3) The existence of a potentially major large-volume customer of the MVFL in Inuvik. In 2010, the government of Canada, in partnership with the GNWT, the local township and local aboriginal governments, established the Inuvik Satellite Station Facility. This satellite receiving station is located in an ideal geographic position to receive data from an increasing number of remote sensing satellites.

The GNWT realised that the MVFL system would benefit from the data traffic generated by a global satellite station in Inuvik, in a similar way that the satellite station would benefit from a high-speed fibre connection to the southern Canadian telecommunications fibre grid.

The long-term vision for the Inuvik Satellite Station and the MVFL is the creation of data processing, scientific research and data storage facilities in Inuvik.

4) The public good value of providing improved delivery of health care, education and government services to northern residents services.

5) The “enabling” value of modern telecommunications infrastructure

to support existing local businesses and encourage new firms to locate in the Mackenzie Valley region.

Environmental Considerations

The Mackenzie Valley is a pristine subarctic and Arctic environment. The GNWT has been careful to require contractors to conform to both the letter and spirit of environmental legislation and regulations. In particular, special attention was given to the size of equipment proposed by contractors in the construction phase of the project, with an emphasis during the proposal evaluation on light, load-bearing construction equipment and installation techniques with minimal environmental impact.

Local Consultations

Local consultations are an integral part of any infrastructure project undertaken by the GNWT. For the MVFL project, the routing traverses aboriginal land for a significant portion of the distance between Fort God Hope and Tuktoyaktuk. Additionally, the GNWT consulted with, and continues to have a dialogue with, all aboriginal governments along the MVFL route.

MVFL Project Timetable

The planned in-service date for the Inuvik to McGill Lake portion of the MVFL project is summer 2016. This service date requires that construction start on the first winter section in 2014/15, with the summer construction season in 2015 being focused on the southern all-weather road section. The final winter construction season of winter 2015/16 will complete the installation of the project, with system commissioning starting in spring 2016 for a summer in-service date.

The final section from Inuvik to Tuktoyaktuk will start upon completion of the all-weather Dempster Highway extension to Tuktoyaktuk, and is planned to be complete in 2017/18.

12. Research Activities of the KRISO Ice Tank

Kuk Jin Kang

In this article, we introduce the Korea Research Institute of Ships and Ocean Engineering (KRISO, formerly MOERI) Ice Tank facility and research activities for Arctic engineering and then describe ships' performance in various ice conditions. We also present a hull strength assessment based on ship-ice interaction and a shipboard winterization technique. In addition, we discuss how to predict the ice resistance of the ship and the impact of ice loads on the ship as well as how to evaluate a ship's performance in ice model tests. We conclude with an introduction to a full-scale ice trial procedure.

KRISO ICE TANK FACILITY

New hull forms and operational concepts are being developed to meet the challenges facing shipping industries as a result of the increasing demand for ice-strengthened vessels and Arctic offshore structures able to meet regulatory requirements and to deal with extreme environmental conditions. These challenges have led to increased demand for model testing in ice to assist in the design process and to improve the performance of ice-going vessels and ice-operating capabilities of offshore structures. With the support of the Korean government, the research community, and ship building industries, KRISO has completed the construction of an ice tank in Daejeon. The facility, which commenced operation in 2010, employs state-of-the-art technology. The size and shape of the tank are designed to enhance the model test capabilities of offshore structures operating in the Arctic and the maneuvering performance of ice-going vessels in ice. With increasing access to the polar region, the importance of Arctic engineering and infrastructure is growing. The new ice tank is suitable for research on ships operating in this region. KRISO's Ice Tank facility can expand research capabilities and ocean technology worldwide. It can also aid the research community and industries' R&D on ice-going vessels, novel structures, and transportation systems in ice-covered water.

The square-type KRISO Ice Tank is particularly suitable for studies of ice loads on fixed offshore installations, where the interaction between the structure and ice has to be modeled. The tank also permits a model ship to complete a full turning circle test. In a typical ship resistance and/or propulsion test, the 32 m of available ice width allows more than five or six parallel test channels within one ice sheet. The dimensions of the ice tank are as follows: 42 m (long) × 32 m (wide) ×2.5 m (deep).

- Trimming tank size: 10 m (long) × 32 m (wide)
- Usable ice sheet size: 32 m (long) × 32 m (wide)
- Model ice type: ethylene glycol (EG)/aliphatic detergent (AD)/ controlled density (CD) (crystal structure: columnar type)
- Microbubble generation system to control the density of model ice

The KRISO Ice Tank is equipped with a main X-Y towing carriage system consisting of an X-carriage and a Y-carriage. The X-carriage can tow models through the ice sheet or the ice sheet against the model, which is fixed or moored to the bottom of the tank. The Y-carriage is suspended beneath the main X-towing carriage and can move throughout its length. A separate service carriage is installed for modeling ice production and treatment of ice in the model test. After the model test in ice, six movable blades installed at the front of the service carriage push the broken ice sheets into an ice-melting pit. The properties of the towing carriage system

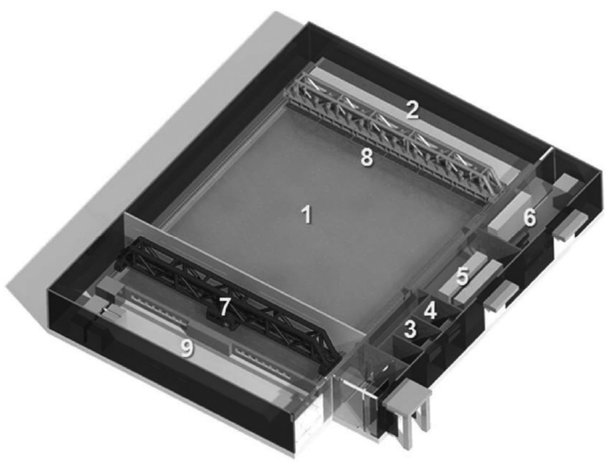


Figure IV-4. Layout of KRISO Ice Tank

Figure IV-5. X-Y carriage and service carriage

are as follows:

- X-carriage speed: max: 3.0 m/s and min: 0.005 m/s
- Y-carriage speed: max: 1.5 m/s
- Towing force capability: X-direction, 50 kN; Y-direction, 3 kN
- Service carriage speed: 1.5 m/s

The KRISO Ice Tank is equipped with an air cooling system and uses natural convection to generate the model ice sheet. This is a very effective method to produce an ice sheet with uniform thickness and strength for model tests.

- Air temperature control range: from -30°C to 15°C
- Minimum temperature changing rate: 5°C/h
- Ice growth rate: 2.5 mm/h at -20°C
- Maximum ice thickness: 100 mm

The KRISO Ice Tank uses EG/AD-CD model ice. The ice is a dilute aqueous solution of EG and AD in an approximate ratio of 0.39/0.036%. By fine-tuning ice model techniques, model ice up to 100 mm thick can be produced, with an allowance of about 5 mm. The ice production and modeling procedures are similar to those used by National Research Council-Ocean, Coastal, and River Engineering (NRC-OCRE, formerly NRC-IOT). The following procedures will form the starting point for future refinements. The preparation of the model ice sheet will begin with a wet-seeding procedure. The model ice will be grown at a temperature of -20 ± 0.5°C. The growth rate during this period is expected to be approximately 2.5mm/h. During the latter part of ice growth, the air temperature will be

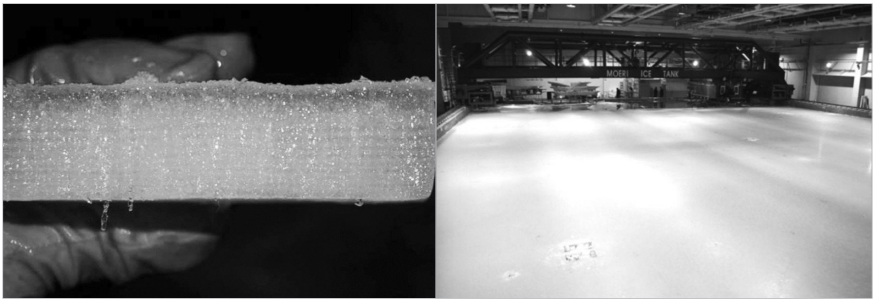


Figure IV-6. EG/AD-CD model ice

raised to +2°C to control the strength of the ice. The target ice strength will be achieved via tempering processing. The properties of the model ice will be routinely measured for each ice sheet, and a database of ice properties will be maintained for quality control and prediction. Microbubbles will be uniformly discharged from the bottom of the ice tank over the full ice-grown area during the entire freezing process to adjust the model ice density to simulate that of the natural range.

In the model test, ice conditions include level ice, brash ice, pack ice, and ridged ice. Resistance tests, propulsion tests, and maneuvering tests can be performed in the KRISO Ice Tank. The model tests in ice in KRISO's Ice Tank can be used to determine the correlation between model-scale results and full-scale results. Ice model tests can be performed with either a fixed model or a free-running model. During the fixed-model tests, the model ship is towed by the main X-towing carriage at a controlled constant speed. In the free-running model tests, the model ship is equipped with its own propulsion system. The model test procedures will follow the recommendations of the International Towing Tank Conference (ITTC). If the procedure recommended by the ITTC cannot be followed, KRISO's

Figure IV-7. Self-propulsion test and underwater image

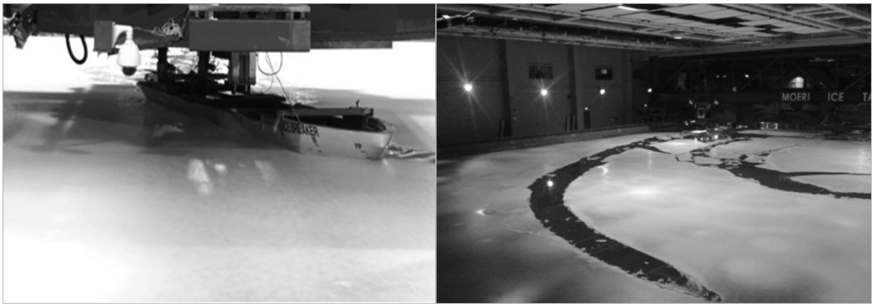


Figure IV-8. Free-running ice propulsion test and turning circle test using auto-tracking system

standard procedures will be adopted. Features of the model tests are described below:

- Study the mechanical properties of model ice,
- Resistance, propulsion, and maneuvering tests for icebreaking vessels,
- Prediction of ice load acting on fixed or floating structures,
- Ship/structure and ice interaction analyses.

