

PROPRIETARY INFORMATION

WÄRTSILÄ MARINE
ARCTIC TRANSPORTATION
'ICE CLEANER'
PROJECT

NOVEMBER 1988

WÄRTSILÄ MARINE
ARCTIC TRANSPORTATION
HELSINKI, FINLAND

PROPRIETARY INFORMATION

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DESCRIPTION

THE WMAT - LORI "ICE CLEANER"

"Ice Cleaner" is a system being developed for use in operations conducted to recover spilled oil from ice-condition seas.

"Ice Cleaner" is being developed jointly by Wärtsilä Marine Arctic Transportation, a division of Wärtsilä Marine Industries Inc., and Lori, a member of the Kone group.

The "Ice Cleaner" is a system which is comprised of two patented concepts: (A) a structural device designed and tested by WMAT for collecting oil from a body of water covered by broken or solid ice and (B) a mechanical device designed and tested by Lori for removing the collected oil from sea water.

The efforts of Wärtsilä Marine, the established world leader in the design and construction of vessels intended for operation in ice conditions in arctic seas, dates back to the early 1980's when the oil collecting structure was conceived and tested at the Wärtsilä Arctic Research Centre.

During the past two years, Wärtsilä Marine has also built and delivered two special purpose vessels equipped with oil clean-up systems for operation in ice-free seas.

The efforts of Lori, a company whose oil removal equipment for operation in ice-free seas is installed and operated on fourteen oil pollution clean-up vessels built in the period 1985-1988, dates back to the mid-1980's and includes field tests of oil recovery in an actual major oil spill in ice conditions which happened in Finland in the 1986-87 winter.

The "Ice Cleaner" system is being developed for services in arctic or sub-arctic offshore or port operations where oil spill emergencies can occur in ice condition seas.

The "Ice Cleaner" system consists of a structure and equipment for recovering oil from ice-conditions at sea which can either be built as an appendage for operation with an existing offshore supply vessel or sea-going tug boat or as an integral part of a specially constructed new vessel.

WMAT-LORI ICE CLEANER

TARGETED MARKET CLIENTS

*FINNISH GOVERNMENT AGENCIES

*CANADIAN GOVERNMENT AGENCIES

*UNITED STATES GOVERNMENT AGENCIES

*BALTIC STATES TREATY MEMBERS

*ARCTIC OPERATING OIL COMPANIES

*ARCTIC OPERATING SERVICE COMPANIES

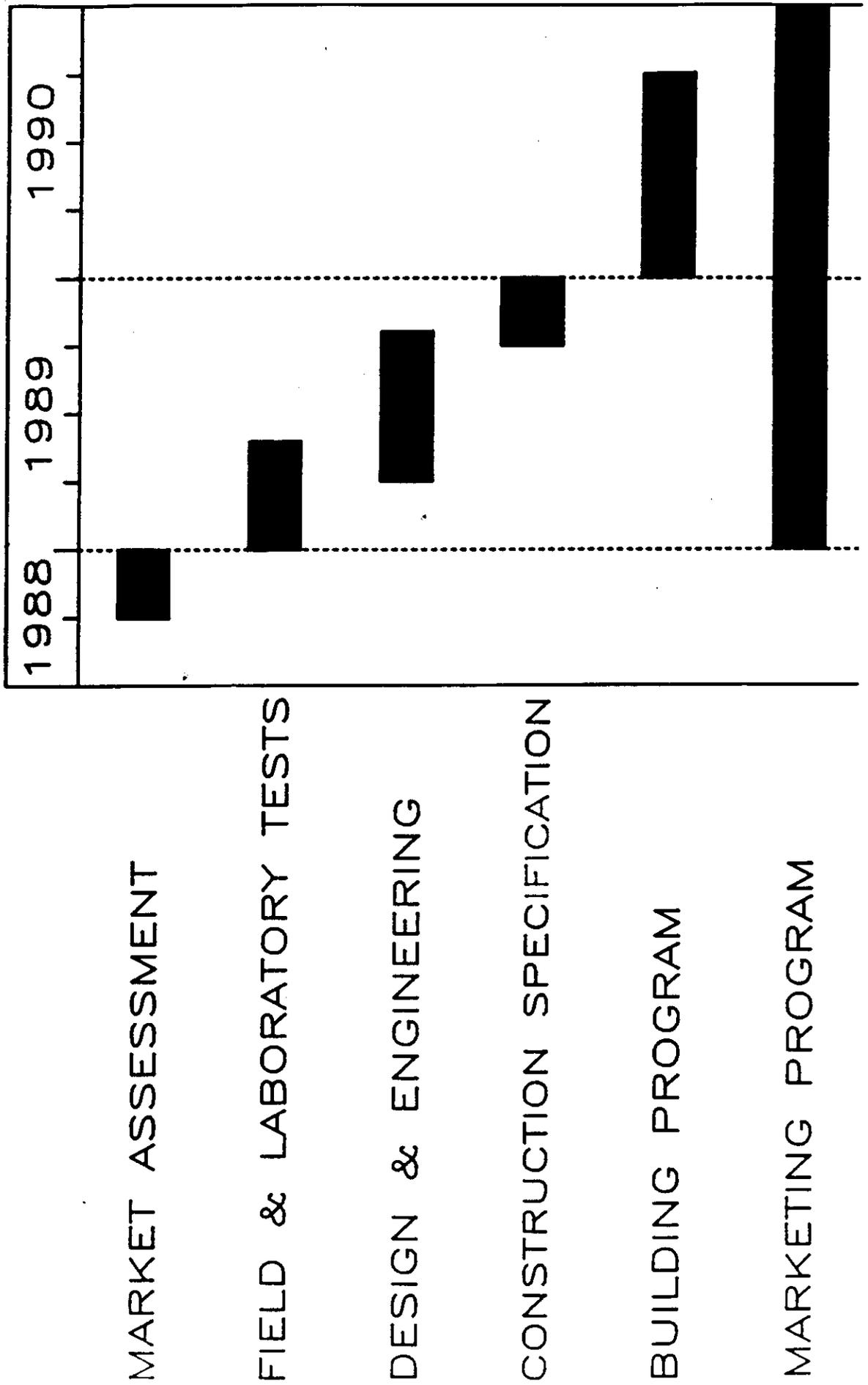
WMAT-LORI ICE CLEANER

WÄRTSILÄ MARINE

PARTICIPATING ORGANIZATIONS

- *WÄRTSILÄ MARINE ARCTIC TRANSPORTATION
- *WÄRTSILÄ ARCTIC RESEARCH CENTER
- *WÄRTSILÄ MARINE NORTH AMERICA
- *WÄRTSILÄ MARINE SPECIAL PROJECTS
- *WÄRTSILÄ MARINE ENGINEERING
- *WÄRTSILÄ MARINE MARINE TECHNOLOGY
- *TURKU SHIPYARD
- *HELSINKI SHIPYARD
- *LATE SHIPYARD

WMAT-LORI ICE CLEANER DEVELOPMENT SCHEDULE



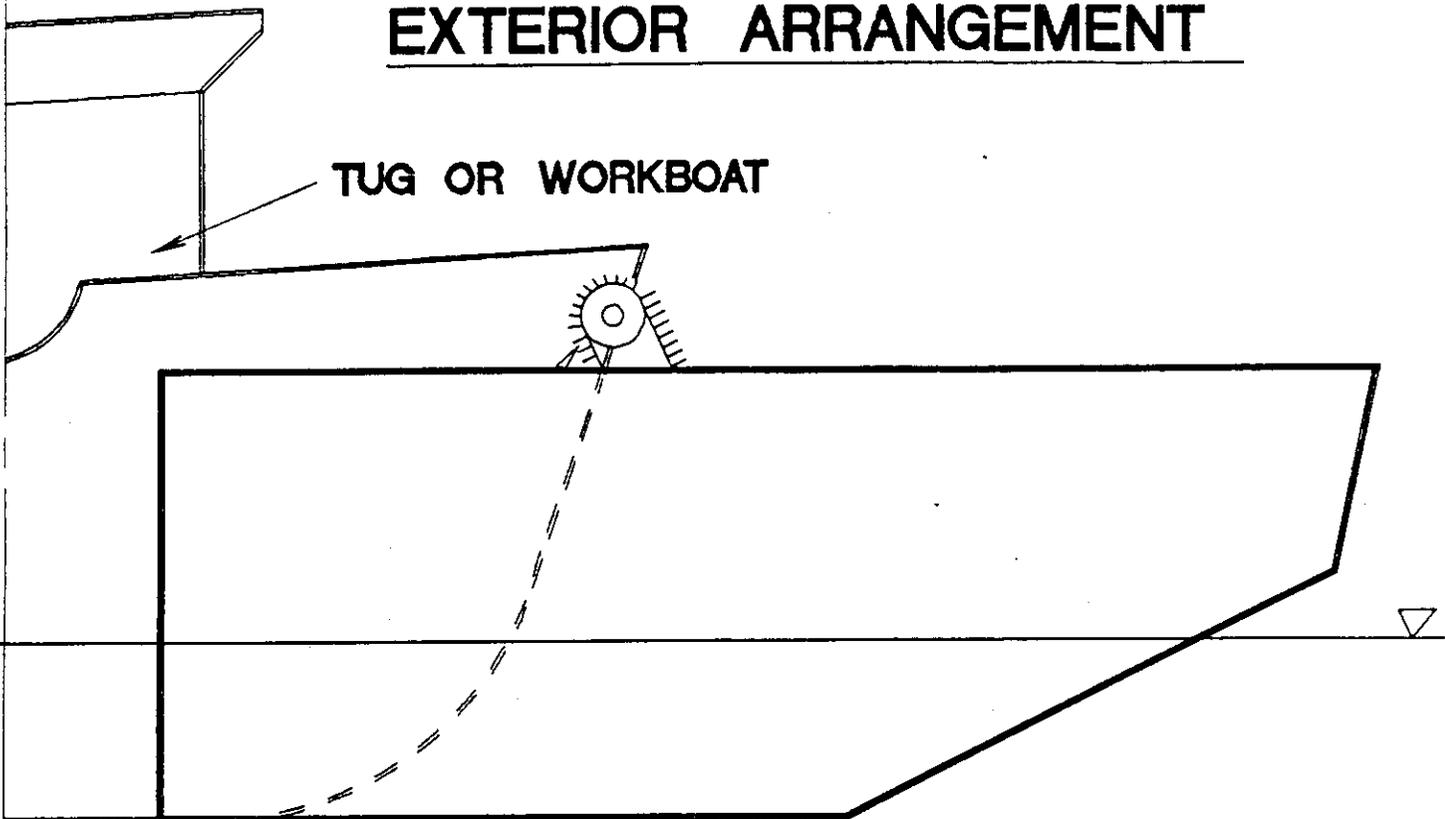
WMAT-LORI ICE CLEANER

ICE CLEANER FEATURES

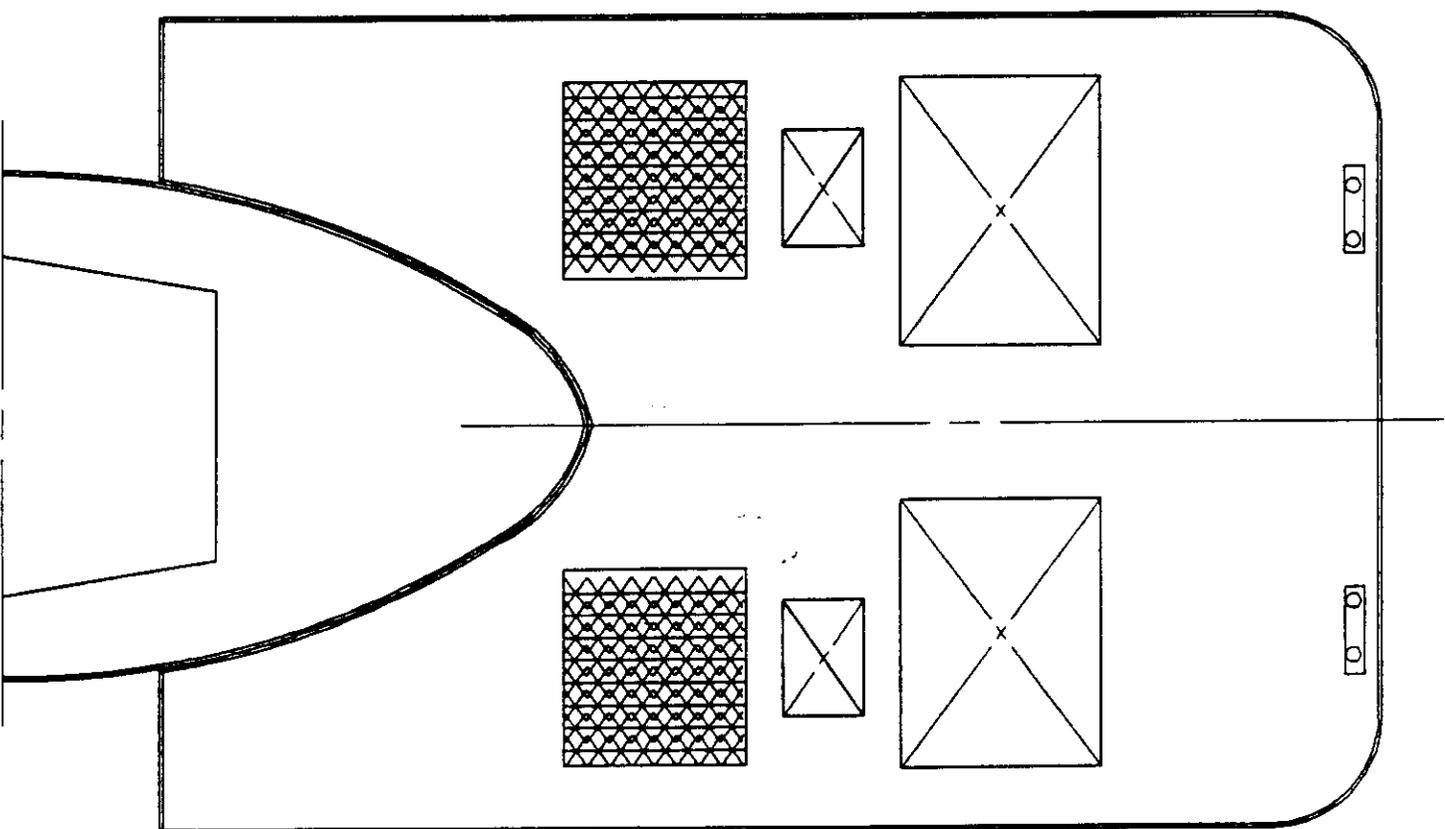
- *PATENT FEATURES OF WMAT AND LORI PATENTS ACTING AS SYSTEM IN COMBINATION IN ICE COVERED WATERS
- *ABILITY TO BE APPENDED TO EXISTING VESSELS SUCH AS OFFSHORE SUPPLY VESSELS OR SEA GOING TUGS OR ALTERNATIVELY INCORPORATED INTO A NEWLY CONSTRUCTED VESSEL
- *ABILITY TO PERFORM IN OIL SPILL RECOVERY OPERATIONS IN BOTH ICE FREE WATERS IN NON-WINTER PERIODS AND ICE CONDITION WATERS IN WINTER PERIODS

EXTERIOR ARRANGEMENT

TUG OR WORKBOAT

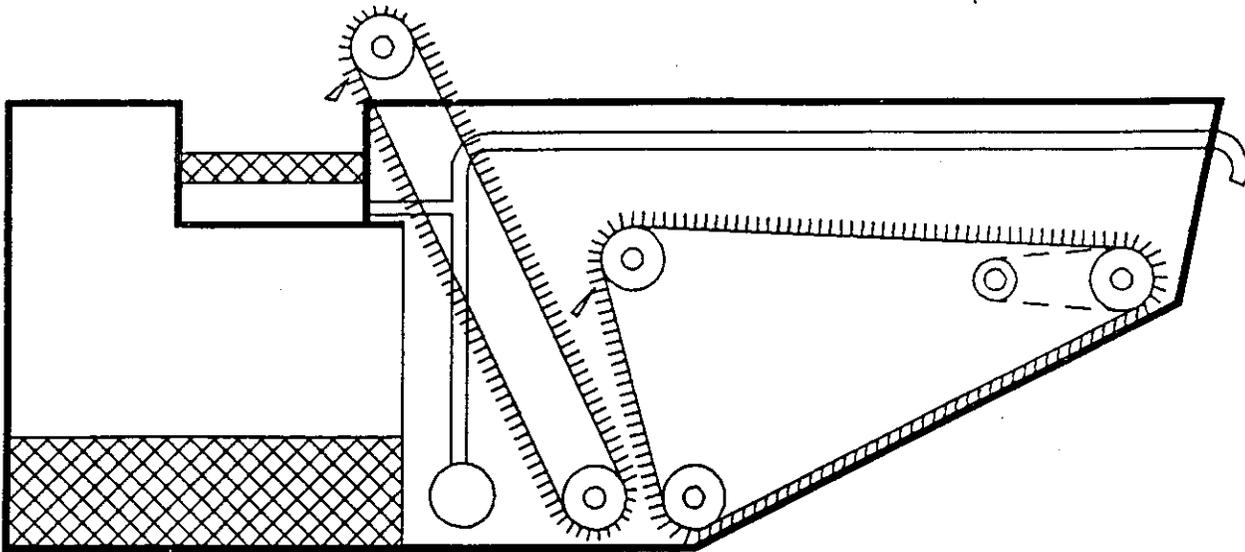


**ELEVATION VIEW
EXTERIOR**

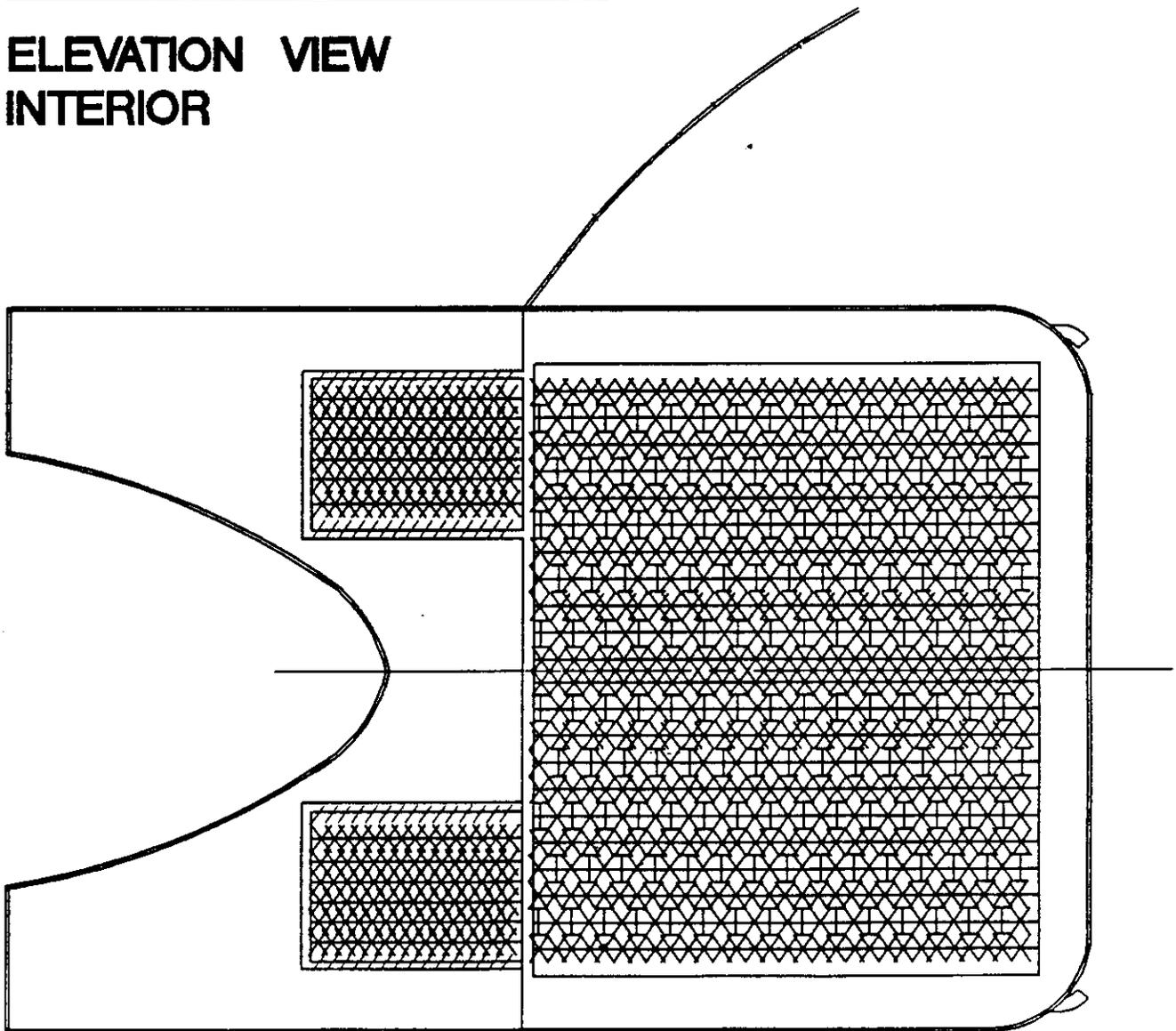


**PLAN VIEW
EXTERIOR**

INTERIOR ARRANGEMENTS

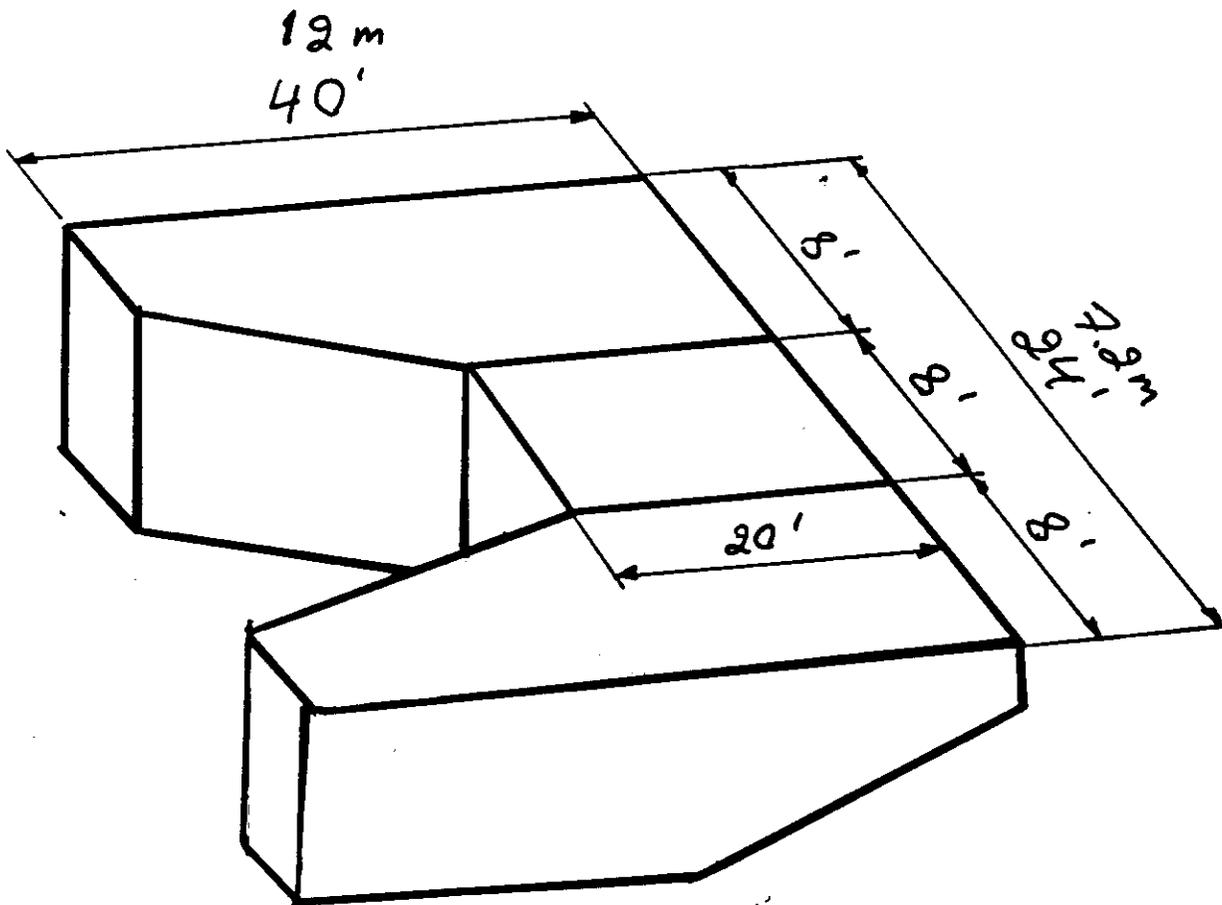


**ELEVATION VIEW
INTERIOR**



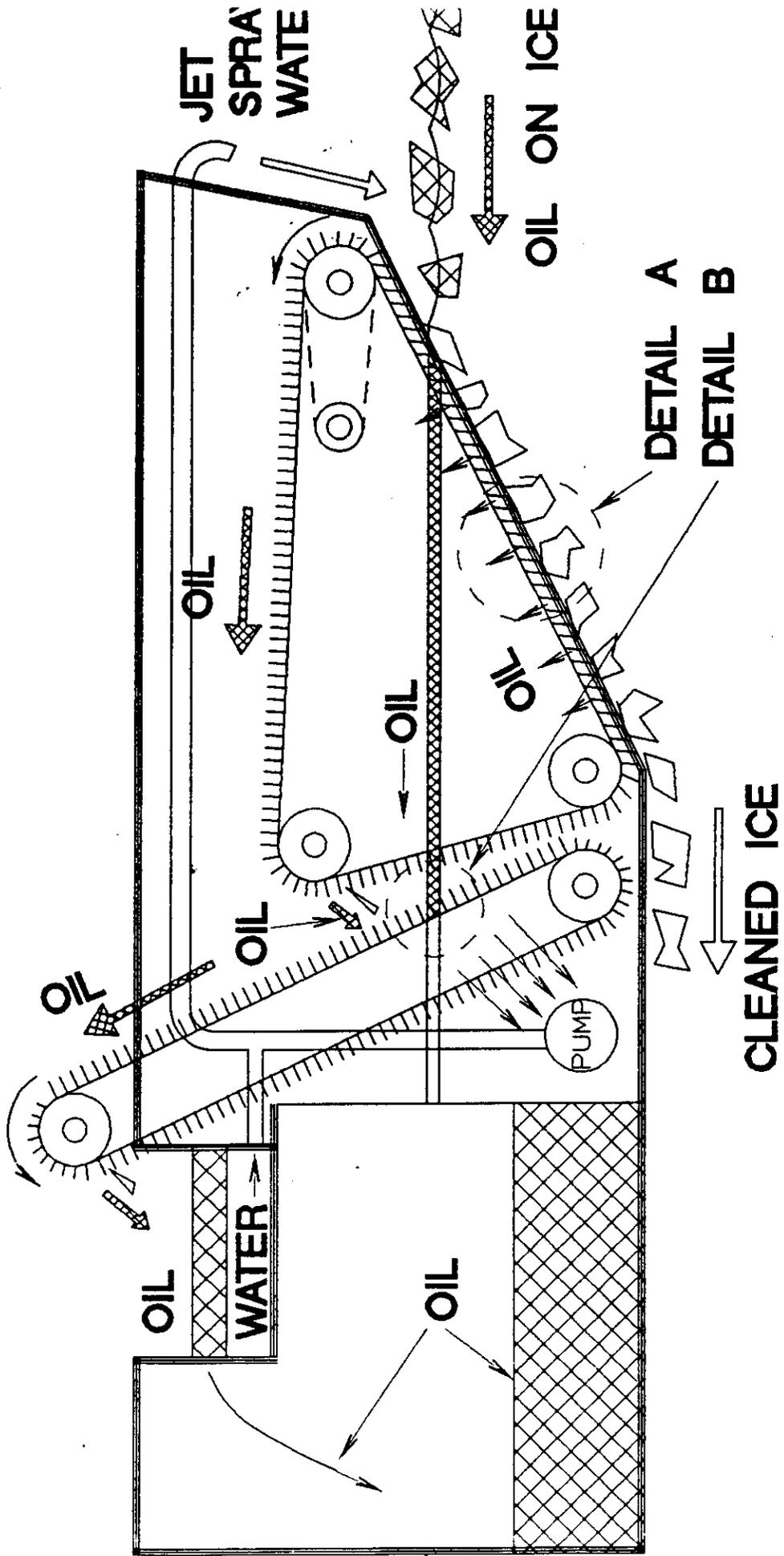
**PLAN VIEW
INTERIOR**

ICE CLEANER
MODULARIZED CONSTRUCTION

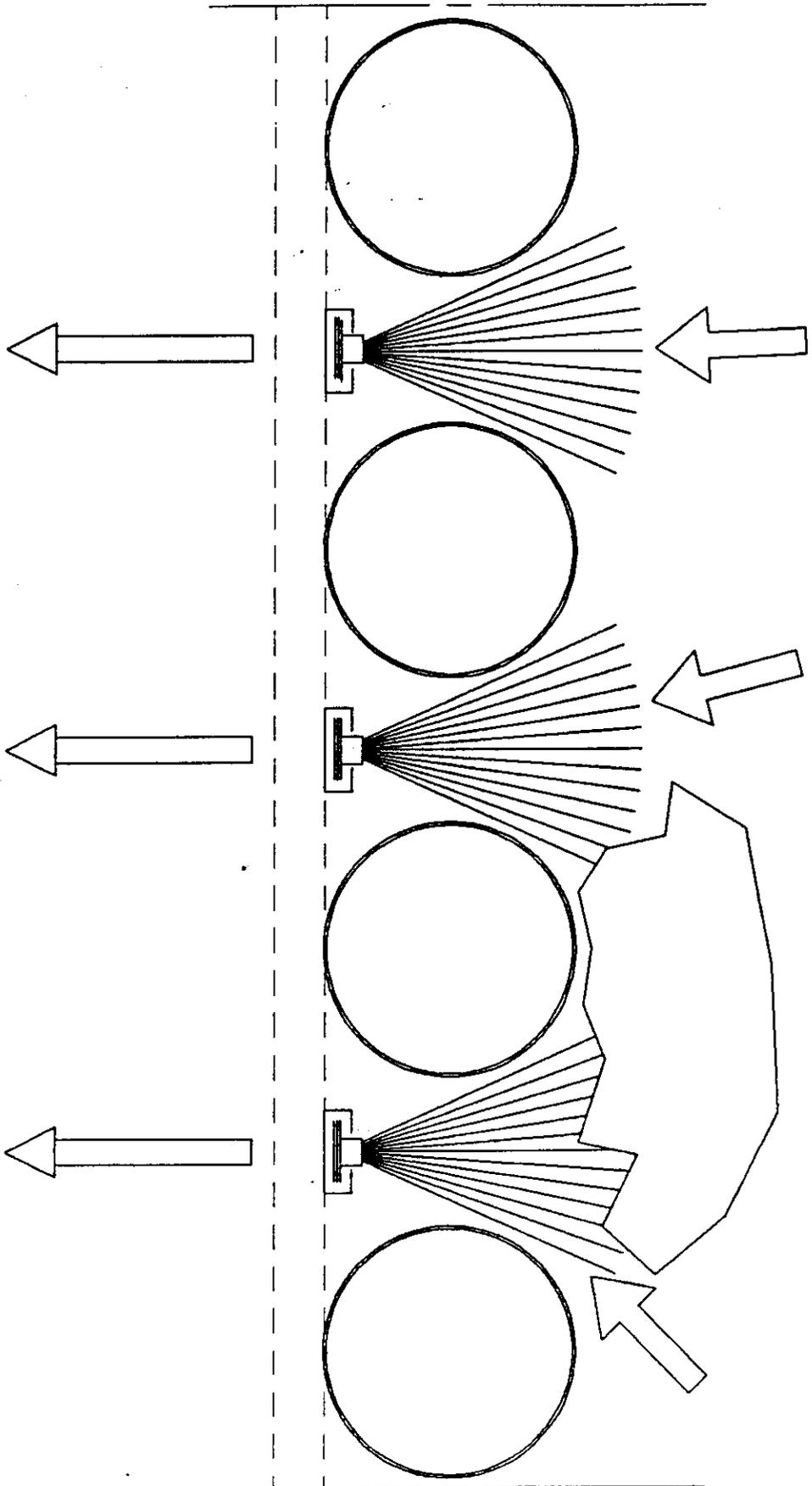


ICE CLEANER

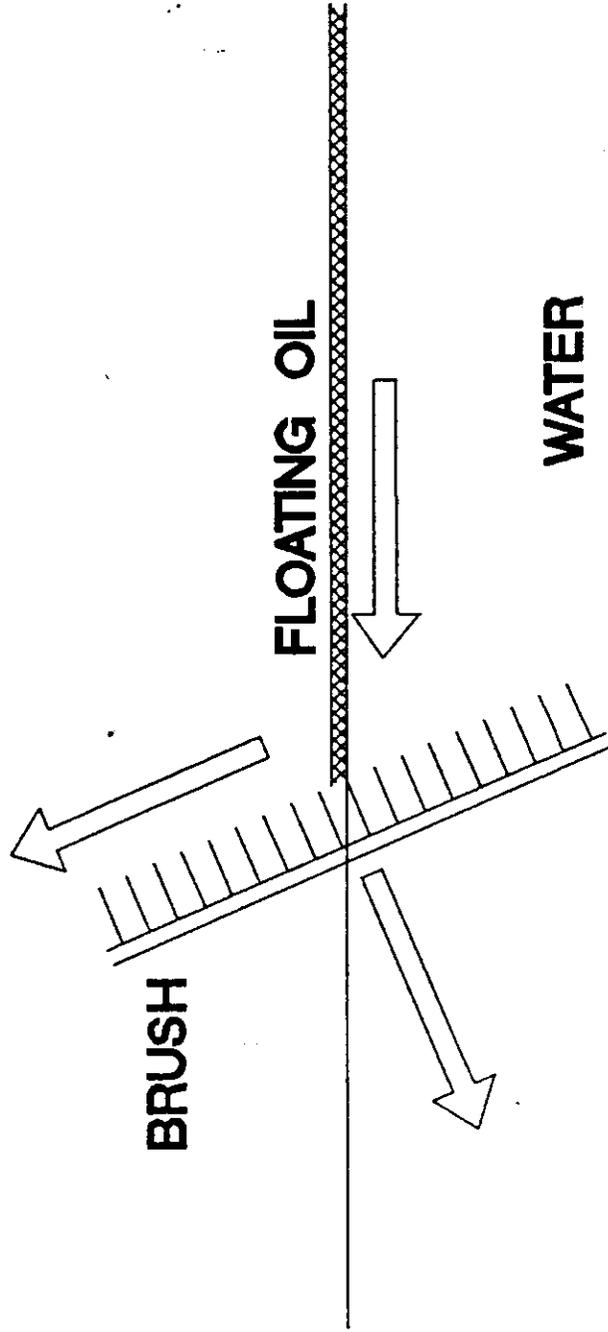
FLOW SCHEME



DETAIL A



DETAIL B



ICE CLEANER

PROTOTYPE

WMAT-LORI ICE CLEANER

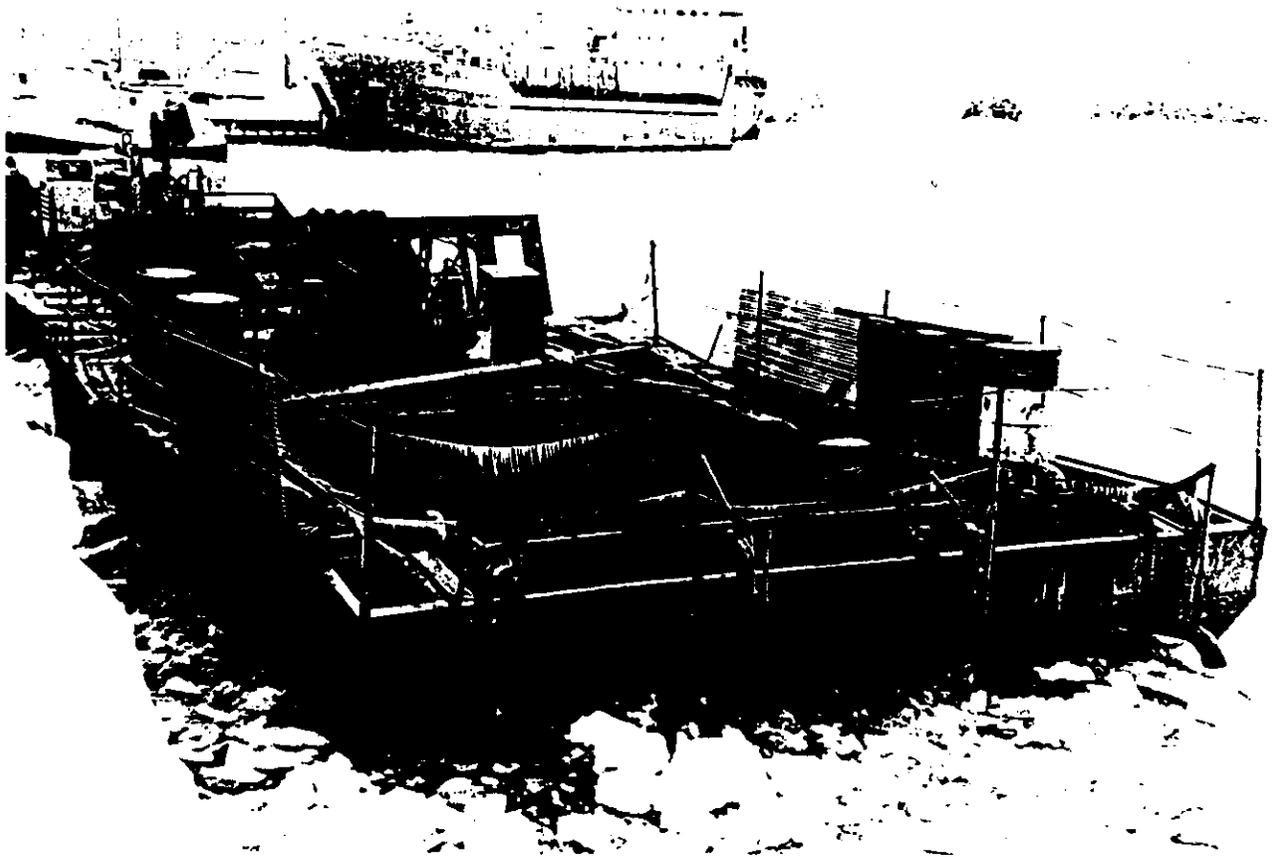
PROTOTYPE DESCRIPTION

*DIMENSIONS 10 m – LENGTH
7 m – BEAM
1.7 m – DEPTH (AFT)
0.5 m – DEPTH (FWD)

WEIGHT OF STRUCTURE AND
EQUIPMENT 22 TON

*FEATURES:

- SUBMERGENCE STRUCTURE FOR COLLECTING OIL FROM ICE
- LORI BRUSH EQUIPMENT FOR CLEANING ICE AND REMOVING OIL FROM WATER



WARTSILA-LORI ICE CLEANER

TESTS IN MARCH 1988

WMAT - LORI ICE CLEANER

PROTOTYPE TEST

- * In 15-17.3.1988, a test demonstration was conducted for Finnish Ministry of Environment.
- * In test, 3 barrels of heavy fuel oil (FOR 180) were spilled into a broken ice sea area measuring approximately 7 m by 50 m in area.
- * The average thickness of the broken ice was 40 cm and the extent of broken ice coverage was 100 %.