Recently, an auto-tracking system that can measure the model ship's location, speed, and heading angle in real-time was developed for the free-running ice maneuvering test. The system consists of a vision camera and real-time data processing software. The system can define an accurate turning circle diameter and the breaking-out length in a full turning circle test and breaking-out test. In addition, in ice propulsion tests, the model ship's auto-tracking system can accurately measure the model ship's speed at a constant propeller revolution, thereby improving the accuracy of the

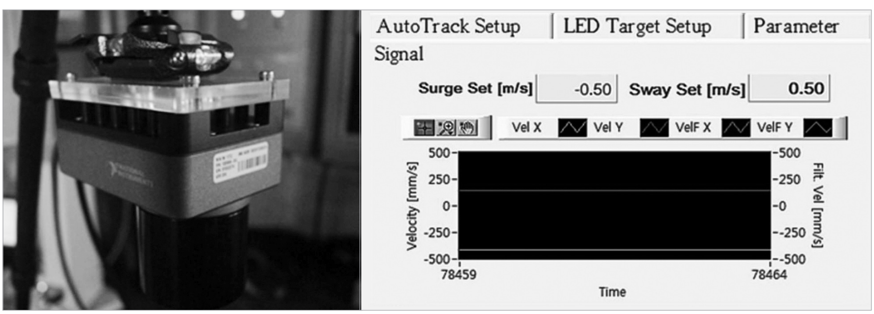


Figure IV-9. Auto-tracking system and measurement software ice propulsion test.

RESEARCH ACTIVITIES OF KRISO ICE TANK

When a ship navigates ice-covered waters, it encounters various problems, such as ice resistance and ice load. These can affect the performance of the ship and offshore structures in ice. These problems are significant factors in Arctic shipping, in ice-related research areas in Arctic regions, and in Arctic engineering. Since 2010, model tests for ice-going vessels, including ice resistance tests, ice propulsion, and ice maneuvering tests, have been conducted in the KRISO Ice Tank. The results of such tests are important for determining ship performance in ice conditions. Recently, an ice model test for icebreaking vessels, large shuttle tankers, and large LNG carriers operating in ice-covered water was conducted in the KRISCO Ice Tank. In the model test, the ice conditions consisted of level ice, brash ice, pack ice, and ridged ice. The model test in the tank can be used to determine the correlation between model-scale results and full-scale results.

In addition to ice model tests in the tank, full-scale ice performance tests of vessels are important. Such tests are needed to derive the correlation between model-scale and full-scale results and to improve the accuracy of model tests. The aim of an ice trial is to evaluate the ship's power and performance in various thicknesses and strengths of ice, but field tests are needed along with extensive experience and expertise. In the last two years, ice field tests of the Korean icebreaking research vessel Araon were conducted in the Arctic in July-August 2010 and 2011. These Arctic ice trials, six in total, were performed from 73°N to 78°N. During this period, sea ice floes consisted of thicker first-year ice, multiyear ice, and ridge ice. Ice trials were also conducted in the Amundsen Sea in February and March of 2012. During an Antarctic cruise, two ice trials were carried out to evaluate the performance of the research vessel Araon on big floes. In the ice trials, in addition to ice

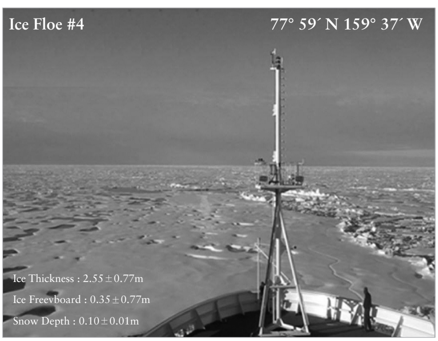


Figure IV-10. *Full-scale ice trial of Korean icebreaker Araon*

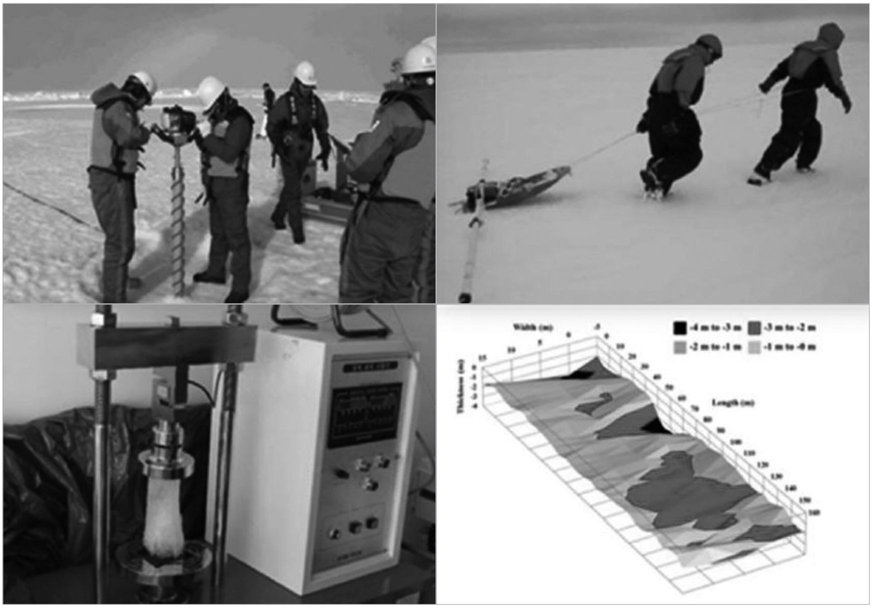


Figure IV-11. *Ice thickness and strength measurement on old ice floe*

properties, the time, location, engine power, revolutions per minute during the trial, and trajectory of the ship were recorded.

In ice trials, sea ice information is divided into concentration, thickness, and strength, and this information is used to evaluate the icebreaking performance of the ship. In the ice trials of an ice navigator from the Arctic and Antarctic Research Institute, the sea ice concentration at the ship's bridge and in the ice floe field was measured. Ice detection radar and a helicopter were used to define the size and condition of the sea ice. The thickness of the sea ice was measured by ice drilling. The ship's speed and main engine power were also recorded during this period. Using these data, we evaluated the ship's icebreaking performance.

As mentioned earlier, the sea ice thickness was measured by ice drilling in the field. Ice freeboard and snow depth were measured with an ice thickness gauge at intervals of 10m or 20m in selected test ice floes and a measuring stick. Figure IV-11 shows an intended ship track on a selected ice floe and ice drilling and coring with an ice auger and ice-coring device. During field measurements, sea ice thickness, temperature, weight, density, salinity, and crystal structures were measured by ice drilling. The compressive strength of the ice was measured with a universal test machine, and the flexural strength of ice was calculated using salinity, temperature, and density results. The ship speed and power of the main engine plant were also measured in onboard tests on the ship. The performance of the ship in ice can be determined based on the measured engine power and ship speed for time history.

Until recently, the KRISO Ice Tank conducted only national research projects for Arctic research. This project focused on the development of safe operation methodology for ice-class vessels operating in Arctic sea routes and cryogenic evaluation techniques for determining a ship's ice performance. The project was carried out with the participation of universities, ship registers, shipbuilders, and marine research institutes. The strategic objectives addressed during the project were as follows, shown in order of priority:

1. Develop safety assessment techniques for the hull structure of icebreaking vessels to assess the design loads on a ship's hull,
2. Develop ice model test methodology to evaluate the ship's performance in ice and improve model test results,
3. Develop anti/de-icing techniques for ship machinery to secure its operating performance in low-temperature conditions to get the required ice class.

The aim of the project was to perform fundamental research for ice-going vessels based on ice-class rules. The main purposes were to develop a model test technique and analysis method, to determine the ice resistance of and ice loads on a ship's hull, to define the correlation between model-scale and full-scale results, to assess the hull's strength during ship-ice interactions, and to develop a numerical simulation technique for ship-ice collision. The outline and research extent is summarized below:

Project title: Development of Safe Operation Methodology for an Ice-Class Vessel Operating in Arctic Sea Routes and Cryogenic Evaluation Techniques for Determining its Performance in Ice

Total project period: 2009.06–2014.05

Total project funding: 2 million USD/year, Ministry of Knowledge and Economy, Korea

- Part 1. Safety Assessment Techniques for Hull Structure of Icebreaking

Vessels (Organization: Korea Maritime and Ocean University),
- Part 2. Development of Ice Test and Ice Performance Optimization Methodologies (Organization: Korea Research Institute of Ships and Ocean Engineering),
- Part 3. Arctic Design Technology and Winterization Performance Evaluation (Organization: Korea Research Institute of Ships and Ocean Engineering).

This research project resulted in the development of various new technologies and applications, as described below:

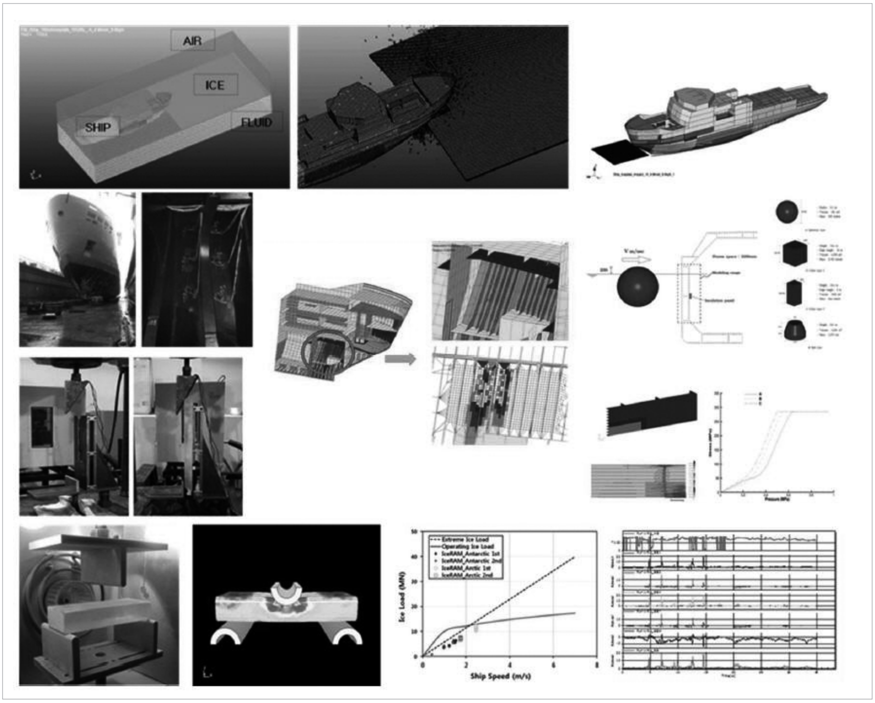
1. Development of accurate ice model test methodology and optimization of the performance of ice-going vessels in ice conditions.
2. Evaluation of the winterization performance of marine equipment of ice-going vessels.