- * The spilled oil was recovered during a testing time of 35 minutes.
- * The recovered oil amounted to 95 % of the spilled oil.
- * During the test, the Ice Cleaner was manoeuvred and controlled into the broken ice by means of tug "Henric".

WÄRTSILÄ MARINE

L.C.S. Kobus/AKo

WMAT - LORI ICE CLEANER

PROTOTYPE EXPERIENCE

- * In early February 1987, tanker Antonio Gramski went aground in sea channel near Porvoo spilling 570 tons of Soviet export blend crude oil into broken ice sea.
- * WM built oil pollution vessel, Hylje, recovered some oil by bucket-lifting oil from lightly-covered broken ice sea area around tanker.
- * In April 1987, LORI constructed prototype "Ice Cleaner" was deployed to recover only spilled oil that could be found in region.
- * Spots of oil was located in ice sheet measuring 150 m by 30 m.
- * Amount of oil located estimated to be 3 tons of which 90 % was recovered within a testing period of 3 hours. An ice lead was broken from open water to oil area in ice sheet.
- * During the recovery operation, the Ice Cleaner was manoeuvred and controlled by means of tug "Henric".

APPENDICES:

- 1 WMAT-LORI PATENT FEATURES
- 2 WMAT-LORI ICE CLEANER
WMAT RELATED EXPERIENCE
- 3 WMAT-LORI ICE CLEANER
LORI RELATED EXPERIENCE
- 4 OFFICE TRANSLATION OF ICE
CLEANER TEST REPORT