Part 1. Safety Assessment Techniques for Hull Structure of Icebreaking Vessels

Project outline
1. Research objective: Development of safety assessment techniques and analysis procedure of icebreaking vessels,
2. Participating institutions: universities, ship registers, shipbuilders, and research institutes.

Research results
- Estimation and analysis of full-scale ice load acting on a ship's hull
  a. Ice modeling technique for theoretical ice load estimation
  b. Numerical modeling method for ship and ice interaction
  c. Full-scale ice load measurement procedure and analysis method,
- Impact response of ice collision and safety assessment of ship hull
  a. Ship and ice collision analysis using LS-DYNA
  b. Ice load estimation based on various ship and ice collision scenarios
  c. Safety assessment of Mark III membrane CCS.

Applications
- Estimation of ice load on large icebreaking vessels,



- Safety assessment of icebreaking vessels and ice-load prediction design.

Part 2. Development of Ice Test and Ice Performance Methodology

Project outline

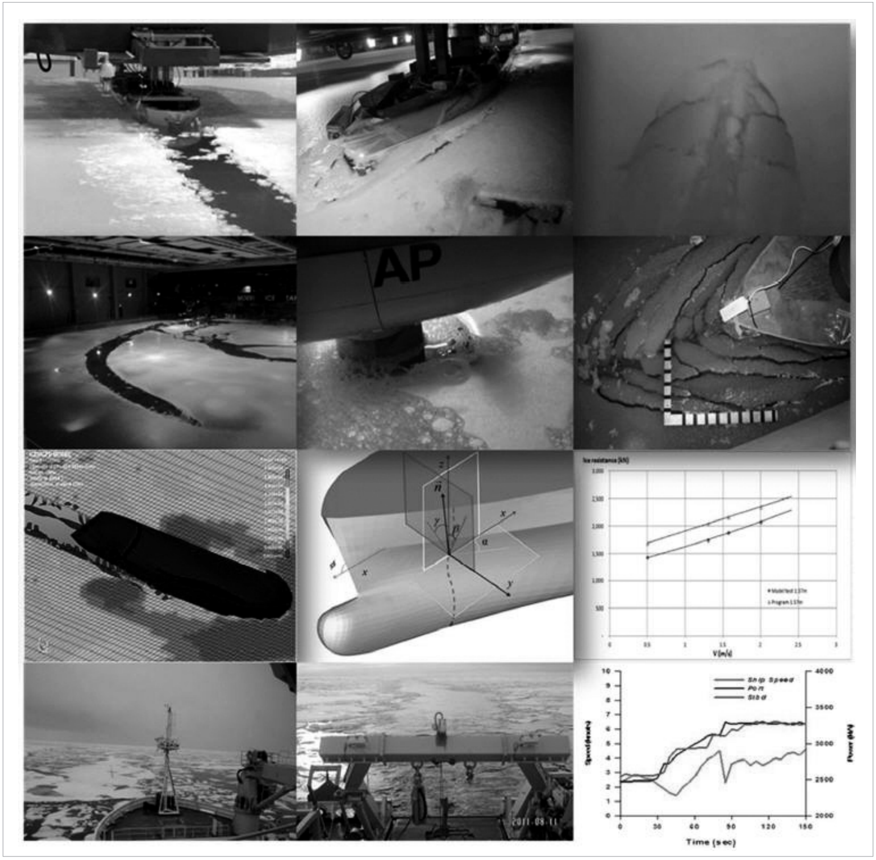
1. Research objective: Development of model test and ice performance analysis methods,
2. Participating institutions: Research institute and universities.

Research results

- Model test and analysis of icebreaking vessels:
  a. Uniform model ice-generation methodology
  b. Ice model test in various ice conditions (level ice, brash ice, ridged ice, etc.) with standard ice model test procedure
  c. Numerical simulation of ship and ice interaction
  d. Propeller and ice interaction analysis
  e. Ice resistance and delivered power prediction of icebreaking vessels

f. Full-scale ice trial test procedure.

Applications
- Delivered power and resistance prediction of large icebreaking vessels,
- Numerical simulation and analysis methods using commercial code,
- Technical services to shipbuilding company to improve the ice performance of icebreaking vessels.



Part 3. Arctic Design Technology and Winterization Performance Evaluation

Project outline
1. Research objective: Development of shipboard winterization techniques,

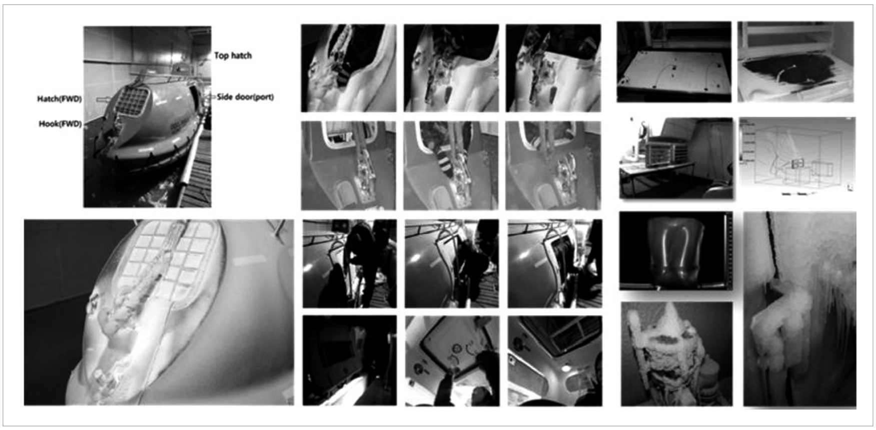
2. Participating institutions: Research institutes, universities, ship registers, shipbuilders.

Research results

- Winterization techniques for Arctic vessels based on ice-class rules:
  a. Standard winterization performance test procedure in cold room
  b. Anti/de-icing techniques for ship machinery (P/V valves, walkways, handrails, and louvers, etc.)
  c. Heat transfer analysis of ship equipment.

Applications

- Winterization performance evaluation of ship equipment at low temperature,
- Shipboard winterization techniques for ice-class vessels.



FUTURE PLANS FOR KRISO ICE TANK

The KRISO Ice Tank will provide the research community and industries with reliable access to an ice-modeling facility and expertise for their R&D activities on ice-going vessels and novel structures, advanced transportation systems and technology, and operational concepts for services in ice-covered water. Initial research activities will be devoted to adapting and fine-tuning various ice-testing techniques by performing a variety of tests on icebreaking ships and on fixed and floating structures under various ice conditions.

Future work:

- Ice model test for a second Korean icebreaker and ice-performance evaluation,
- Development of safe operation technology in Arctic sea routes,
- Ice-structure interaction analysis and development of model test methodology for various offshore structures operating in Arctic regions,
- Development of cooperative relationship and partnership between members of the KRISO Ice Tank facility and others.

DISCUSSION: WHAT NEW TECHNOLOGIES IN THE AREAS OF FUTURE ARCTIC MARINE SHIPPING AND ASSOCIATED R&D ARE ON THE HORIZON THAT WILL IMPACT THE FUTURE OF THE ARCTIC?

Floating structures, such as large-size semi-submergible, drill-ship and LNG-Floating Production Storage and Offloading (FPSO), are believed to be feasible for marine operation in ice-covered waters. Many types of ice features, including level ice, ice ridge, pack ice and rubble ice, will pose potential challenges with respect to concept design and operations. The discussion takes into account what critical technology for floating structures operating in Arctic regions will be needed. The aim of this discussion is to contribute knowledge about ice actions on floating structures, how they can be estimated, as well as the dynamic response from model tests in ice. The specifications of the critical technology of floating structures are given for operations in ice-covered waters. This effort focuses on the requirements that should be met when the floating structures go to operate in the Arctic. The intention of this discussion will be to contribute increased knowledge about the interaction between floating structures and ice by conducting model tests in ice and by developing methodology for numerical studies. First, the fundamental studies of ice-structure interaction and ice failure mode will be discussed. Ice model tests to estimate the resistance in ice, mooring force and ice load will be conducted in the ice tank facility. Then, design concepts based on ice class rules will be provided. The intended research areas of this discussion are summarized as follows:

Table IV-1. New Arctic technology research

Technology group	Research theme	Critical technology elements
Fundamental research	Ice-structure interaction analysis	Ice-Structure Interaction Scenarios and Failure Mode of Ice
		Probability Distribution and Extreme Value Analysis of Local Ice Pressures
		Prediction of Design Ice Load of Floating Structure
		Estimation of Ice Impact Force Acting on Floating Structures Based on Impact Mechanics
Advanced research	Model test for ice-structure interaction	Modeling Techniques of Arctic Sea Ice Conditions in Ice Tank (Rubble ice, Ridged ice, etc.)
		Development of Model Test Methodology for Structural Shape (GBS, Floating, etc.)
		Development of Model Test Methodology for Various Floating Structures
		Comparison of Model Test Results Between Other Ice Tank Facilities
	Analytical and numerical and analysis	Ice-Structure Interaction Analysis Based on Analytical Method (Empirical method, Energy consideration, etc.)
		Ice-Structure Interaction Analysis Based on Numerical Method (Ice fracture simulation, Structural analysis, etc.)

APPENDIX: FULL-SCALE ICE TRIAL PROCEDURE

An analysis of ship performance in ice is important at the ship design stage. Such analysis is normally executed using a computer program based on accumulated experimental data and a ship model test in an ice tank. After construction, sea trial tests are usually used to evaluate the power performance of ships. The results of sea trial tests provide valuable technical data to investigate the correlation between predicted results and trial test results. The technical data accumulated in the tests can be used to predict the power performance of another ship and to develop new hull forms for ships. It is difficult and expensive to conduct field trials of icebreaking vessels because it is not easy to navigate the sea ice field. The correction method of sea ice field test results is requested to develop. The speed of icebreaking vessels is related not only to the propulsion power of the ship but also to sea ice properties, such as the thickness, strength, and crystal structure. These exert individual and combined effects on the propulsion characteristics of icebreaking vessels. Therefore, the results of many field trials are needed. The results of field tests of a number of icebreaking vessels in sea ice were combined in the present project.