WMAT-LORI ICE CLEANER

WMAT PATENT FEATURES

- *THE INVENTION RELATES
TO A METHOD FOR COLLECTING
OIL FROM A WATER BODY COVERED
BY BROKEN OR SOLID ICE

- *PERFORATED ICE SUBMERGENCE
STRUCTURE SO THAT BUOYANT FORCES
ACTING ON OIL OVERCOME ADHESIVE
FORCES KEEPING OIL ON ICE

WMAT-LORI ICE CLEANER

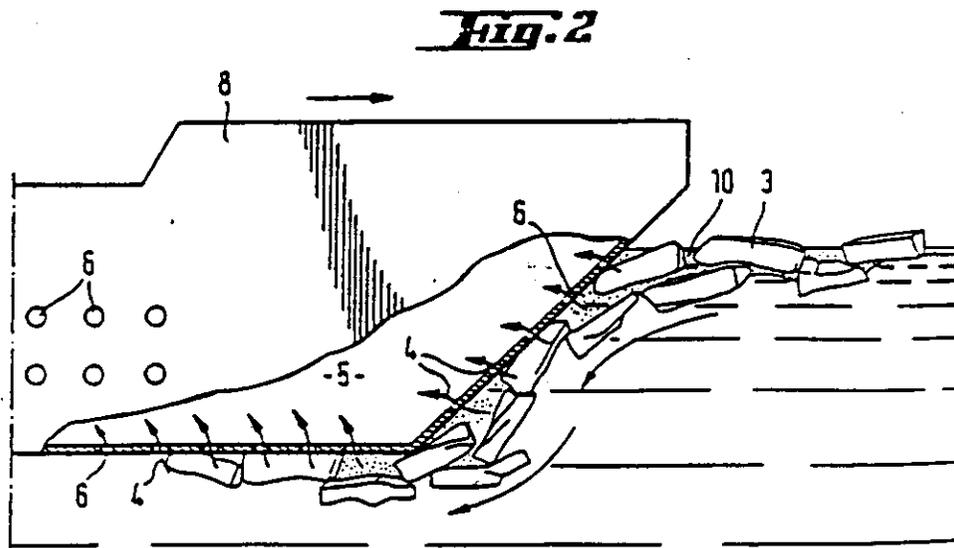
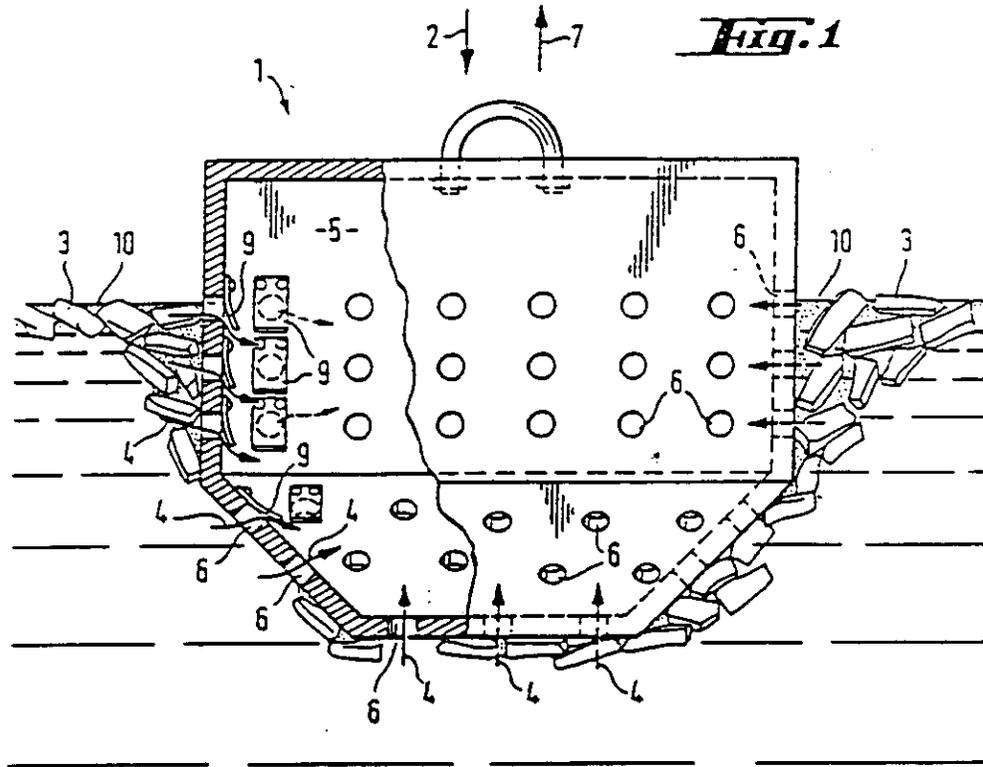
WMAT PATENT FEATURES

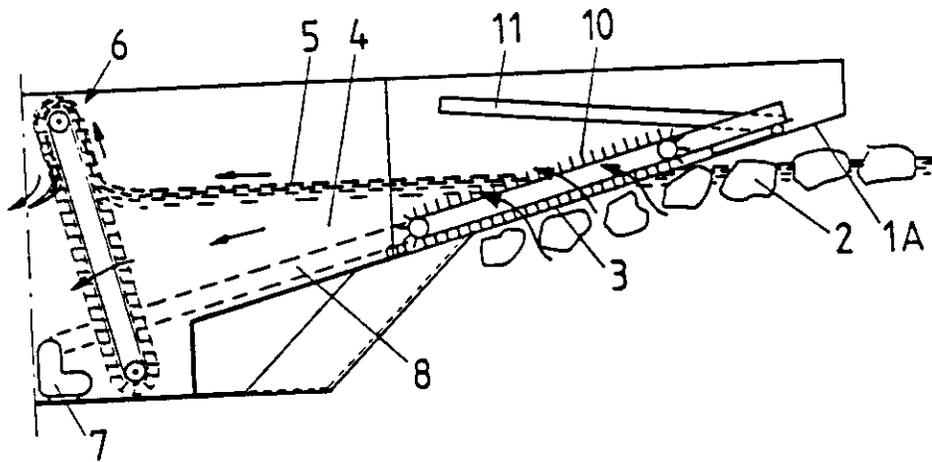
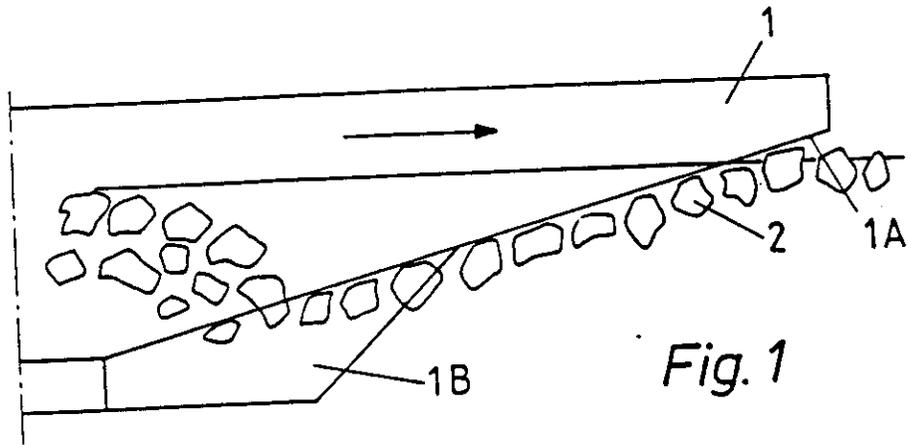
- *SEPARATED OIL FLOWS UP INTO
HOLE PERFORATIONS IN ICE SUBMERGENCE
STRUCTURE INTO STRUCTURE
WHERE IT IS COLLECTED
- *FLOW INDUCED CURRENT THROUGH
PERFORATIONS CONTRIBUTE TO
WASHING EFFECT OF OIL OFF
ICE SURFACES
- *OIL INSIDE STRUCTURE IN ICE
FREE WATER CAN BE RECOVERED
FROM THE WATER BY OTHER
CONVENTIONAL METHODS

WMAT-LORI ICE CLEANER

WMAT PATENT FEATURES

FROM CANADIAN PATENT NO 1242655





WMAT-LORI ICE CLEANER

WMAT RELATED EXPERIENCE

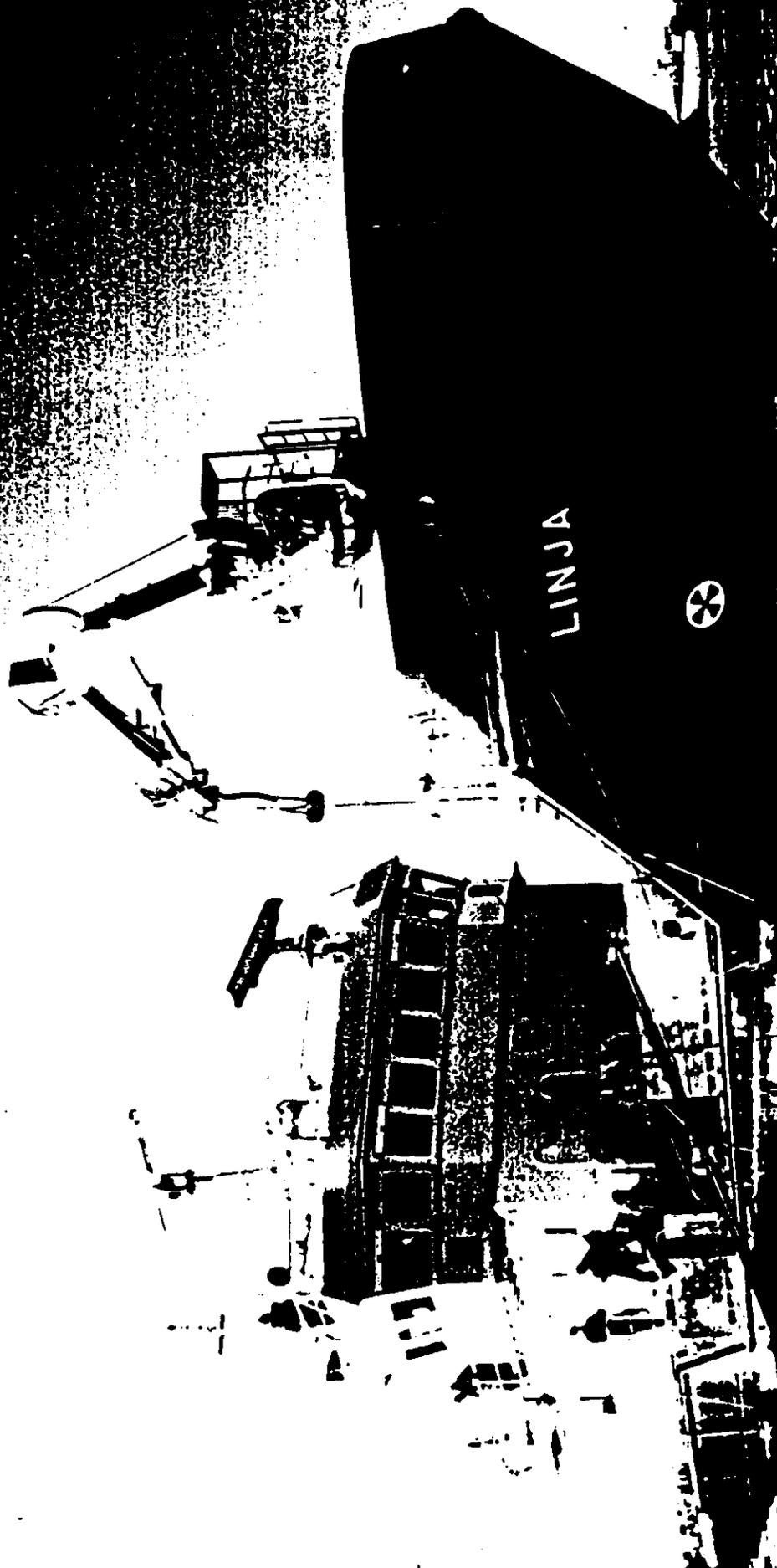
*WMAT HAS DESIGN AND
CONSTRUCTION RECORD WHICH
INCLUDES OVER 100
POLAR REGION ICE BREAKERS,
RESEARCH VESSELS AND NUMEROUS
POLAR NAVIGATING SPECIAL DUTY
VESSELS

*WARC HAS OVER 20 YEARS
EXPERIENCE IN DESIGNING
AND TESTING VESSELS,
FACILITIES AND EQUIPMENT
FOR SERVICE IN ICE CONDITIONS
AS WELL AS BASIC STUDIES
AND TESTS OF ICE PROPERTIES
AND CHARACTERISTICS

WMAT-LORI ICE CLEANER

WMAT RELATED EXPERIENCE

- *WARC HAS PERFORMED LABORATORY AND FIELD TESTS OF RECOVERY DEVICES FOR OIL SPILLS IN ICE CONDITION SEAS
- *WMAT HAS PATENTED DEVICE CONCEPT FOR RECOVERING OIL FROM ICE CONDITION SEAS
- *WM SHIPYARDS HAVE CONSTRUCTED THREE VESSELS NOW IN SERVICE AS OIL SPILL CLEAN-UP UNITS
- *WM SHIPYARD HAS PATENTED DEVICE FOR REMOVING OIL FROM ICE-FREE SEA WATER



WÄRTSILÄ MARINE OIL CLEANING
VESSEL 'LINJA'

'LINJA' CONTAINMENT BOOM



Model and Full-Scale Tests with an Innovative Icebreaker Bow

E. Enkvist,¹ Visitor, and E. Mustamäki,¹ Visitor

The traditional icebreaker bow form is a compromise between level icebreaking capability, performance in other ice conditions, and hydrodynamic behavior. The uncompromised need for capability to break thick level ice recently resulted in applications of both rounded and box-shaped bow forms for use on Siberian rivers. To investigate the potential of such non-shipshaped designs, a project was initiated at WARC in 1984. From this research, a successful combination of round bow and plow was selected for further testing in full scale. An experimental bow of 300 tonnes displacement was constructed and suspended from a 2000-kW icebreaking salvage tug by means of eight force transducers producing full data in the X-Y-Z planes. The model test results correlated with extraordinarily elaborate full-scale tests. Significant results included an increase in icebreaking capacity from 0.5 to 0.9 m and propulsion free from ice interaction. First-year ridges were forced without difficulty and the turning radius was the same as for conventional forms and smaller than those obtained for box-shaped bows. Conclusions are drawn as to the advantages and drawbacks of the new bow form, which is not intended for universal use on icebreaking ships.

Introduction

THE CLASSICAL wedge-shaped icebreaker bow of the sixties has evolved from some 100 years of trial and error. The wedge form is intended and used for many purposes, is versatile, shipshape, reasonably full and seakindly [1, 2].² The eras of spoon shape, extremely sharp-edged stems and even upward-breaking bows had been passed.

Historically, it has been recognized that lower stem angles with the horizontal as well as greater flare of bow sections would increase the vertical forces acting on the ice cover. This follows from direction cosine mathematics shown by Runeberg [3] and considering mechanical friction. Still, the naval architects' dislike for excessive ship length combined with considerations of poor extraction performance of low-powered and rough-skinned early ships precluded general use of stem angles of less than 25 deg.

Early model tests did not change the situation rapidly in the seventies. They called attention to low friction coatings and confirmed the advantages of low stem angles, but the shortcomings of the model ice did not permit safe conclusions on rounded stems and extraction ability. At Wärtsilä Icebreaking Model Basin, both rounded and square bow forms were tested [4], and at least one circular bow was proposed for a serious project, but it was never realized. For the Finncarrier and Urho classes of ships a 20-deg stem angle was introduced and proved successful. In the United States and Canada a concave stem type with a small stem angle near the waterline was introduced for several ships [5].

In the 1980's some specialized extreme-shape bow forms were introduced, such as *Canmar Kigoriak* [6] and *Robert LeMeur* [7] with spoon bows, the Wärtsilä-built *Kapitan Eodokimov* river icebreaker with circular bow, numerous Soviet river icebreaking/ice clearing devices with square (landing

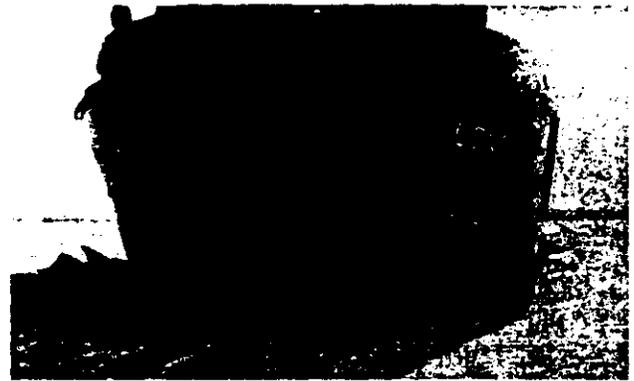


Fig. 1 Test run in a slotted ice field with a ship of conventional design. The slot eliminates crushing and shearing near the stem

craft) bows and a plow [8], and the *Max Waldeck* test bow of square type [9]. As these modified bow types seemed to create some interest among icebreaker operators it was decided at WARC to evaluate the influence of the basic elements in these innovations and try to develop an improved specialized level-icebreaking bow without considering the limitations normally introduced to satisfy a multipurpose design.