Further ice-performance tests will be conducted to evaluate the icebreaking performance of ice-going vessels. The results of these tests will be used to develop full-scale tests, test procedures in ice trials, and test equipment. The results will be compared with predicted data in the design stage. They will also be used to predict the power performance of icebreaking vessels and to develop optimum hull forms. The trial tests will be carried out in ice floes with various thicknesses and ice properties. After landing on the ice floe for the ice trial test, a running track will be marked, and ice properties along the track will be measured. The thickness distribution of the ice floe will be surveyed using electromagnetic induction instruments. The density and salinity of the sea ice will also be measured from cored sea ice samples. The crystal structure of sea ice will be analyzed in the laboratory after completion of the icebreaking tests. After finishing the survey work on the ice floe, the icebreaking test will be started. As the ship runs along the marked track, the ship's speed and engine power will be measured. The acceleration and rotational rate of the ship will also be measured with an accelerometer located nearly at the gravitational center of the ship. The ship's motion during the icebreaking will be analyzed from the results obtained. In addition, the sea ice condition and floe size will be evaluated using radar and satellite data. All these data will make it possible to fully evaluate the ship's icebreaking performance.

Commentary

Robert W. Corell

CONTEXT FOR R&D INNOVATIONS APPLICABLE TO THE ARCTIC

The Arctic region is changing, and the changes are accelerating at rates and levels that have not been experienced by modern humankind or humankind's ancestors for at least 800,000 years, and quite possibly for millions of years. Further, the Arctic is increasingly impacted by globalization processes and socioeconomic changes that have their genesis outside the region and hence are shaped by, but in turn are shaping, the course of world affairs. The climate and other environmental changes within the Arctic and around the planet are emerging with greater clarity and are inexorably linked. These changes and the new development opportunities they have created have turned the Arctic into an increasingly important region in political and socioeconomic terms. The consequences of developments and the feedbacks between regions of the Northern Hemisphere and the Arctic regarding climate change, ecosystems, human health, and socioeconomic and resource development have the potential to affect substantively and directly the interests of the eight Arctic countries, the Asian Pacific countries of Korea, China and Japan as well as much of Europe and the rest of the planet. The Arctic is no longer a remote, isolated, inaccessible region, but one that generates intense interest on the part of Arctic and non-Arctic countries alike that face the challenges of balancing their socioeconomic and development interests with the environmental and geopolitical governance challenges of a region rich in natural resources and socioeconomic potential.[1]

It is increasingly clear that these changes raise important research and development issues. This session seeks to identify the range of R&D challenges in a context of the innovations that are likely to be necessary and applicable to the Arctic, its peoples, its socioeconomic conditions, and the geopolitical realities of the opportunities and challenges that a "twenty-first century Arctic" presents.

FRAMING THE DIALOGUE FOR THE SESSION

This session's papers prepared by Mike Aumond, deputy minister of finance, Government of the Northwest Territories in Canada and Kuk Jin Kang, principal research scientist, Advanced Ship Research Division, Korea Research Institute of Ships & Ocean Engineering, focus on specific R&D developments that are likely to foster and support new innovations for the Arctic region and the world at large. Both have outlined in detail important technological developments, i.e., the Korea Research Institute of Ships and Ocean Engineering (KRISO) ice tank facility and research capabilities (by Kuk Jin Kang) and a fiber-optic system for Canada's Western Arctic (by Mike Aumond). These are excellent contributions to NPAC 2014 and for the book to come. In addition to the discussions that will follow their presentation, I would like to posit a few ideas to frame other dimensions for the dialogue following these presentations.

What do we mean when we title this session R&D: Innovations Applicable to the Arctic?

- R&D: R&D[2] is defined as "creative work undertaken on a systematic basis in order to increase the foundations of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications."
- A New Framing for Research: A new framing for R&D indicates that a broader perspective has been posited by the U.S. National Academies (Science, Engineering and Medicine), particularly suggesting that "use-inspired" research[3] be implemented in ways that seek to connect all three of the above research activities.
- Innovation: Innovations involve the implementation of new or significantly improved products (goods or services), processes, new marketing methods, or new organizational methods in business practices, workplace organization or external relations. Innovative activities are those scientific, technological, organizational, financial and commercial steps that actually, or are intended to, lead to an implementation. Innovative activities by necessity include the R&D efforts that are directly related to the development of a specific innovation, but also may not be directly related to the development of an innovation.

The reason for suggesting these framing concepts for R&D and innovation is that it is posited that it will be essential to develop concrete programs to field the needed research, development and innovation that is applicable to the Arctic. The gaps in knowledge and understanding are real, and addressing them will require a substantial coordinated international effort. Virtually all the issues addressed to date by the NPAC Conference series can provide a roadmap for the development of such a plan. The consequences of inadequate knowledge and understanding likely will adversely affect the socioeconomic development of the region and can raise geopolitical realities that challenge the opportunities raised by the opening of seaways and other consequences of climate change and globalization facing a "twenty-first century Arctic." Here are some thoughts for discussion during Session IV.

USE-INSPIRED RESEARCH PLANNING

ICARP III: The Third International Conference on Arctic Research Planning (ICARP III)[4] will be held in Toyama, Japan during 27-30 April 2015. ICARP III provides a framework to address a number of issues being raised during NPAC 2014, and more particularly in Session IV. ICARP III also seeks to:

- Identify Arctic science priorities for the next decade,
- Coordinate various Arctic research agendas,
- Inform policy makers, people who live in or near the Arctic and the global community, and
- Build constructive relationships between producers and users of knowledge.

The ICARP III Symposium in Japan will mark the closure and culmination of ICARP III processes. The symposium will present and discuss the outcome of the planning process, including a consensus statement identifying the most important Arctic research needs for the next decade and a roadmap for research priorities and partnerships. The ICARP III planning process is well underway, and it is posited that it will provide a serious opportunity for the NPAC community to contribute their perspectives to the planning processes and the establishment of internationally endorsed research priorities of importance to the NPAC community. It is recommended that the NPAC process take advantage of this opportunity to foster its interests.

National Arctic Research Planning: The eight nations of the Arctic Council all have developed their Arctic strategies,[5] as have many of the 12 official observer nations to the Arctic Council. Further, many of these 20 nations have drafted research plans in support of their Arctic strategies. In some cases these national-level plans are produced by individual government agencies,[6] whereas in other cases the plan is national in organization and implementation.[7] This commentary, in this context, is not designed to be comprehensive, but to identify issues for discussion. A recent comprehensive national research plan was published by the U.S. President's Office of Science and Technology Policy which in summary states that the Arctic's central role in environmental change makes this region a critical target for research as scientists and other experts work to understand better the feedback mechanisms influencing the global climate, and support policymakers and businesses as they consider opportunities while minimizing human and environmental costs. To address these challenges and opportunities, the U.S. Interagency Arctic Research Policy Committee (IARPC) has crafted a 2013-2017 Arctic Research Plan.[8] The plan provides a blueprint for U.S. federal coordination of Arctic research for the next half-decade. It states that it is now national policy for Arctic research to consist of seven overlapping research areas:

- Sea ice and marine ecosystems
- Terrestrial ice and ecosystems
- Atmospheric studies of surface heat, energy, and mass balances
- Observing systems
- Regional climate models
- Adaptation tools for sustaining communities
- Human health

A Recommendation: Given the rich array of formal national Arctic policy strategies and the emergence of national R&D plans and planning mechanisms that have the potential to address gaps in knowledge and opportunities of socioeconomic and sustainable development for the Arctic that have been raised during the four NPAC Conferences, it is recommended that a comprehensive effort be undertaken through the

NPAC process to codify the full range of national Arctic policies and research/ development plans for the decades ahead, possibly in the form of an Arctic Policy, Development and Research Compendium,[9] which would assemble the national Arctic strategies (for the 20 Arctic interested nations of the Arctic Council and the others that participate in IASC) and the emerging research, development and innovation strategies of these nations. It should be extended to encompass the interests of NGOs with research, development, conservation and sustainability interests. Most importantly, it must include the six indigenous peoples' organizations of the Arctic Council and other appropriate indigenous peoples' organizations of the Arctic region.[10]

Coordinated Arctic Research Funding: The NPAC 2014 Conference is considering a wide range of international cooperation issues driven by a rapidly changing Arctic, with Session IV focusing on the requirements for research, development and innovation in the Arctic. This is nested in the reality of the different Arctic than we have known for centuries, a region which herein is called a "twenty-first century Arctic." The fact is that all nations will be addressing R&D issues in which national budgets for R&D are increasingly stressed and where national agencies that fund Arctic research are being seriously impacted by policy, political and budgetary stresses. Most of the 20 national funding agencies associated with the Arctic Council support Arctic research and in a number of cases development, but with the increased interest in the Arctic region the demands to do so are growing. These agencies vary in size; some focus on different areas of research and some fund both research by others or conduct research by national institutions.

It is suggested that these national R&D funding agencies also share important goals: to enable scientists, engineers and other experts to understand better system processes in the Arctic and how they are changing and to understand better interactions between these changing processes and our societies and economies. They also want the R&D they sponsor to be able to take advantage of newly available technologies and newly available databases. As we all know, achieving these objectives requires substantial financial and infrastructural resources.

Many gathered here at 2014 NPAC have worked in the Arctic and have learned long ago that international cooperation in Arctic research brings tremendous benefits. Teams of researchers from different countries, often using shared facilities, have achieved increases in knowledge–knowledge that is now increasingly widely available.

It is recommended that the time has come now for the national agencies that fund Arctic research and development to work together internationally. It is suggested here that we in the NPAC community consider encouraging these agencies to get together to cooperate and coordinate their efforts, e.g., to consider how the financial resources to support such research and development might best be obtained; how allocation of such funds might best be coordinated to assure their most effective use, and how funding for shared use of research facilities in the Arctic might be better facilitated.