Development of a low-resistance bow

Elementary field observations show that the stem of an icebreaker does not break the ice by bending but rather by crushing and shear [10]. This is a continuous process which consumes more energy than the intermittent bending action of the rest of the entrance [11]. A simple segmented model test to demonstrate this was made at Wärtsilä Arctic Research Centre (WARC). The width of the stem segment was 19 percent of the maximum beam, but its resistance was 37 percent of the total in the conditions tested. During full-scale tests, slots have been sawn in front of the stem, Fig. 1, resulting

¹ Wärtsilä Arctic Research Centre (WARC), Helsinki, Finland.

² Numbers in brackets designate References at end of paper.

Presented at the Annual Meeting, New York, N.Y., November 19-22, 1986, of THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

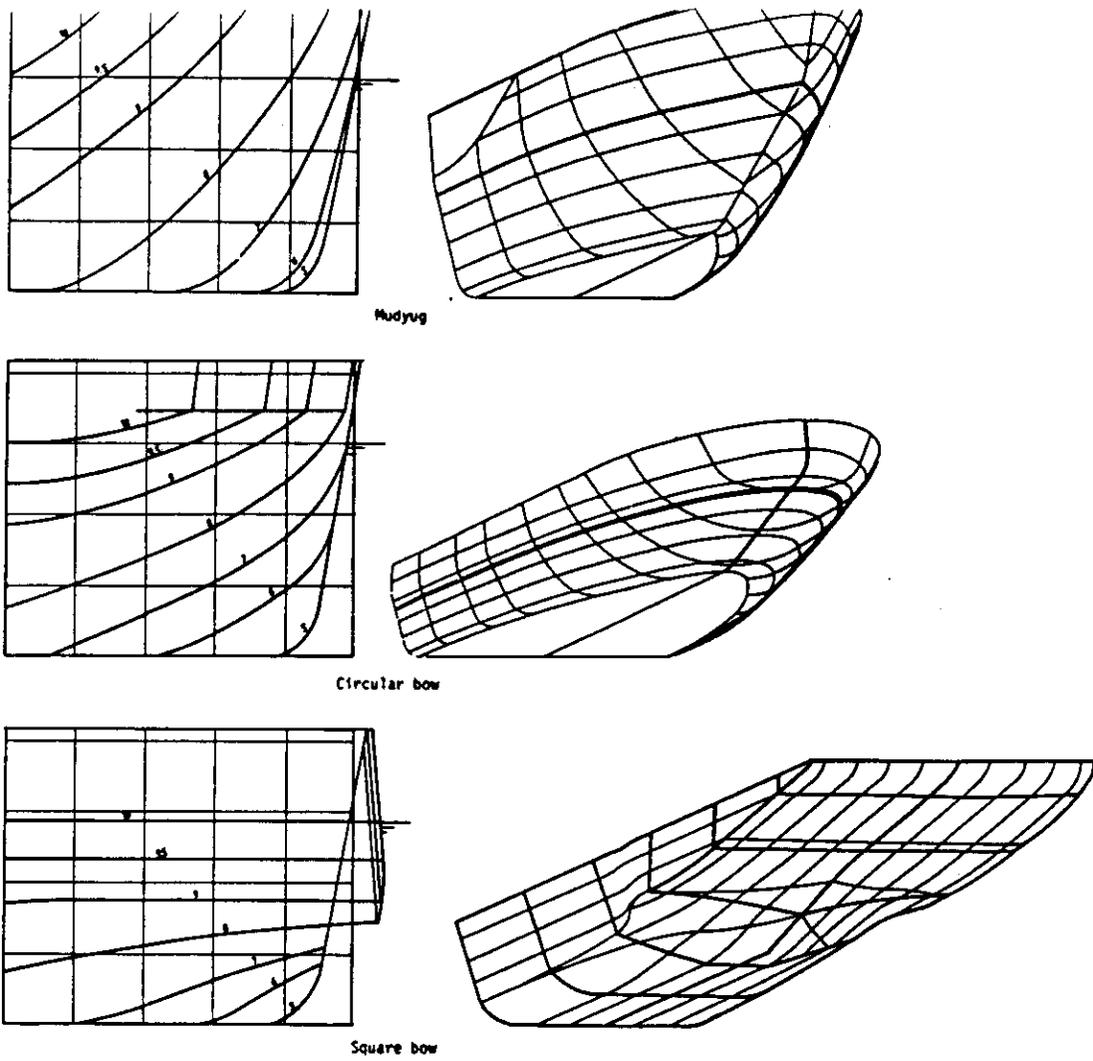


Fig. 3(a) Forebody plans and perspective drawings of models in comparative test series



Fig. 3(b) Models of comparative test series

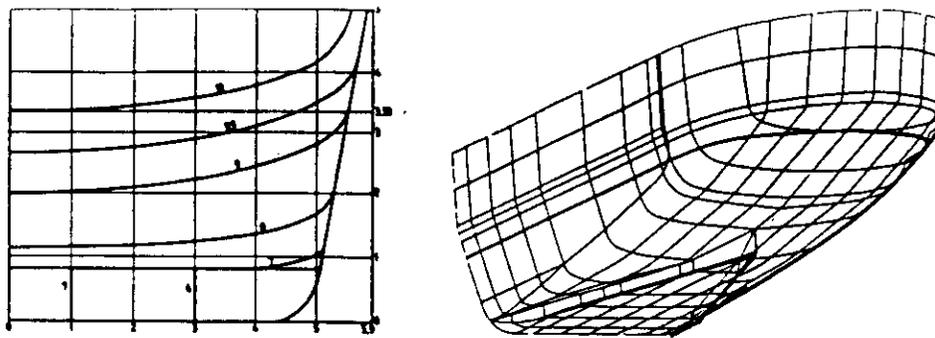


Fig. 6(a) Forebody plan and perspective drawing of the Wärtsilä experimental bow



Fig. 6(b) Wärtsilä experimental bow model

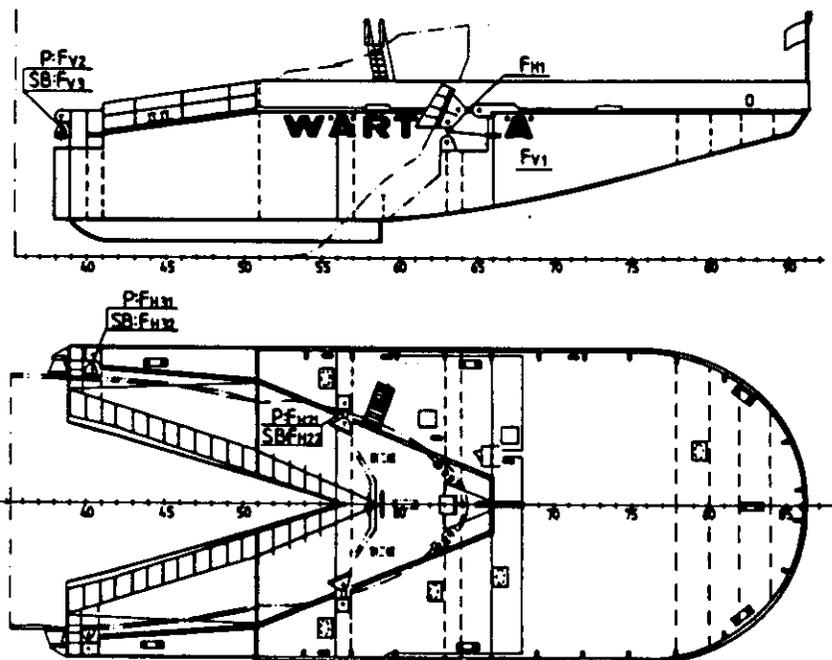


Fig. 7 Connection arrangement

Innovative Icebreaker Bow

Table 1 Weather data from Kotka Rankki during the period March 10-30, 1985

Date	Temperatures			Precipitation, mm	Wet Snow	Drizzle	Water	Fog
	T_{min} (°C)	T_{mean} (°C)	T_{max} (°C)					
March 10	-12.7	-4.2	-1.8	6.3				
11	-5.8	-2.2	2.0	0				
12	-6.6	-2.1	0.3	0.6				
13	-3.8	-1.5	1.1	0.7				+
14	-0.9	0.2	1.7	0.1				
15	-1.1	-0.1	1.8	1.2				
16	-3.5	-0.9	1.9					
17	-5.5	-2.3	1.2					+
18	-11.1	-4.9	1.5					
19	-11.6	-4.4	2.3					
20	-9.5	-2.9	0.7	0.5				
21	-1.2	-0.5	1.3					
22	-5.2	-2.1	1.2					
23	-7.1	-3.4	1.2					
24	-9.5	-4.5	0.6					
25	-8.5	-2.9	2.2	0.7				
26	-2.0	0.3	1.7	6.6	+	+		
27	0.2	0.7	1.2	9.8	+			+
28	0.2	0.9	1.6	8.6	+		+	+
29	-4.6	-2.5	1.3	1.5				
30	-8.4	-4.3	0.2					

Table 2 Weather data from Hanko Russarö during the period March 18-April 1, 1985

Date	Temperatures			Precipitation, mm	Wet Snow	Drizzle	Water	Fog
	T_{min} (°C)	T_{mean} (°C)	T_{max} (°C)					
March 18	-5.0	-3.0	0.2					+
19	-7.7	-3.6	0.1	0				
20	-5.5	-1.3	-0.1	3.4				
21	-0.9	0	1.2					
22	-4.8	-0.6	0.6					
23	-6.1	-2.1	1.4					
24	-7.6	-2.0	1.0					
25	-5.3	-0.7	1.5	0.8				
26	-0.5	0.2	0.7	7.3	+			+
27	-0.2	0.5	1.0	5.7	+		+	+
28	-0.2	0.5	1.9	0.2				+
29	-3.7	-1.8	0.6	0.3				
30	-5.7	-1.9	1.4					
31	-4.5	-1.3	1.8	0.1				
April 1	-2.9	-1.3	1.4					+

Fig. 12 Routine ice chart covering test areas →

disturbance in equipment) the thrust was obtained using the torque signal. The torque-thrust relation was checked both in bollard pull and during ice tests, Fig. 14.

Utilizing the suspension arrangement of the test bow, there was the interesting possibility of measuring the force by which the bow was pushed. At low speed the measured force is equal to the resistance of the bow. At higher speeds the potential flow will cause a growing force which pushes the bodies together. If the measured force was lower than the resistance obtained from shaft recordings, then the measured force was adopted as resistance. The logic for this is that the direct resistance represented by F_x is safer than the propulsion data except when increased by hydrodynamics.

The formulas used were then:

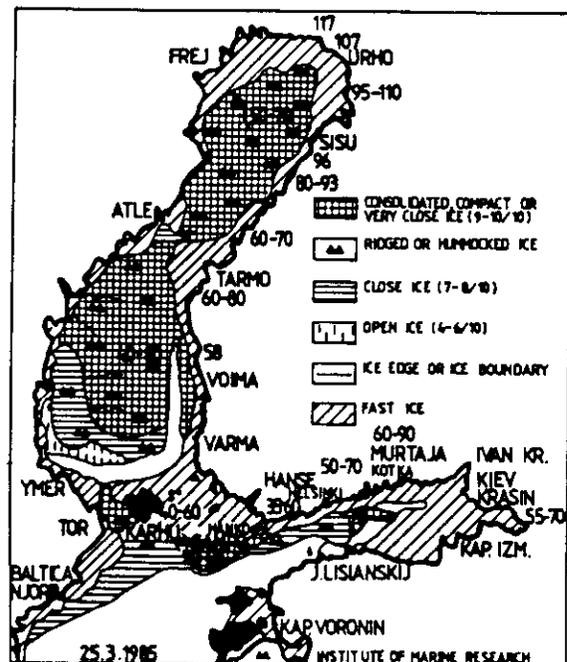
$$R_{tot} = T(1 - t) \quad \text{if } F_x > T(1 - t) \quad (1)$$

$$R_{tot} = F_x \quad \text{if } F_x < T(1 - t) \quad (2)$$

Ice resistance is obtained by reducing the open-water resistance:

$$R_{ice} = R_{tot} - R_{ow} \quad (3)$$

The ice resistance was corrected to correspond to standard



target ice thickness and strength by the following formula:

$$R_{\text{corr}} = (R_{\text{ice}} - R_{\text{Bm}} + R_{\text{Bt}}) \left(\frac{H_{\text{icorr}}}{H_{\text{icorr}}} \right)^x \quad (4)$$

The breaking components for measured and target ice strength were based on model scale results. The thickness correction exponent was chosen to fit full-scale results ($x = 1.5$).

In ridge tests, where the speed was not constant, the F_x force was used for resistance calculation. The mass force caused by the bow added with 10 percent, due to added mass of water, was taken into account.

Connection forces—Since all force transducers used for measurement of forces acting on the bow were parallel to the coordinate axes it was easy to determine the three force components. It was done as follows simply by adding the correct forces:

$$F_x = F_{h1} \quad (5)$$

$$F_y = F_{h21} - F_{h22} + F_{h31} - F_{h32} \quad (6)$$

$$F_z = F_{o1} + F_{o2} + F_{o3} \quad (7)$$

Seakeeping model tests

Objectives

A disadvantage of a bow type presented in this paper or other innovative forms is their open-water characteristics. Both the open-water resistance and the seakeeping performance, especially slamming, are poorer than for a conventional icebreaker bow form, not to mention that of a good open-water bow. Due to this fact such new bow forms are feasible only in some special icebreaker applications where high capability for breaking level ice is needed and rough open-water crossings are scarce. To be able to judge the possibilities of using such a new bow form, its open water characteristics should be known.

Models tested

Seakeeping tests with pressure transducers for slamming for three different icebreaker hull forms were performed at the Technical Research Centre of Finland (VTT). The tested models were:

- conventional icebreaker
- square type
- Wärtsilä experimental bow

The Mudyug-class icebreaker (built in Finland in 1982 for the U.S.S.R.) was chosen to represent the conventional icebreaker type. The main particulars of the Mudyug class are as follows:

Length, dwl	78.5 m	(257 ft-7 in.)
Breadth, dwl	20.0 m	(65 ft-7 in.)
Draft, dwl	6.0 m	(19 ft-8 in.)
Displacement	5560 t	

Both the square bow and the Wärtsilä experimental bow were tested together with the aft part of the Mudyug model. The lengths of the bows were chosen so that the machinery spaces of the vessel would not be touched if a bow of this type was mounted on the ship. This requirement results in a higher length than that of the Mudyug class. The lengths of the models were (in full scale) 88.4 m (290 ft) for the square bow and 92.1 m (302 ft-2 in.) for the Wärtsilä experimental bow.

Results

Ice tests

Tests in level ice—Some 100 resistance tests were made in level ice. The corrected results for the reduced ice thicknesses 30, 60 and 80 cm are plotted in Fig. 15.

The icebreaking capability of *Protector* with the test bow is expressed in the form of a speed versus ice thickness curve in Fig. 16. The figure shows that the test bow increases the icebreaking capability considerably. However, the original bow of *Protector* is not particularly efficient.

A comparison of measured thrust, and measured F_x force for tests in 60-cm-thick ice is shown in Fig. 17. The influence of potential flow is clear on higher speeds when the x force is considerably higher than thrust and net thrust.

An example of an x -force time history is shown in Fig. 18. At low speed it is clearly shown how the force decreases after breaking of each new cusp.

F_y and F_z were also recorded. F_y was used at the shipyard as a reference ice load when designing a rigid pusher-barge coupling. F_z has been used in global ramming response research. Potentially, it may produce results on global friction.

A photo of level ice tests is shown in Fig. 19.

Ice cleared of snow—Two approximately 300-m-long (984 ft) paths, Fig. 20, were cleared of snow outside Kotka on March 28. The purpose of this was to find out the influence of snow on the ice resistance. Due to rain on the test day, the cover was wet but still the effect on the resistance was significant. A comparison between the two test points in snow-free ice and some points from the same snow-covered ice field is shown in Fig. 21.

From Fig. 21 it can be seen that about one half of the snow thickness should be taken into account when reducing the ice thickness, which has been done in the analysis.

Ridge tests—In the three ridge tests made there were no difficulties in penetrating the ridges, and the exit speed was in the range of 1 to 2.5 m/s (~3.3 to 8.2 fps). The cross section areas of these ridges were of the order of 130 to 180 m² (1399 to 1938 ft²).

The measured ice resistances versus ridge thicknesses are shown in Fig. 22. A photo of one of the encountered ridges is shown in Fig. 23.

A comparison between *Protector* with test bow and *IB Ale*, Fig. 22, shows that the resistance of *Ale* is 20 to 40 percent higher than that of *Protector*.

When the slightly larger dimensions of *Ale* are taken into account, it may be concluded that the ridge resistance of the test bow is of the same magnitude as that of a conventional bow.

Channel tests—Channel tests were performed both on the way out from Helsinki and at the test areas when moving from one location to another. During tests in the 10.0 fairway west of Kotka, the channel profile was measured in three places. The average thickness in the measured profiles varied from 1.30 to 1.46 m (4.26–4.79 ft), and the average of all profiles was 1.40 m (4.59 ft). The results of all channel tests are plotted in Fig. 24.

In no phase of the channel test had the bow any tendency to push the channel mass in front of itself. Instead, it submerged the mass without difficulties.

The plow did not work as well as in the level ice. A part of the thick layer of ice blocks ended in the propeller. In the shaft torque record up to 15 ice interactions per minute are found.

Due to the round waterline form the bow showed good ability to widen the channel and to break its way out of it.

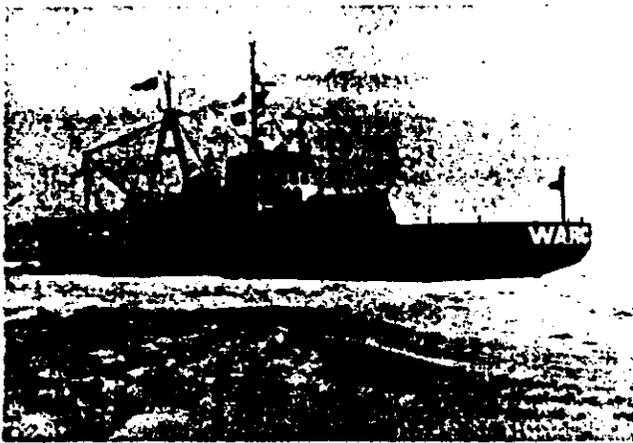


Fig. 19 Protector during full-scale tests in level ice



Fig. 20 One of the paths cleared of snow

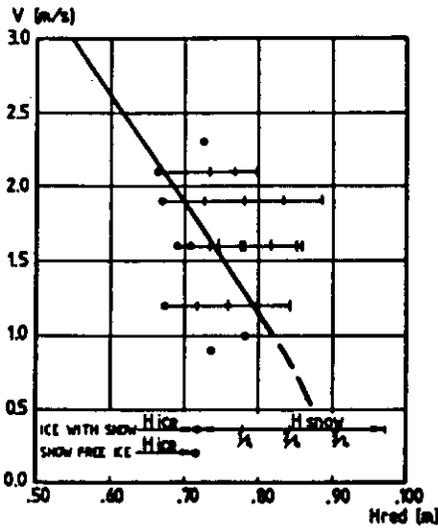


Fig. 21 A comparison of tests in snow-covered and snow-free ice. The points show the ice thickness and the lines represent snow cover, as a scale with four ticks. The relationship between speed and ice thickness from Fig. 16 is also shown

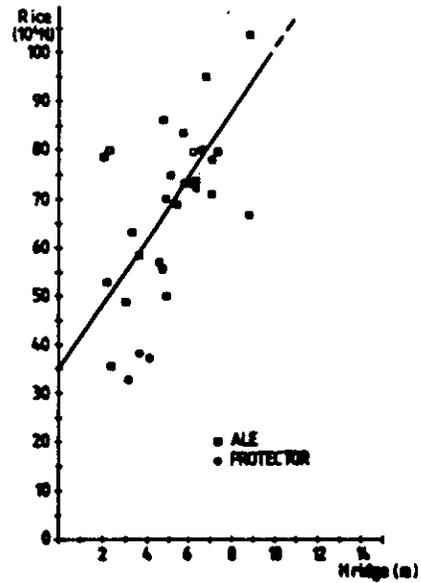


Fig. 22 Ridge resistance versus ridge thickness. For reference, some results with the icebreaker *Ale* are shown



Fig. 23 Measuring a ridge profile

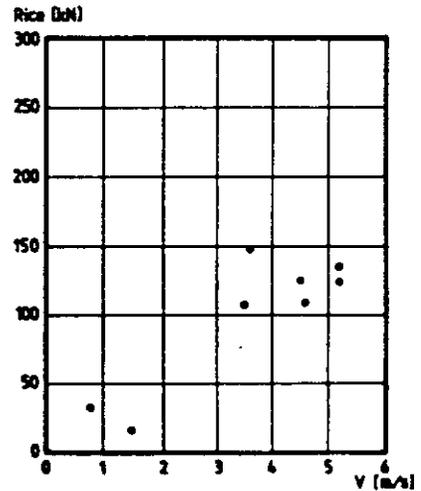


Fig. 24 Channel resistance versus speed

thick (~27 in.) ice when the bending-type breaking occurred. See also Fig. 29.

Ice loads

The ice loads could be analyzed starting from strain gages, measured normal force on high-pressure friction device, and any permanent hull damage.

The strain gage measurements and high-pressure friction panel gave ice pressures of the same magnitude, but the highest ice load was calculated from ice damage in an area above the instrumentation. When a $300 \times 150 \text{ mm}^2$ ($12 \times 6 \text{ in.}^2$) contact area was assumed, the highest measured ice pressures were in the range of 1.1 to 3.7 MPa (160–540 psi), Fig. 30. The ice loads based on damages are mostly of the same magnitude, but the largest damage gave a value of 11.5 MPa (1700 psi), which is about three times higher than the measured values. Some other damages gave 9 MPa (1300 psi). The largest damage in the instrumented panel gave 3.8 MPa (550 psi), which is almost the same as the highest measured value.

The relation between ice loads and permanent damage was established by making finite-element model (FEM) calculations and bench tests with structure models.

The instrumented area was situated just below waterline, while the deepest damage deformations occurred above the waterline. This indicates that high-speed transits in old channels resulted in maximum load. The bow-wave made large old lumps of ice hit the area above the waterline. See Fig. 31.

Friction measurements

As was expected, the high-pressure device gave much lower friction coefficient values than the low-pressure device. This is due to the higher pressure. The measured average friction coefficients vary between 0.045 in the old broken channel and 0.130 in the snow-covered level ice for the high-pressure device and between 0.157 and 0.255 for the low-pressure device, respectively. Surprisingly, clearing away or wetting the snow did not change these figures significantly. The measured friction coefficients as functions of normal force are shown in Figs. 32 and 33 for the two devices. These plots are made by sampling at 100 Hz, when the normal force has exceeded 2 kN. As may be seen, there is a lot of scatter in the results. This is due to the nature of friction. Examples of measured time histories are shown in Figs. 34 and 35.

Model-scale correlation

A lengthy final correlation test series with a 1:10 scale model was made during the autumn of 1985. Tests in level ice and ridges as well as maneuvering tests were performed in fine-grain model ice.

As in the full-scale tests, the model-scale test bow was connected to the tug by force transducers. Although the connection arrangements were not identical, the connection forces have been measured both in full scale and model scale.

When comparing model-scale and full-scale results, the model-scale results have to be scaled:

$$R_{\text{ice ship}} = \lambda^3 \cdot R_{\text{ice model}} \quad (8)$$

The friction coefficient of the model was 0.05.

The comparison between the model- and full-scale results for the ice thicknesses 30, 60 and 80 cm are shown in Fig. 36.

As the figures show, the overall correlation is good with the friction coefficient 0.05 as in the preliminary comparison series. There is some discrepancy between this value and those physically measured in full scale by means of friction panels, which indicates scale effect in ice modeling.

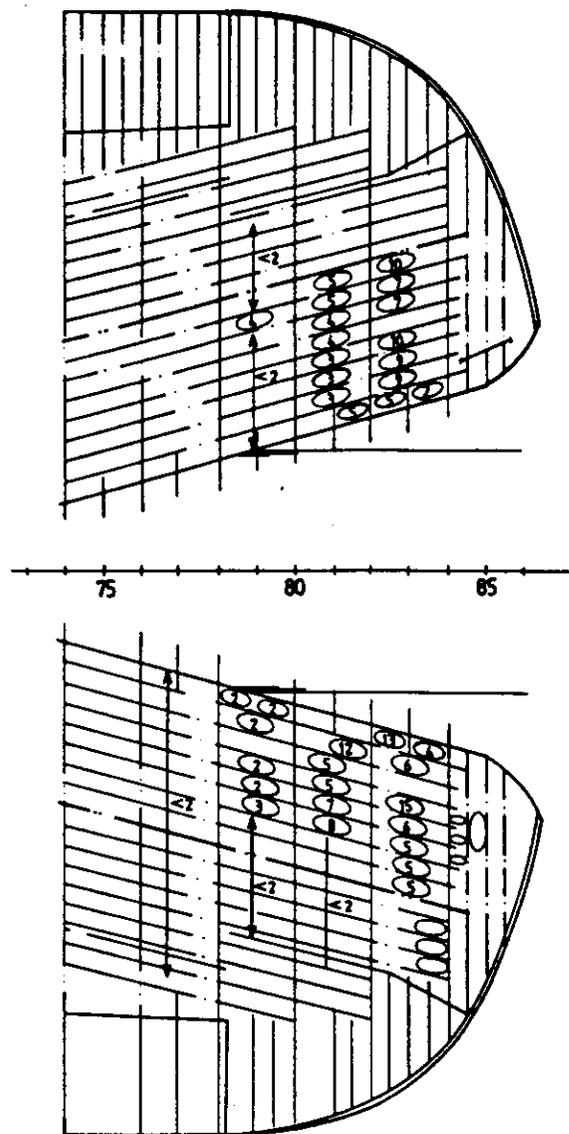


Fig. 31 Ice damage measured on bow shell plating after tests. Figures indicate permanent set in millimeters

Open-water tests

Resistance tests—It is self-evident that the square-type bow and the experimental bow are not optimized for open-water conditions. The result is a much higher resistance than for the original icebreaker, which is not a good open-water bow itself. In practice this means a speed reduction of about 1 knot for the experimental bow and about 2 knots for the square-type bow compared with the original bow. The resistance curves are compared in Fig. 37. The result means that the higher length of the square type and experimental bow does not compensate for the poorer form.

Seakeeping tests—The seakeeping tests were performed in an irregular sea with a significant wave height of 4.58 m (15 ft). Resistance in waves, pitch, and the pressure in five positions in the bow area were measured.

- **Resistance in waves:** Figure 38 shows the added resistance in waves. At 6 knots, only the square bow shows a significant increase in relation to the conventional, but at 12 knots, both innovation bows have a nearly doubled added resistance.