Funding agencies in the area of global change research came together more than 20 years ago and established the International Group of Funding Agencies for Global Change Research (IGFA). IGFA was–and is–a relatively informal group that brings together national funding agencies from a wide range of countries, both large and small, with objectives similar to those outlined above. It might well provide a model for an international mechanism for coordinating research and development across the Arctic. The interactions that IGFA has fostered among funding agencies is well reflected in the scientific success of the international global change research programs where IGFA has developed and maintained strong links with the World Climate Research Program (WCRP), the International Geosphere-Biosphere Program (IGBP), DIVERSITAS, the International Human Dimensions Programme on Global Environmental Change Program (IHDP), the Earth System Science Program (ESSP), and now the emerging Future Earth research program.[11] It is suggested for discussion purposes that an informal group of national agencies from nations with interests in funding Arctic research could similarly link with bodies, such as IASC and the International Arctic Social Sciences Association (IASSA),[12] that focus on Arctic research and often in cooperation with international global research programs such as the WCRP and the new initiative–Future Earth–that have an interest in the Arctic as well.

A CONCLUDING THOUGHT

These ideas are not designed to be comprehensive or complete, but to open doors for conversations during the NPAC 2014 session on R&D: Innovations Applicable to the Arctic.

Notes

1. These opening observations are adapted from the *2011 North Pacific Arctic Conference proceedings: The Arctic in World Affairs: A North Pacific Dialogue on Arctic Transformation, edited by Robert R. Corell, James Seong-Cheol Kang, and Yoon Hyung Kim.*
2. These definitions are taken from the *Oslo Manual*, which is the recognized international source of guidelines for the collection and use of data on innovation activities in industry.
3. The term "use-inspired research" was developed and published by the U.S. National Academy of Science to indicate "that research should include and integrate disciplinary and interdisciplinary research across the physical, social, biological, health, and engineering sciences; focus on fundamental, use-inspired research that contributes to both improved understanding and more effective decision making; and be flexible in identifying and pursuing emerging research challenges. (http://www.nap.edu/download.php?record_id=12782)
4. The ICARP planning effort is held every 10 years and provides a unique opportunity to develop plans for Arctic research for the coming decades. It is sponsored by the International Arctic Science Committee (IASC). See: http://icarp.iasc.info
5. See: http://www.arctic-council.org/index.php/en/document-archive/category/12-arctic-strategies
6. Such as KMI in Korea: http://www.kmi.re.kr/kmi/en/publication/ and the Polar Research Institute in China seek programs to promote sustainable development of the Arctic (http://barentsobserver.com/en/arctic/2013/12/china-nordic-arctic-research-center-opens-shanghai-12-12)
7. Norway (http://www.forskningsradet.no/bibliotek/publikasjoner/strat_arktis_engelsk/arct_kap4.html)
8. http://www.whitehouse.gov/sites/default/files/microsites/ostp/2013_arctic_research_plan.pdf
9. An example of a compendium is "The Arctic Governance Compendium" which has assembled and evaluated a wide range of governance proposals through an electronic Arctic Governance Compendium. See the compendium at: http://arcticgovernance.custompublish.com/compendium.137742.en.html
10. There are over 40 different ethnic groups living in the Arctic.
11. See Future Earth Program at: http://www.icsu.org/future-earth. The Future Earth is designed to be a global platform, including considerations about the Arctic to deliver:

- Solution-orientated research for sustainability, linking environmental change and development challenges to satisfy human needs for food, water, energy, and health;
- Effective interdisciplinary collaboration across natural and social sciences, humanities, economics, and technology development, to find the best scientific solutions to multifaceted problems;
- Timely information for policymakers by generating the knowledge that will support existing and new global and regional integrated assessments;
- Participation of policymakers, funders, academics, business and industry, and other sectors of civil society in co-designing and co-producing research agendas and knowledge; and
- Increased capacity building in science, technology and innovation, especially in developing countries and engagement of a new generation of scientists.

12. http://www.iassa.org

Commentary

Mikko Niini

FINLAND'S PERSPECTIVE: TECHNOLOGIES AND R&D IMPACTING THE FUTURE OF THE ARCTIC

The industrialization of the world some hundred years ago took place in the northern areas of the globe, where many freezing areas required regular sea transport over the whole year. Thus, the first icebreakers and icebreaking technologies emerged in the Great Lakes, Baltic and White Sea areas. More of a focus on the natural resources hidden in the Arctic was not seen before the 1970s, when the first efforts involving Arctic hydrocarbon exploration and transports started to take place. The U.S.S.R. decided to open the western part of the Northern Sea Route (NSR) for strategic mining efforts. Some innovative solutions for icebreaking had already emerged in the 1890s, but basically the industries adapted naval technologies into ice-going vessels until the 1940s. Since the 1960s, Arctic needs facilitated the technology push that today's Arctic developments rely on. Finland has for more than a hundred years been a key developer and user of marine icebreaking technologies, with up to 10,000 annual port calls during winter months assisted by a national fleet of icebreakers.

Finland initiated the Rovaniemi process leading first to the establishment of the Arctic Environmental Protection Strategy and then to the Arctic. Council Finland is a member of the Council. In August 2013, the government of Finland decided on a national Arctic strategy in which Arctic technologies, related R&D, and business developments have a central role. As a reflection, this year Finland's Tekes national technology fund launched a 100 million euro support program called "Arctic Seas" for enterprises and universities.

SPECIFICS OF ICE NAVIGATION

Ice-operating vessels require some special features in order to make passage in ice safe and efficient. These include specific reinforced materials, hull form, adequate hull and propulsion strength as well as specific

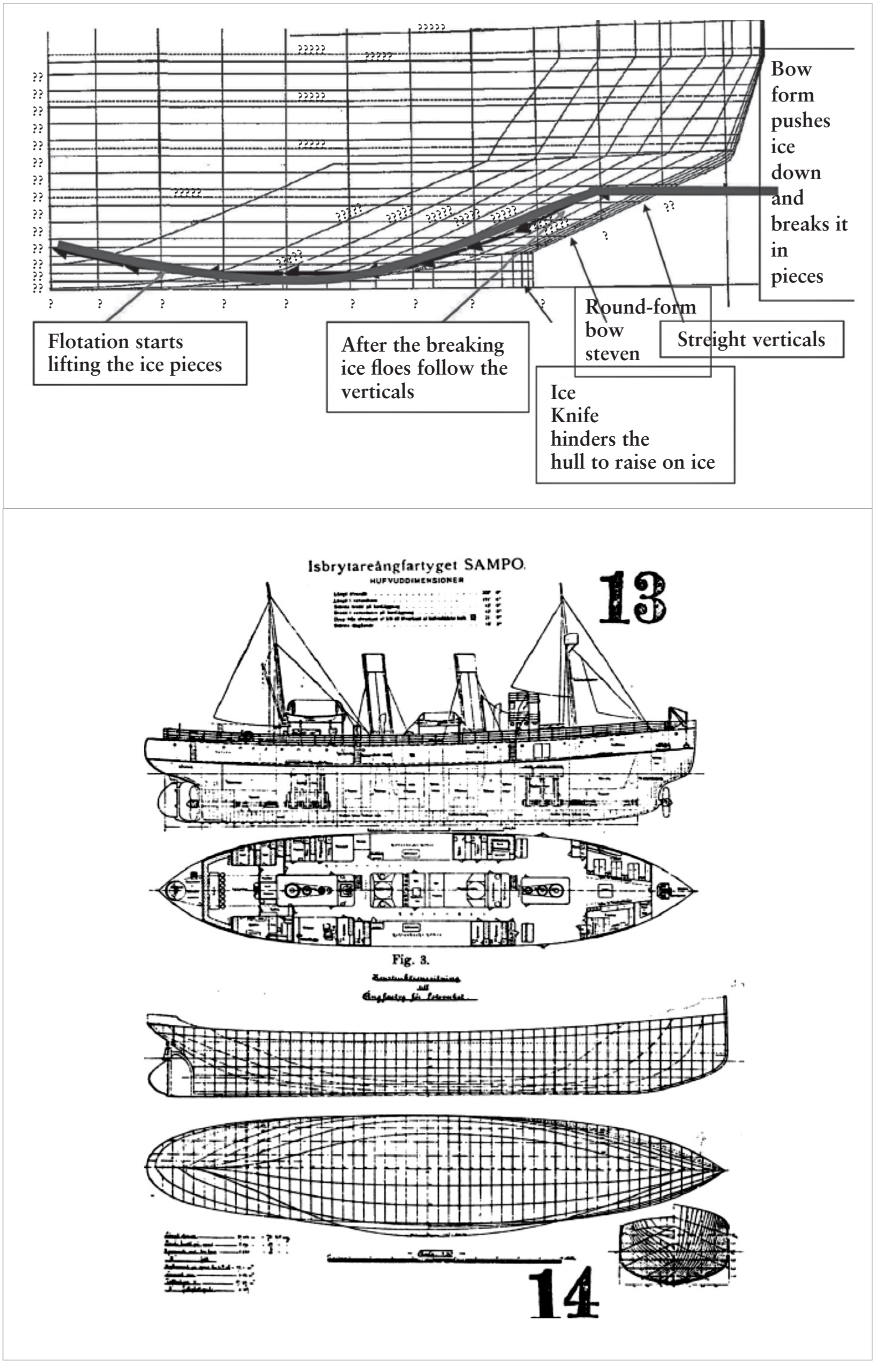


Figure IV-12. *Icebreaking process and typical special features in an ice-operating vessel (top). Icebreaker Sampo from 1892 (bottom).*

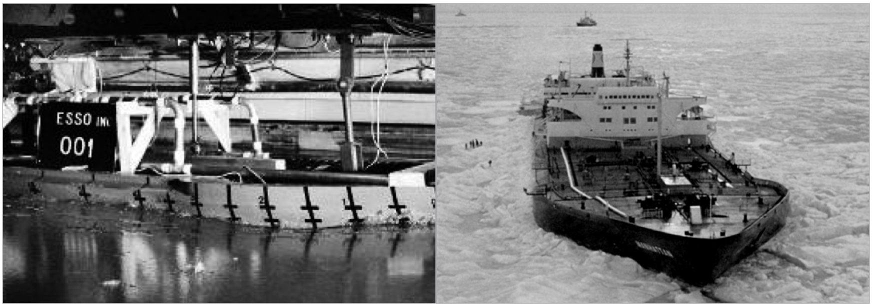


Figure IV-13. Manhattan in thick ice

winterization and cold environment operations features.

The general development of ship machinery brought diesel-electric installations into icebreakers in the 1930s. Overall material development since the 1970s has allowed the use of direct diesel drives and geared propulsion installations, mainly with controllable pitch propellers, although fixed propellers in shaft lines remained the standard solution in lower ice classes. Russia started focusing on the application of nuclear power for icebreakers, especially for their remote Arctic destinations for which frequent refueling was not possible. The largest *Yermak* class diesel-electric icebreakers built in the early 1970s in Finland for Russia had close to 10,000-ton capacity for fuel, and yet suffered from limited endurance.