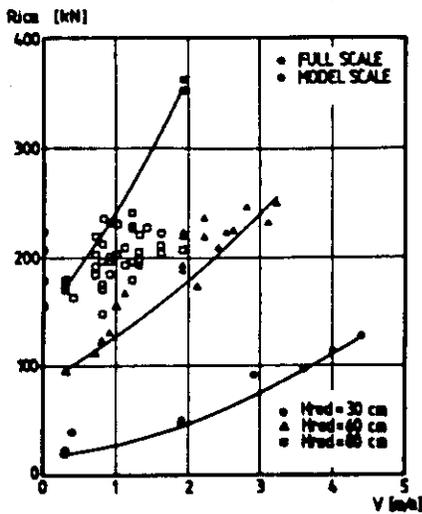


Fig. 36 Comparison of model- and full-scale ice resistance

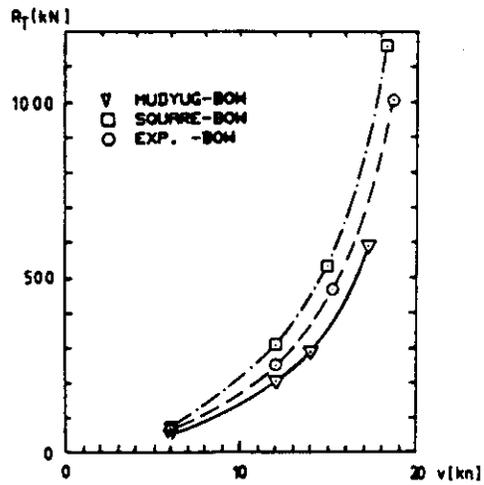


Fig. 37 Measured open-water resistance of tested hull forms

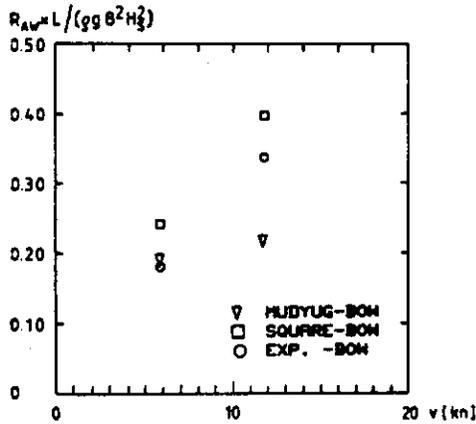


Fig. 38 Added resistance in waves

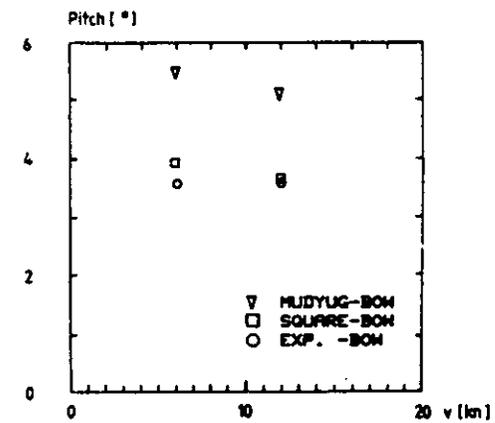
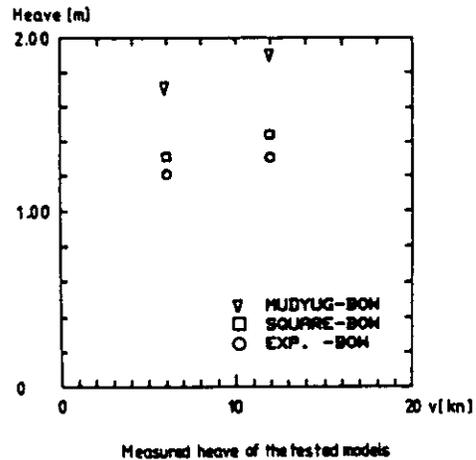


Fig. 39 Measured heave and pitch of tested models

- Motions in waves: Due to the larger waterplane surfaces the square type and the experimental bows have smaller motions in waves. When the significant amplitudes are compared, the experimental bow has some 30 percent smaller pitch and sway motions. For the square-type bow the figure is about 25 percent. A comparison of these results is shown in Fig. 39.
- Slamming pressures: The slamming pressures were measured at five positions on each bow, Fig. 40. The highest measured slamming pressures for the original, square type and experimental bows were 120, 453, and 428 kPa (17, 66, and 62 psi) respectively at a speed of 6 knots. The results show a very significant difference to the advantage of the original bow. The average pressures for the tested models at a speed of 6 knots were 29, 41, and 34 kPa (4.2, 5.8, and 5.0 psi) for the original bow, square-type bow and experimental bow respectively. The distribution of the significant pressures is shown in Fig. 40.

During an open-water transit in about 2.5-m-high (8.2 ft) head seas the *Protector* full-scale experimental bow slammed,

producing a 1600-kN (160 tons) vertical force peak and a 470-kPa (68 psi) maximum pressure at the high-pressure friction panel. Figure 41 shows the time history for this particular case.

There is no doubt that slamming is a major problem associated with innovative icebreaker bow forms. Improved experiments are needed to obtain the total slamming force, which would be more interesting than local pressure peaks.

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WMAT-LORI ICE CLEANER

LORI RELATED EXPERIENCE

- *LORI HAS PATENTED DEVICE
FOR REMOVING OIL FROM
ICE-FREE SEA WATER
- *LORI HAS CONSTRUCTED AND/OR
MODIFIED 14 VESSELS FOR SERVICE
AS OIL SPILL CLEAN-UP UNITS
EQUIPPED WITH LORI PATENTED DEVICE
- *LORI HAS PATENTED DEVICE FOR
REMOVING OIL FROM ICE CONDITION SEAS

WMAT-LORI ICE CLEANER

LORI RELATED EXPERIENCE

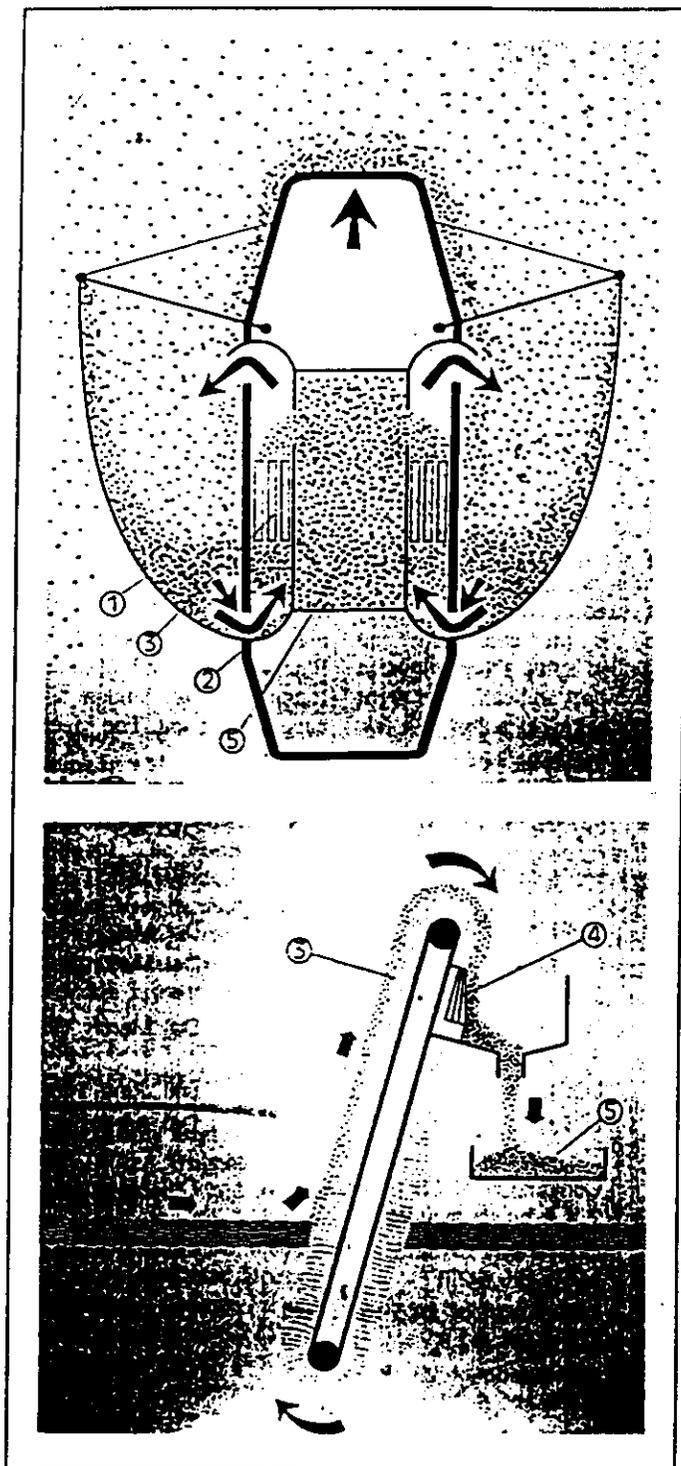
- *LORI HAS CONSTRUCTED PROTOTYPE OF PATENTED DEVICE WHICH HAS BEEN TESTED IN ACTUAL OIL SPILL CONDITIONS IN FINLAND IN 1987
- *LORI MODIFIED PROTOTYPE AND TESTED IT IN ICE CONDITIONS IN 1988 UNDER SPONSORSHIP OF FINNISH MINISTRY OF ENVIRONMENT

MacLori

An oil recovery system that works at sea

Most oilspills at sea pertain to accidents, which are at least partly caused by difficult weather conditions, such as fog, storm or winter. The same factors cause also the biggest problems pertaining to recovering the oil from sea. This means that the oil recovery equipment should be capable of working in as bad weather conditions as possible. Other requirements to be imposed on efficient oil recovery equipment are the capability to cope with all oil grades, sufficient tank capacity on board and minimum draught for working in shallow waters near the shoreline.

Until recently there has not been equipment available that could cope with the above combination of requirements. This is due to the fact that they have collected mainly water and thus called for big receiving tanks. This being the case the ultimate oil spill fighting has too often been carried out by cleaning the shores on the



shore manually.

The technical prerequisites for fighting the oil spills effi-

ciently at sea have been greatly enhanced with the development of the MacLori-system.

The concept is based on the inventions of Lars Lundin and the product is marketed globally by the MacGregor-Navire Organisation.

With the MacLori-system the oil contaminated layer on the surface is forced to pass through the ducts (2) in the hull by utilising the wing shaped oil booms (1) fitted on both sides of the vessel and the movement of the vessel through the water. In the channels there is a set of brushes (3) fitted on endless chains, which are driven by a hydraulic motor. There are several brushes, the amount depending on the desired capacity, mounted abreast in an inclined position. When the oil laden water is flowing through the bristles and the chains are rotated, the oil adheres to the brushes and is being lifted up. Behind the upper pulley the bristles land in a scraping device (4), which removes the oil from the brushes. Subsequently the oil falls or is pumped to the storage tank (5).

90% recovery rate

The water is discharged through the doors in the forward part of the hull. This means that the possible oil, which escaped the brushes at the first go, is again led by the oil booms to the ducts. This results in the recovery rate in the order of 90%. The MacLori unit can also clean very thin oil films and chase the drifting oil in shallow waters due to the small draught. The MacLori-concept makes working speeds of up to 2 knots possible without oil escaping under the booms. The biggest units in service have a sweeping width of 30 metres at one go.



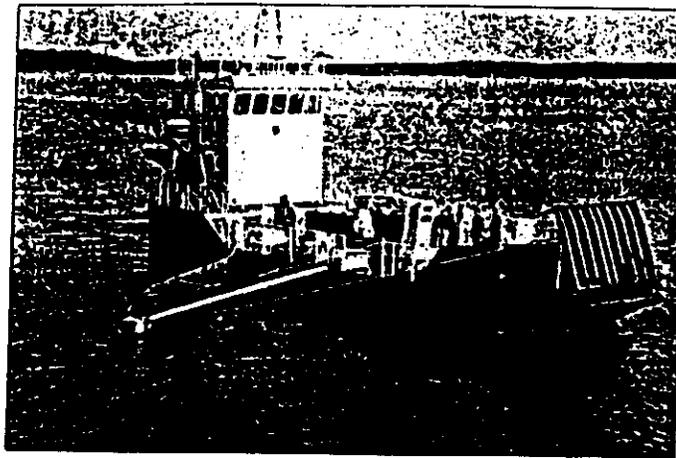
An oil . . .

A significant feature in the MacLori -concept is that there is only 5...10 % free water in the recovered oil. This means that a relatively small tank capacity is sufficient for receiving the oil. The MacLori -system works also with very high viscosity and emulgated oils. Solid debris or blocks of oil are recovered as well. For facilitating the transferring of heavy oil from the tanks heating system can be provided.

The ability to work in extreme weather conditions is significant. A MacLori unit can carry on working even when the wave height is 1.0...1.5 m, wind speed 10 . . . 12 m/s and temperature at the freezing point.

Versatility

An important prerequisite for fighting an oil spill successfully at sea is the minimum delay in getting the work started. This calls for the equipment to



be positioned at strategic locations over the whole length of the coastal shipping lanes. In order to keep the costs in check it is important that the oil recovery vessels are versatile so that they are not waiting idle for the oil spills, which, nevertheless are quite rare. MacLori vessels can be fitted for fire fighting, buoy maintenance, cargo transportation and other utility purposes. For fast deployment it is important that the oil recovery equipment is carried on board, when the vessel is being used for other purposes. This is the case with the MacLori units. The equipment is compact and can be brought into working position in a few

minutes. Further the cranes needed for handling the oil booms can be used for a lot of other purposes making the vessel a multipurpose unit as such.

The small crew of 2...3 persons needed for operating the MacLori vessel in fighting oil spills contributes in an efficient way to the reduction of costs.

The first test

The MacLori -concept got the first real test in September 1984, when m/s "Eira" went aground in the Gulf of Bothnia near the Swedish and Finnish coast and about 200 tonnes of heavy bunker oil escaped in the sea. The MacLori

prototype was carried over the land to the spot and could start the recovery work about 48 hours after the accident. During the next five days the MacLori -unit could recover about 37 m³ of oil with the water content below 5 %. This stands for about 90 % of the recovered amount while all available Swedish and Finnish vessels were employed. The prevailing circumstances were: wind speed 12 m/s, wave height 1.5 m and temperature 8...10 degr.centi-grade. Equally good results have been achieved in later tests as well as in real work, too.

The convincing performance of the MacLori -system has resulted in a number of orders, both newbuildings and conversions. The reference list comprised of 12 vessels in 1987. Five of them were small units of the same size (length about 10 m) as used in the "Eira" case while the biggest is the 60 m multipurpose vessel "Halli" built by Hollming Shipyard. The rest of the deliveries comprise of Swedish and Finnish coast guard and oil recovery vessels, which have been fitted with MacLori -system in a conversion project. One of the major advantages of the MacLori -system is that it suits very well for conversions. Jumboisation has proved to be the most advantageous type of conversion, because all MacLori -equipment can be built into the new hull section, which is simply welded between the halves of the original vessel. This results in a short conversion time and additional tank capacity, which is useful for the future oil recovery work.

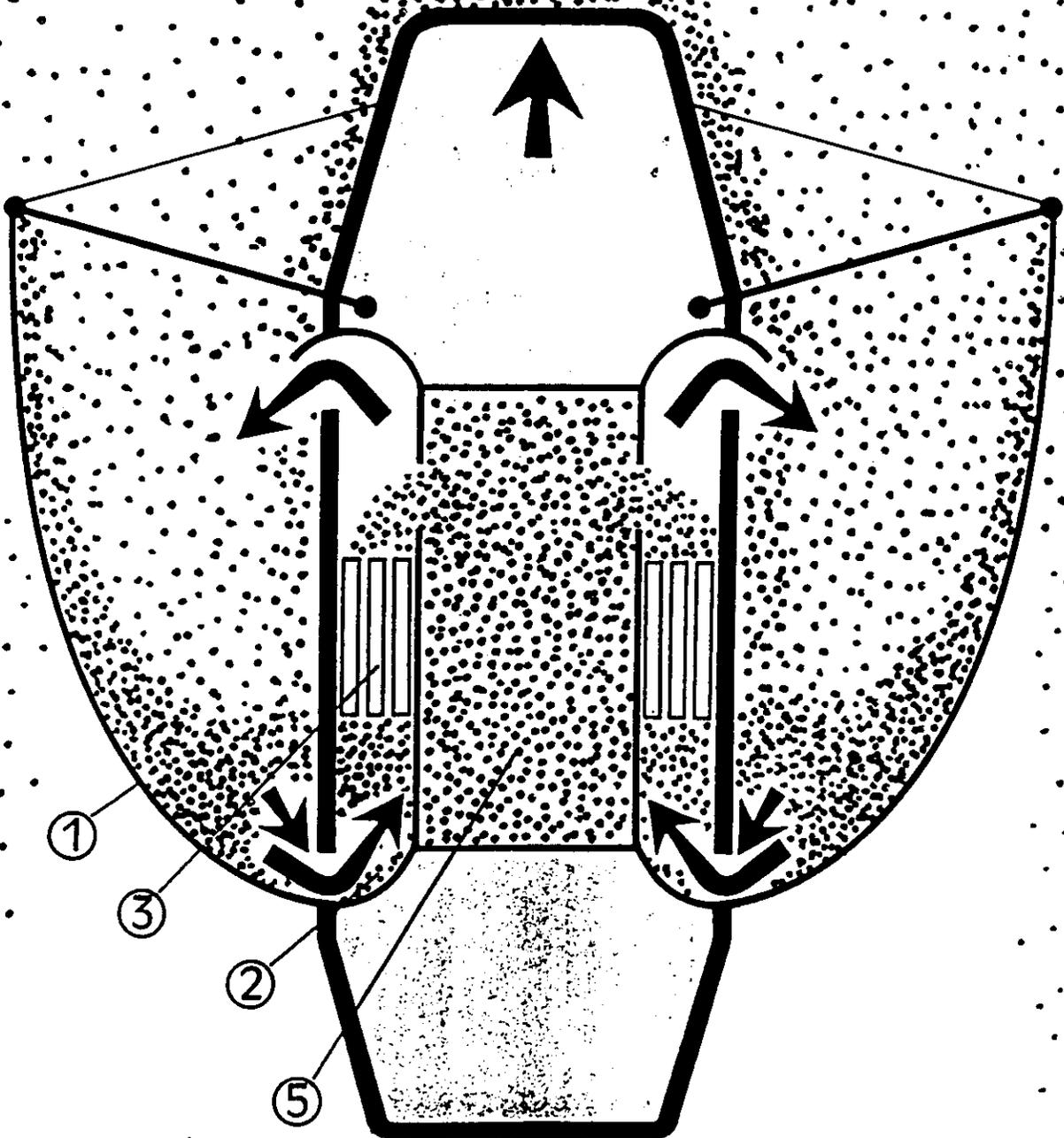
While the MacLori -concept has proved to perform in an excellent way at rough circumstances in open water a solution for recovering oil in winter from ice still remains to be developed. The work was started in 1987, when the tanker "Antonio Gramski" went aground in the Gulf of Finland. The basic ideas were tested and the work will be continued in 1988 in cooperation with the Finnish authorities. □

Customer	System/Vessel	Status
Finnish Ministry of Environment	LORI 1050 A	Del 1985
Kotka Port Authorities	LORI 1010 B	Del May 1986
Swedish Coast Guard Tv 051	Conversion of 33 m vessel 5 x 5 brush system	Del May 1986
Finnish Ministry of Environment	Newbuilding of 60 m vessel 2 x 10 brush system	Del March 1987
Neste	LORI 1010 B	Del June 1986
Finnish Ministry of Environment "Oili 4"	LORI 1900 A	Del April 1987
Swedish Coast Guard Tv 050	Conversion of 33 m vessel 2 x 5 brush system	Del May 1987
Finnish Board of Navigation, "Sektorii"	Conversion of 32.5 m vessel LORI HK 5-2.8	Del May 1987
Finnish Board of Navigation, "Oili 2"	Conversion of 24.5 m vessel LORI HK 5-2.8	Del June 1987
Finnish Board of Navigation, "Kummeli"	Conversion of 28 m vessel LORI HK 5-2.8	Del July 1987
Finnish Board of Navigation, "Oili 1"	Conversion of 24.5 m vessel LORI HK 5-2.8	Del Sep 1987
Finnish Board of Navigation, "Oili 3"	Conversion of 24.5 m vessel LORI HK 5-2.8	Del Oct 1987

FUNCTION PRINCIPLE

The oil is collected and concentrated from the water surface by booms (1) at the sides. The booms guide the oily water into open ducts (2) where rotating bristle chains

(3) are located. The oil adheres to the bristles, whereas the cleaned water flows through and out from the forward gates. The oil is removed from the bristles mechanically by means of patented cleaning



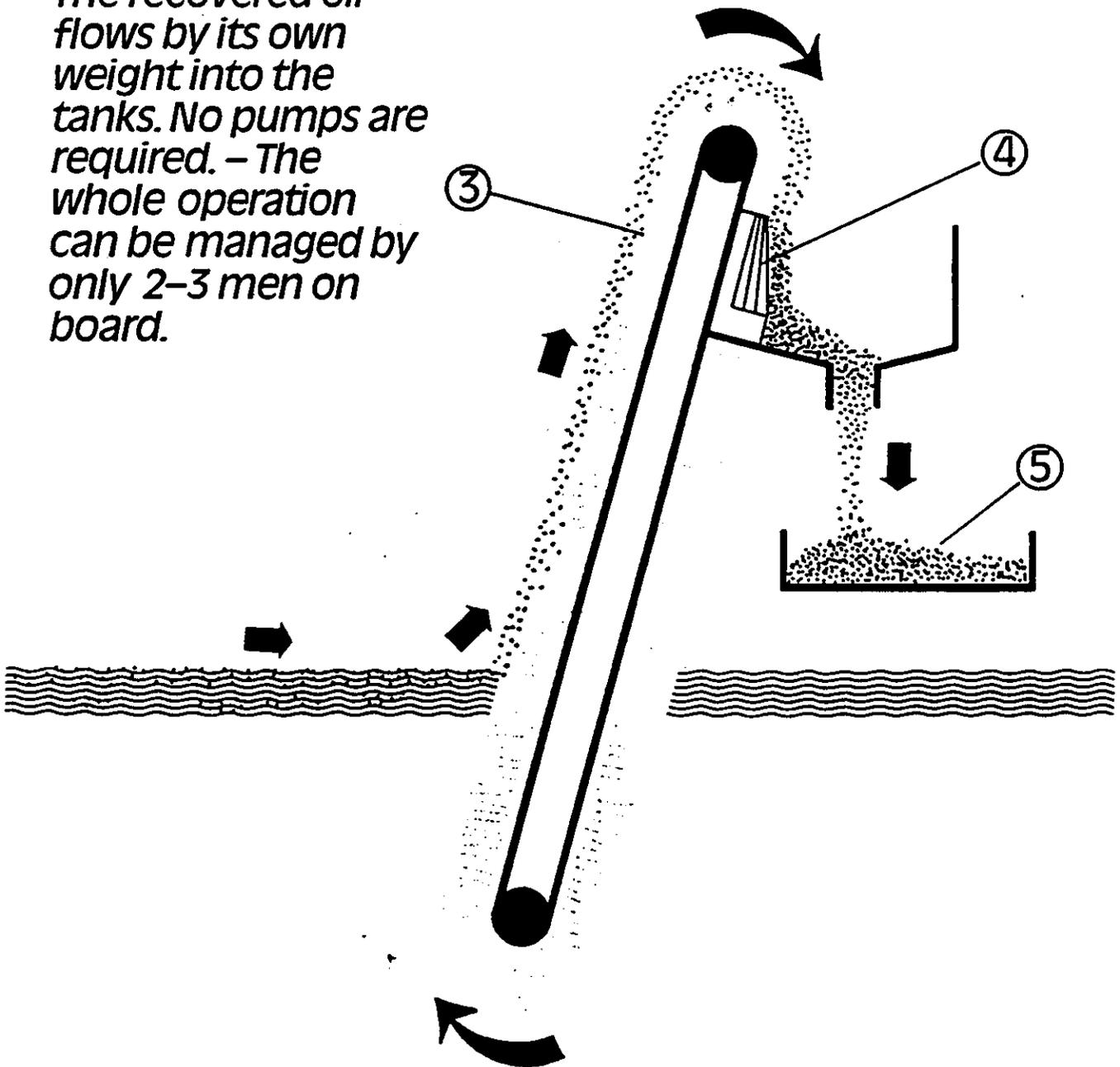
device (4) and flows down to the storage tank (5) by its own weight. The whole operation is handled by only one moving part – the bristle chain.

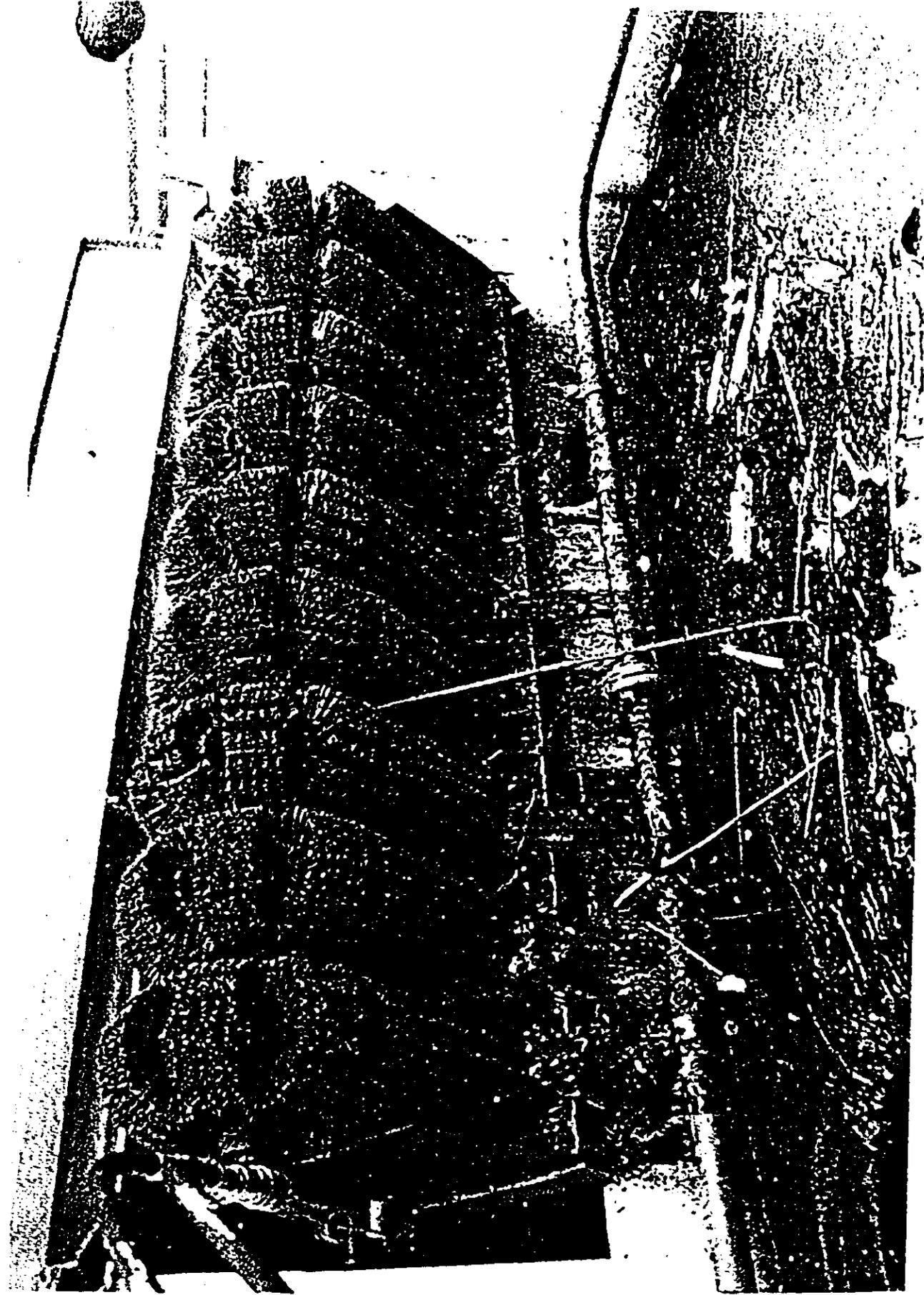
- The storage tank can be heated to facilitate the transfer of the recovered oil to a tank ship or to large floating rubber sacks.

- Wave movements do not affect the recovery capacity.

- The recovered oil flows by its own weight into the tanks. No pumps are required. – The whole operation can be managed by only 2-3 men on board.

- The unit is always ready for action. The complete equipment for oil recovery is permanently stored on board. It takes less than 10 minutes for two men to prepare the unit ready for action.





LORI brush mat cassette

Office translation of an inspection report by Finnish Ministry of Environment

ICE BOW TEST 17.3. IN LOVIISA ESTUARY

Time: 15-17.3.1988
Place: N 60° 22' 50"
E 26° 17' 40"
Weather: half clouded, weak wind from NE, temperature -5°C
Ice: 30 - 35 cm
Test set up

Ice bow dimensions:

breadth 6,4 m
length 10,6 m
weight 22 tons (est.)

The bow is fitted with a set of 10 brushes.

The bow was connected to the barge "Onas" and the system was pushed by the tug "Henric".

In the operation area ballast water was pumped in.

The position of the ice bow was not optimum for oil cleaning in 15.3. Therefore, it was readjusted for 16-17.3. tests. The adjustment was carried out by weights lifted by a car crane in Valko.

The oil used was 3 barrels of heavy fuel (FOR 180), totalling abt. 500 liters.

Testing times

Oil was poured in the sea between 1155 - 1205. Actual ice cleaning took place between 1205 - 1240, when major part of oil was recovered.

After this the test area was cleaned for an additional 1 1/2 hours to make sure that the area was cleaned as well as possible.

Some conclusions

According to a visual inspection some small spots of entrapped oil was left in the ice. This was approximately 5 % of the

poured oil. This oil will evaporate before the open water season and thereby it was not considered to cause adverse environmental consequences.

By connecting the bow with the barge "Onas" and the tug "Henric", an estimated "optimum" position for the bow was achieved.

In my opinion the oil recovery operation was successful considering that the unit was a prototype.

Observations

An effective improvement in the test setup was done by Mr Lars Lundin when he placed two hoses in the bow so that the desired spraying effect was achieved. Earlier the spraying from top with high pressure had caused the oil to escape to the sides and below so that the cleaning action was not so effective.

Two sets of brushes became inoperative during the tests. This was probably caused by too large a speed in ice. According to Lundin, the change of the sweeping direction of the brushes had been a major improvement as compared with tests in 15.3. Now less ice was entering the mechanisms. The bow section of the brushes was operated only part of the time due to the small amount of oil in the sea. The bow section is more effective in conditions with much oil.

Present in the tests

Lars Lundin	Lori Oy
Lauri Nordström	Safe Metall Oy
Håkan Öhman	McGregor Navire
Martti Virtanen	National Board of Waters and Environment

Matti Virtanen