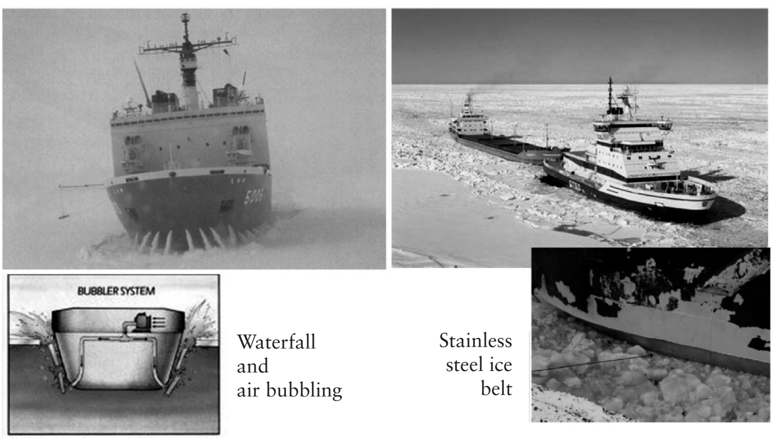


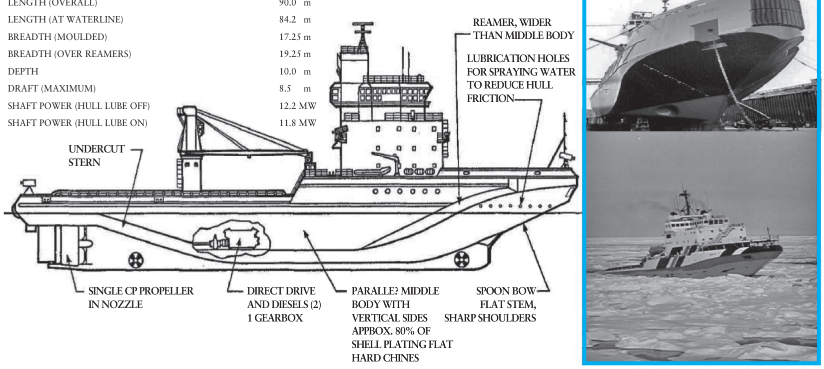
Figure IV-14. Examples of typical additional features for friction reduction for ice-going ships

The “Manhattan” project, a pioneering, full-scale trial initiated by Humble Oil (today ExxonMobil) in 1969 to bring North Slope (Prudhoe Bay) oil to the U.S. East Coast, was a leading effort for the related industries. With the side effect of creating the WIMB ice model test basin (today Aker Arctic) in Finland, the project opened up totally new tools for the related R&D efforts. The first new ships created on the basis of the ice model testing option, the sister icebreakers *Urho* and *Atle*, in 1974 for Finland and Sweden, thus adapted totally new hull forms and more efficient operability in ice. The physical fundamentals of icebreaking were learned simultaneously, and many additional features were innovated, such as air bubbling and solvent-free epoxy coatings as well as stainless steel ice belts, all for reduction of friction.

In this period, Canada opened up the Mackenzie Delta area for hydrocarbon exploration. The specifics of the Beaufort Sea conditions, especially the presence of multi-year ice, divided the ice technology world into two schools. The Canadian designers and operators emphasized–and still emphasize–the role of a strong bow detailed for ice ramming combined with the maximum bollard pull in protected (nozzled) large propellers. Friction reduction was achieved by waterfall outlets in the bow and along the side hull. Simplicity in hull form and shaft line arrangements were also emphasized and direct engine drives preferred, with flywheels providing some of the required ice features for propulsion.

PRINCIPAL PARTICULARS

FEATURE	MEASUREMENT
LENGTH (OVERALL)	90.0 m
LENGTH (AT WATERLINE)	84.2 m
BREADTH (MOULDED)	17.25 m
BREADTH (OVER REAMERS)	19.25 m
DEPTH	10.0 m
DRAFT (MAXIMUM)	8.5 m
SHAFT POWER (HULL LUBE OFF)	12.2 MW
SHAFT POWER (HULL LUBE ON)	11.8 MW



”Canmar Kigoriak”, today ”Talagi”

Figure IV-15. Typical Canadian icebreaker design from the 1980s

The European school, mainly Finland and Germany, started focusing more on economics, fuel efficiency, and better operability and maneuverability. This thinking created ultimate hull forms like the Wärtsilä spoon bow and Thyssen Waas bow. The Ministry for Merchant Marine of the U.S.S.R., which already had operational experience from regular Arctic transports, was a keen client for each of these novelties, including the AC-AC drives made possible through technological innovations on frequency converters. A demonstration of these new features appeared (e.g., in the Baltic icebreaker *Otso* and the shallow-draught nuclear icebreaker *Taymyr* commissioned in 1991. The same technologies were adapted later in the 1990s in the USCG IB Healy built by the Avondale Shipyard with technology and model testing support from Aker Arctic of Finland. These developments were combined with the simultaneous introduction of ice-capable electric pod drives, like the Azipod, and mechanical thrusters, like the Aquamaster.

The Canadian school built several offshore support icebreakers for Beaufort Sea oil companies (Dome Petroleum, Canmar, Beaudrill, Gulf Resources, etc.) with the ultimate example being the Swedish state icebreaker *Oden*, a frequent visitor to the North Pole and Antarctica.

LATEST DEVELOPMENTS

The introduction of the azimuthing thrusters for ice operation opened up also the possibility for a new mode of ship operation. Kvaerner Masa-Yard's full-scale trials of the tanker *Uikku* in 1993-95 showed that ice resistance was reduced up to 50% and the ridge penetration capability significantly improved, although the original target for the R&D work was to achieve better maneuverability for icebreakers. This new energy-saving "double acting" feature was soon adapted by several operators, both for icebreakers (e.g., the USCG IB *Mackinaw*, Norwegian *Svalbard*, and Finnish *Botnica*) as well as in independently operating cargo vessels (Norilsk Nickel's *Norilsk Nickel* type six-vessel series, the 105,000 tdw tankers *Tempera* and *Mastera*, Sovcomflot's *Mikhail Ulyanov* and five *Vasily Dinkov*-type bow-loading 70,000 tdw shuttle tankers built in Korea). The last-mentioned tankers are operating the world's first Arctic oil export shuttle service and have already transported more than 30 million tons of crude oil from Varandei to world markets.

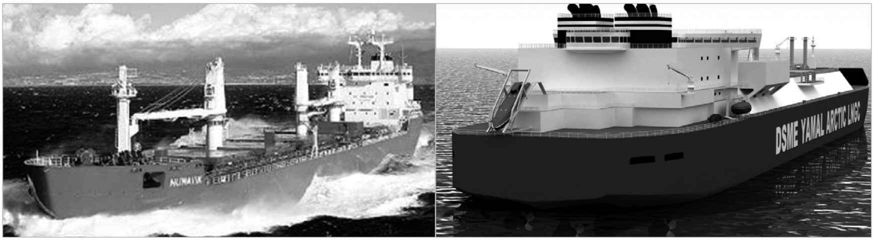
Note: New technology has enabled new logistic systems, allowing for new industrial production investments in the Arctic regions. On the left is the Aker Yards-built DAS™ vessel Norilsk Nickel in independent stern-first ice operation in 1.5m-thick ice in the Kara Sea (photo: Aker Arctic), and the Samsung-built 70,000 tdw Arctic shuttle DAS™ tanker Vasily Dinkov approaching the loading tower in Varandei (photo: Sovcomflot).

Figure IV-16. *Aker Yards-built DAS™ vessel Norilsk Nickel (left) and Samsung-built 70,000 tdw Arctic shuttle DAS™ tanker Vasily Dinkov (right)*

ABB, having taking over the Azipod business, soon got orders for new offshore support icebreaker installations, especially for the Caspian Sea and waters off Sakhalin. The "double-acting" ice operating mode was soon adapted also for mechanical Aquamaster, Steerprop, Schottel and Wärtsilä thrusters, so that today one can say that the azimuthing thruster is a standard solution in modern icebreaking vessels. The recent launch of the gas-fueled Canadian ferry *F.A.Gauthier* for STQ now brings to the market Steerprop's IASuper ice class further developed contra-rotating (CRP) azimuthing thrusters.

The diesel-electric type of propulsion is well-suited for reduced emissions in ice, and most recently the latest stern-first operating new ships have additionally been fitted for the use of LNG fuel. This is the case for the latest state icebreaker for Finland and the 10 Arctic 172.000 m^3 Arc 7 ice class LNG carriers contracted so far for the Yamal LNG project, which simultaneously establishes the first regular transit traffic on the NSR from the Kara Sea to the Pacific Ocean. Three of the carriers are jointly contracted by Mitsui O.S.K. Lines with the China Shipping (Group) Company, and six by Teekay LNG Partners L.P. through a new 50/50 joint venture with China LNG Shipping (Holdings) Limited, with completion from 2018 to 2020. The expected unit cost is 314 million USD, compared to some 200 million USD for similar standard carriers. The planned fleet, totalling 16 vessels, is being built by DSME of Korea.

Compatriot SHI has simultaneously signed contracts for smaller Arctic 40,000 tdw twin Arc 8 ice class Azipod DAS™-type crude oil shuttle tankers that will enter service in 2016.



Note: The JMU-built Arctic bulk carrier MS Nunavik (photo: JMU) and an impression of the Yamal LNG Arctic LNG DAS™ carriers now under construction by DSME (photo: DSME).

Figure IV-17. The latest Arctic cargo vessels

Earlier ths year Fednav in Canada took delivery from JMU, Japan of the 25,000 tdw Arctic bulk carrier *Nunavik* for year-round operation for Glencore Xtrata's nickel mine from the Hudson Strait Deception Bay to Quebec. She is an improved sister to Fednav's *Umiak* I that operates from Labrador's Voisey's Bay. These vessels represent the Canadian design philosophy of strong bows combined with direct shaft line propulsion in protected nozzles. Waterfalls are provided for auxiliary service in the bow part. The MAN-B&W 21,770 kW slow-speed single diesel is adapted for 1.5m-thick ice operation through newly developed electronic control. The *Nunavik* is now preparing for a commercial voyage through the North West Passage from Northern Canada to China.

The above examples are clear evidence of better solutions introduced to industrial investors to provide improved economies by independent vessel operation in ice. New technology thus clearly enables new industrial investments in the North through improved logistics.

PROSPECTS AND CHALLENGES FOR THE FUTURE

World shipping is conservative, and it always takes a lot of time for technology improvements to be adopted by the shipping community. It has been encouraging, however, to learn that Russia's shipping industry is keen on new developments and solutions, especially for ice operations, in which the nation and crews have long experience. Still, the lead times for implementing new technology introductions have typically been more than 10 years (e.g., the Sakhalin OSV's and the Arctic DAS™ shuttle tankers), which is half the relevant patents' validity time. Only in 2013, some 20 years after the prototype, the first Azipod installation was accepted into a Canadian project in the CCG IB *John G. Diefenbaker* to be completed in 2020.

In world shipping, two major factors affect future solutions: there is a general drive toward improved energy efficiency and lower emissions. The IMO has already issued the EEDI system to enhance the shipping industry's involvement in the Kyoto process and countermeasures against increases of C02 emissions. An exemption for ice-going ships, which typically require more power and burn more fuel, has been issued for vessels that are able to penetrate ice thicker than 1.0m. In certain "ECA" areas, additional emission limitations have been introduced on NOx and SOx. The Arctic Council has established a task force to consider regulations on black carbon, especially for the Arctic trades. One solution has been to use alternative fuels like LNG. But in general, Arctic industries need to seek further, innovative technologies to reach the general industry goals. Today, underwater radiated noise is also considered a kind of emission likely to affect marine mammals.

Environmental movements have recently generated additional challenges, especially for oil drilling-related activities. This has been experienced especially by Shell Alaska, whose drilling campaign in the Chukchi Sea has already been delayed for more than seven years from the original plans. Great emphasis has been put on oil spill combat preparedness, and full mobilization of the necessary support fleet and readiness for drilling a relief well in the same season appear to have become standard requirements that are also reflected in the ExxonMobil/Rosneft drilling campaign of August 2014 in the Kara Sea.

Further challenges to development are arising from the general concern about the safety of Arctic shipping and operations, which have been addressed in the Arctic Council's Arctic Marine Shipping Report for example. This concern for sufficient risk mitigation has now been responded to by IMO, which is in an advanced stage of launching the Polar Code. This code will set common safety standards for all Arctic and Antarctic operations from 2017 onward and additionally provide each vessel with a Polar Operations Manual that will describe the vessel's real ice capability for the intended tasks in specific areas. The code is expected to change many practices adopted by various flag states so far, and with the new environmental regulations will indirectly affect vessel designs.

Commentary

Toshiyuki Kano and Takahiro Majima

First of all, thanks to Mike Aumond and Kuk Jin Kang for their papers on "A Fiber Optic System for Canada's Western Arctic" and "Introduction to the KRISO Ice Tank." They discuss issues of innovations applicable to the Arctic from two distinct points of view.

Last year, we focused on greenhouse gas emissions on the Northern Sea Route (NSR), the energy efficiency of ice class ships, and monitoring navigation systems and introduced a comparison of the Suez Canal Route (SCR) and the NSR in terms of environmental impact. This time, we'd like to introduce results focused on each route from an economic perspective, and make some comments on the two presentations.

Specifically, we would like to comment on the following points:

- Shipping cost estimations for the NSR considering ship performance in ice,
- Expectations for the KRISO ice tank,
- Expectations for the information infrastructure of the Arctic

To begin, we will introduce a simulation study of cost estimates for the NSR considering ship performance in ice. Then, we will comment on the presentations related to our study.

SHIPPING COST ESTIMATES

Objectives

The NSR has distance and time advantages compared to the traditional SCR with regard to shipments between Northeast Asia and Northwest Europe. Considering greenhouse gas emissions on a global level, a significant GHG reduction could be expected by using the NSR. However, larger engine output is required, and GHG emissions increase when navigating in ice. The comparative advantages of the NSR and SCR should be evaluated not only from the perspective of distance and time savings, but also from an environmental conservation perspective (Kano et al., 2013). It is necessary to meet technical innovation challenges for ice-class vessels. Ice-class vessel energy efficiency should be improved (Kano et alet al., (2013). Here, we introduce a simulation study of cost evaluation of shipping via the NSR and the SCR.

Background

Many related studies have been conducted for a comparative analysis of the estimated shipping cost through the NSR and the SCR. Since the assumptions regarding cost estimates vary among the studies, however, there remain some difficulties in comparing the estimated shipping costs in the studies. Furuichi et al. (2012) tried to establish a common platform for a wide range of cost assumptions by clarifying and analyzing cost components, referring to the literature as well as the most recent interviews with NSR shipping professionals. They accomplished an empirical analysis and produced cost estimates for container transport between East Asia and Europe.

Furuichi et al. (2012) had calculated and analyzed specific shipping costs such as container ship price, annual shipping frequency, annual container throughput, depreciation costs, NSR fees, Suez Canal fees, crew costs, maintenance costs, insurance costs, fuel costs and annual port dues, assuming that the totals correspond to the annual shipping cost of container transport between Yokohama and Hamburg. The methodology for cost estimation was clear. However, the analysis did not take into account ship performance in ice, which has a high impact on shipping costs.

Shipping Cost Estimation on the NSR Considering Ship Performance in Ice

Therefore, our study has made an economic evaluation in accordance with Furuichi et al. (2013) considering ship performance in ice. Here we have considered ice thickness and rate of ice that covers the sea and assumed the same ship performance as Kano et al., 2013 and reviewed the calculation method again to analyze the transportation cost.

Furthermore, describing a simple case study of containerized transportation between East Asia (Yokohama, Japan) and Europe (Hamburg, Germany), in this case, using the NSR is 6,975 NM, and the

SCR is 11,465 NM. The distance of the NSR is 40% shorter. The NSR has a draft restriction of 13 m at the Sannikov Strait, and the maximum ship size is approximately 50,000 DWT. Therefore, we set both an ice class container ship and conventional ship at 4,000 TEU (Figure IV-18). We will provide an example of the shipping cost that is calculation-based and analyzed. Moreover, we consider the effects in cases of improving the ship's performance in icy waters.

Results

Here we simulated the shipping cost per TEU in two scenarios intended for a 4,000 TEU ice class container ship.

Scenario 1: An ice class container ship would use the NSR when available to navigate and the SCR when the NSR is unavailable.

Scenario 2: A conventional ship would navigate the SCR at all times of the year.

We simulated and calculated the shipping cost per TEU of a container

Typical 4000 TEU Class Container Ship

Due to Shallow Water at Sannikov Strait (13 m depth)

Route: From Yokohama to Hamburg

Route	NSR	Suez Route
Distance[NM]	6,975	11,465
Capa. Limit. [TEU]	4,000	4,000

Distance of NSR is 40% shorter

Operational Scenarios

Scenario 1: Operate NSR in available season & SCR in unavilable seasons
Scenario 2: Operate SCR in all seasons

Ref. Average on 56 Ships (3950-4049TEU)

Det [ton]	58,000
d [m]	12.9
L_{BP}	260
Power [Kw]	38,800
Speed [Kt]	23.8

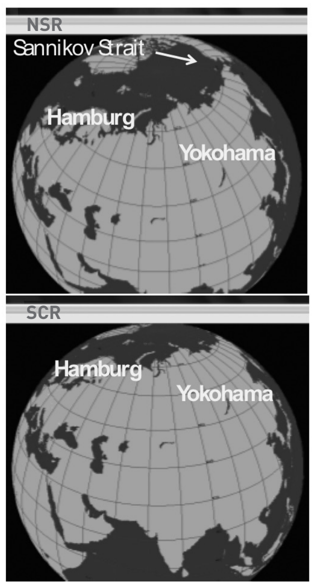


Figure IV-18. Simulation study on NSR vs. SCR ship in the two scenarios. The table in Figure IV-19 shows the shipping cost ratio per TEU of Scenario 1 to 2 corresponding to each condition of ice coverage and ice thickness. The operation using the NSR is cost effective if the ratio is lower than 1. These results show that lower ice thickness and smaller ice coverage and longer NSR available time lead to a considerable cost advantage in using the NSR.

Considering recent ice coverage and ice thickness conditions under the assumption of navigating the NSR for 105 days, Scenario 1 has an advantage in navigating when ice thickness is lower than 0.5m and ice coverage is less than 50%, or lower than 0.7m and less than 20%.

Sea ice is decreasing due to global warming, and ice thickness and ice coverage is declining as well. Therefore, in the future it is expected that the frequency of NSR voyages will increase with enhanced navigational advantage. But the advantages of the NSR vary widely according to ice coverage and thickness. It should be realized that the NSR advantage is enhanced if the ship's performance in ice improves. The simulation can provide useful information for selecting a route when it is possible to

Simulation Conditions

An economical evaluation in accordance with Furuichi's paper and considering the ship performance in ice.

Furuichi, M., Otsuka N., "Cost Component Analysis of Maritime Shipping through NSR and its Alternative Conventional Routes" 48th Conference of Committee of Infrastucture Planning and Management, Japan Society of Civil Engineering, 2013

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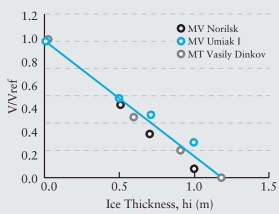
Ship's Speed Reduction by ICE

Estimated by Annex of DE57/11/8 (Sub-committee on ship design and equipment of IMO) 14 December 2012 "Development of a mandatory code for ship operating in polar water"



Shipping Cost Ratio Cost of Scenario 1 / Cost of Scenario 2

NSR 365 days	Thickness of Ice (m)			
Ice converage (%)	0.25 m	0.5 m	0.75 m	1 m
10	0.675	0.695	0.734	0.901
20	0.683	0.725	0.812	1.127
30	0.697	0.725	0.878	1.384
40	0.706	0.786	0.957	1.607
50	0.721	0.818	1.208	1.842

NSR 225 days	Thickness of Ice (m)			
Ice converage (%)	0.25 m	0.5 m	0.75 m	1 m
10	0.773	0.785	0.825	0.971
20	0.780	0.818	0.900	1.145
30	0.787	0.851	0.962	1.313
40	0.794	0.870	1.024	1.447
50	0.814	0.905	1.066	1.552

NSR 105 days	Thickness of Ice (m)			
Ice converage (%)	0.25 m	0.5 m	0.75 m	1 m
10	0.900	0.933	0.947	1.023
20	0.904	0.943	0.997	1.106
30	0.934	0.953	1.018	1.166
40	0.938	0.963	1.064	1.207
50	0.941	0.999	1.081	1.218

Figure IV-19. Comparative simulation analysis of shipping cost on NSR and SCR obtain the situation of ice thickness and coverage in advance.

Considering these results, we have high expectations after the ice tank presentation by Kuk Jin Kang and the presentation on the construction of an information infrastructure using fiber optic cable by Mike Aumond. Obtaining information on the conditions of ice coverage and ice thickness in advance would help in the decision to choose the NSR or the SCR. We expect the information infrastructure using fiber optic cable will collect and organize information on ice coverage, thickness, etc. in the NSR and can be used as an information system.

EXPECTATIONS FOR THE KRISO ICE TANK

A new Korean ice tank was introduced by Kuk Jin Kang of KRISO. The square ice tank allows a model ship to complete a full turning circle test, which is expected to solve one of the problems for icebreakers and ice-resistant ships in actual icy seas. Also, technical expertise, including the measurement of the performance of a ship in ice, is obtained and safe operation could be expected.

The model test conducted in the tank follows the recommendations of the International Towing Tank Conference (ITTC). KRISO is addressing technical problems by determining the correlation between model-scale and full-scale results. The full-scale results are provided from the research vessel Araon.

As indicated in Oran R. Young's article on "Navigating the Arctic State/non-Arctic State Interface," safety standards for vessels are under discussion in the International Maritime Organization (IMO) for inclusion in the Polar Code covering the design, construction, and operation of ships. Actually, confirmation, verification, and inspection are conducted by members of the International Association of Classification Societies (IACS) and play a significant role in insurance. The development of environmental measures for vessels and their application to existing rules are under preparation by the IMO.

The technical expertise obtained from the ice tank may contribute to the discussion and development of such international safety standards. Particular attention should be given to the effects on the environment of the NSR. This means that a vessel with high propulsion efficiency is eagerly anticipated. It is expected to use the technologies acquired from the ice tank and improved systems of vessel propulsion to develop high-performance vessels and reduce GHG emissions in the future.

EXPECTATIONS FOR ARCTIC INFORMATION INFRASTRUCTURE

Mike Aumond shows one way to improve the information infrastructure in Canada's Western Arctic. This infrastructure will allow the government, hospitals and schools to provide for residents and enrich social and medical services to improve human well-being. Additionally, it will become much easier to summarize information in the region and send it to people who need it. We suggest using the infrastructure to collect weather information that could help in understanding the change of the environment in Arctic areas.

One possibility is a navigation monitoring system. If we could obtain accurate ice information and have access to tools for precisely predicting future ice conditions, we could select the optimum route. A captain could choose the best route, using either the NSR or the SCR, a procedure called "ice routing," analogous to "weather routing." Technology in the area of fiber optic cables and Arctic communication is applicable to the development of such a navigation monitoring system.

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Commentary

Hyoung Chul Shin

INTRODUCTION

With climate change occurring in the Arctic at an unprecedented rate, environmental concerns as well as economic potential acquire importance and receive attention in an way that nobody imagined before. Accordingly, Arctic research and development (R&D) has been experiencing substantial changes over the past several years. More and more countries around the world have taken an interest in this terra incognita, and begun to stake claims and make investments. Indeed, Arctic R&D ought to respond to new needs in rapidly changing environments, and is required in a variety of disciplines and areas. Recent Arctic changes are new to everybody; these challenges are faced by forerunners and newcomers and Arctic states and non-Arctic states alike.

The current Arctic R&D can be described as having three characteristics. First, it seems that knowledge about the Arctic is almost in its infancy stage. Despite the global attention and recently developed interest from nearby countries, there seems to be a lack of profound research compared to that for the Antarctic, for example. Moreover, Arctic R&D is also a little too diverse, or somewhat scattered, to say the least. In other words, each country is taking various steps to provide more knowledge and experience in the Arctic, but this is not necessarily well-balanced. It could be an institutional issue; it could very well be a governance issue. Lastly, along with the basic and scattered knowledge, the R&D needs to be better organized in terms of both research coordination and funding.

Perhaps there is no perfect model or sample case of Arctic R&D so far because there really is not much done at this stage of time. Today's diverse presentations and commentaries ranging from fiber optics and shipbuilding to an overall framework for research is in a way an illustration of this early stage of development and immaturity.

PREMISES FOR ARCTIC R&D AND QUESTIONS POSED

There are three fundamental premises for Arctic R&D in the new era. One is that Arctic changes must be understood and accounted for; another is that new developments must be safe and sustainable for the environment; and the third is that the human dimension must be cared for as much as in the rest of the world.

These premises require us to ask the following questions at the same time. First, do we understand the nature and causes of Arctic changes? There are scientific findings from the IPCC and various organizations within the international community dedicated to understanding the changing environment, but a majority of them are not specifically Arctic focused. Without such a focus, it is questionable whether we can properly grasp what to expect in the future. Second, are we (getting) prepared for the developments we are looking for? The word "getting" is in parenthesis because, as aforementioned, since knowledge about the Arctic is too diverse, it would be rather difficult to state if we are actually prepared or if we are still preparing. Third, are our expectations based on proper research or are aspirations for developmental opportunities mostly setting the agenda? As most stakeholders in the region may agree, Arctic development does not involve just scientific issues. Environmental, social, economic and national security issues are all intertwined based on the interests of the various stakeholders. Such knowledge may be driven by local, regional, or global communities seeking opportunities for themselves. Last, are the different R&D pursuits linked or coordinated? As stated in the introduction, Arctic R&D is in need of coordination and cohesiveness. Without deliberate planning efforts, it is unlikely that such pursuits will aid each other and generate synergies.

KOREAN DEVELOPMENT AND PERSPECTIVES ON THE ARCTIC

With these questions in mind, I would like to elaborate some experiences and perspectives from Korea. Geographically, Korea is a near-Arctic state. Using the East Sea as the first waypoint, Korea can access both the Northern Sea Route (NSR) and the Northwest Passage, a distinct feature found only in East Asia. Korea has always been under pressure from a scarcity of natural resources, resulting in an unbalanced energy supply system. Moreover, the opportunities posed for shipping and logistics using the NSR are becoming a large attraction. Lastly, the recent unstable climatic conditions threatening the natural security of the Korean Peninsula have led Korea to proceed with significant scientific investments and develop economic interests in the Arctic.

Korean R&D in Arctic science dates back to the 1990s. As the 11th national and 18th team overall to explore the Arctic successfully with the AURORA exploration team in 1990, Korea has engaged in joint research projects with China, Japan and Russia. By setting up the Dasan research station in 2002, Korea kicked off full-fledged scientific research in the Arctic. For more than two decades, Korea has been able to gain strength in environmental research and in shipping and ocean plant technology, as well as energy and mineral science. However, the majority of this research is again scattered, and research coordination and prioritization are much needed.

Over the past few years, there has been an upsurge of interest from both the public and private sectors. Unfortunately, there is as yet only a modest increase in financing. As seen in Figure IV-20, the number of Arctic-related research projects is clearly on the rise, whereas the budget increase is not in proportion. Moreover, not all of these projects are wholly dedicated to the Arctic.

As Korean Arctic R&D has surged in recent years, there have been many diverse players on the scene. For example, the Korea Polar Research Institute is the operator of the national Arctic program, with a mostly scientific focus. There are government-sponsored research institutions ranging from engineering and policies bodies to primary industries, as well

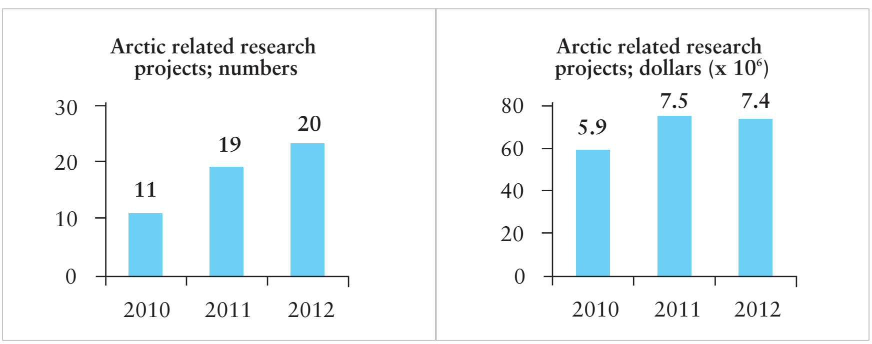

Figure IV-20. Arctic-related research projects and finance as government-invested energy- and mineral-related public corporations. Individual universities and related academia are taking more of an interest in Arctic R&D, and private sector organizations from engineering and maritime shipping firms are performing their own research to gain practical knowledge of the Arctic. Lastly, government ministries such as the Ministry of Oceans & Fisheries and the Ministry of Trade & Industry, Science & Future Planning are paying close attention to Arctic affairs and providing support.

Despite the increased interest and various players in the field, there are many issues that need more thought. Are we doing what we need to do? Because there is so little knowledge about the Arctic, perhaps the focus may not be in tune with what is required. Is the funding adequate? As seen in Figure IV-20, despite the upsurge in interest and projects, adequate funding is still lacking. Last but not least, what is the linkage between types of research, for example, between "basic science" and "application-oriented research"? Depending on the stakeholder and interested parties, there seem to be gaps among different research efforts that need to be filled.

It is easy and tempting to finance "user-defined" research. What we now need is rather "need-inspired" research. Korean Arctic R&D has just begun and is on a steep learning curve; this is most probably the situation faced by many other countries as well. Perhaps it is high time for a new move where a nationwide research consortium is designed and prepared.

LESSONS FOR KOREA AND FOOD FOR THOUGHT FOR ALL OF US

The growing interest, inadequate financing, and multiple stakeholders are not just an issue for Korea. Both forerunners and newcomers in the Arctic will need to deal with similar challenges. Perhaps what we need is a proactive research strategy to address future needs, which should be long term. In the process, securing sufficient funding is also a must. Basic research to determine the baseline and to be able to make predictions and provide guidelines for ensuing research efforts is also crucial. We must remind ourselves that innovative technologies are badly needed for our Arctic endeavors in order to observe with minimal impacts but with greater efficiencies and coverage and in order to manage the risks. In this way, we can protect Arctic environments and communities, while extracting and using resources safely and sustainably in the future.