# THE NARWAL II SUBMERSIBLE SYSTEM FOR SEISMIC DATA ACQUISITION UNDER THE ARCTIC ICE*†

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## Abstract

The Narwal II Seismic System consists of a Hercules transportable three man submarine, a set of Binary Gain floating point seismic instruments, an hydraulically operated implosive source and a 3,000 foot 12 channel streamer. The advantages of such a system are its greatly enhanced productivity over an on-ice system, the very good chance that such a quiet vehicle will produce better quality data and its ability to be run on a regular grid as opposed to marine surveys which may be conducted only where the ice conditions will allow. The design of system components has been completed and the actual construction of the vehicle and its sub-systems commenced. An ancillary navigation system using extra low frequency radio signals and caesium beam clocks will be used to position the lines of data within ± 50 feet absolute. The first production surveys will commence in March of 1976 within the Sverdrup Basin. It is expected that up to 3,000 miles of such data will be collected in the initial year and increasing amounts in successive years as experience is gained. Some experimental work will be carried out in the first year to examine the problems associated with working under the polar ice pack with a view to extending the capability of the submarine to the northern side of the Sverdrup Basin and to the Beaufort Sea. The submarine may also be used as a vehicle to carry out engineering studies such as side scan sonar and sub-bottom profiling for those interested in laying pipelines or examining off-shore drill sites.

Planning for somewhat larger and longer range submersibles is under way with the rough water areas of the world in mind.


## Introduction

The offshore areas of the Canadian Arctic Islands are in the initial phase of a major exploration program. The geology is attractive. Namely, strong negative tectonics, large down-dropped grabens, and the promise of large structures, in which the reservoir beds may be less deformed than those underlying some onshore Arctic island areas. There is potential for giant sized hydrocarbon fields. The offshore Federal permits are mature to the point where offshore drilling will be required within a few years. The long lead times and huge capital costs required for building drilling vehicles necessitate the early development of a large number of potential drillsites.

Consequently, the oil industry is faced with the acquisition of between 10 and 20,000 miles of seismic control in say, the next 3 or 4 seasons.

Ice conditions prohibit normal marine seismic operations from large parts of the offshore inter-island areas. Conventional land seismic methods, or variations thereof are being used to acquire coverage on the ice. Productivity is limited by the short season, ice conditions and the restricted rate of advance of tracked vehicles over the ice — an average speed of 2 - 4 mph has been used for the FN 60's to be used for the submarine project.

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Arctic Canadian Continental Shelf Exploration System or ACCESS have been developing a submersible seismic system over the past two years. The award of a contract to ACCESS for seismic data acquisition by the Polar Continental Shelf Project solidified their intent to proceed with the construction of Narwal II. This system comprises a quiet, hydrodynamically clean, Hercules transportable, 3 man submarine, a precise navigation system, an implosive, no-bubble energy source, modern digital instrumentation and a 12 group ½ mile streamer. This system is designed to provide 1200% productivity CDP coverage under continuous tow at 5-5½ knots.

It is proposed to operate at a depth of 80-100 feet below the ice, and in water depths of at least 200 feet.

The advantages of the submersible system are:

1. The potential productivity of a normal marine system, limited only by the mobility of the surface support and positioning systems. 3,000 to 6,000 miles of data per season are expected.
2. An extremely low noise level recording system.
3. A low energy and downward directive source, well removed from the ice, that should eliminate or at least minimize horizontally propagated ice noise.
4. The advantages of massive recording for high fidelity or "bright spot processing".
5. A regular and orderly control grid unaffected by surface ice conditions.

## Submersible — Narwal II

The submersible Narwal II has been designed by and will be built under the supervision of Bill Rand, Technical vice-president of ACCESS. Mr. Rand has 30 years experience as a submariner and was project director of the Gulf Stream Drift Mission, during which the submarine "Ben Franklin" drifted 1,600 miles from West Palm Beach, Florida to Nova Scotia, staying submerged over a 30 day period. The other technical members of the present ACCESS staff were also involved with the Ben Franklin as submariners and design and construction technicians. Energy source construction, subsystems finalization and preparation for sea trials are being carried out at West Palm Beach. Pressure hull and fibre glass fairing construction will be done at Maple, Ontario. Ice surface operation and seismic data acquisition and processing responsibilities are Calgary based under the direct supervision of the authors of this paper.

The vehicle has been designed specifically for seismic work under the Arctic ice. However, sufficient flexibility has been built in, so that upon the completion of a season's work the submersible can be used for such things as pipeline route studies with only slight modification.

The Narwal II is shown in Figure 1 in an artist's conception of it's under the ice refurbishing position. The cylindrical trunk has been lowered down a 42" hole augered through the ice, hydraulically locked at the hatch area of the sub, pumped out and a direct connection made thereby to the service module on the ice surface. The characteristics of the Narwal II are as follows:

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|---|---|
| LENGTH | 45 feet |
| BEAM | 8 feet |
| DISPLACEMENT | 57,669 pounds |
| AIRLIFT WEIGHT | 41,429 pounds |
| SPEED | 5.5 knots |
| RANGE | 111.5 nautical miles |
| RESERVE | 15.0 nautical miles |
| MAX. OPERATIVE DEPTH | 1,000 feet of sea water |
| ENDURANCE | 90 man days |
| CREW | 3 men |

It has been designed with a fibreglass propeller to minimize electrical noise. The prop has a large diameter and rotates at 60 rpm with only 15 h.p. applied to it.

## Safety

In general terms the 90 man day life support system provides a large excess safety margin over the time required to resolve any of the foreseeable emergencies.

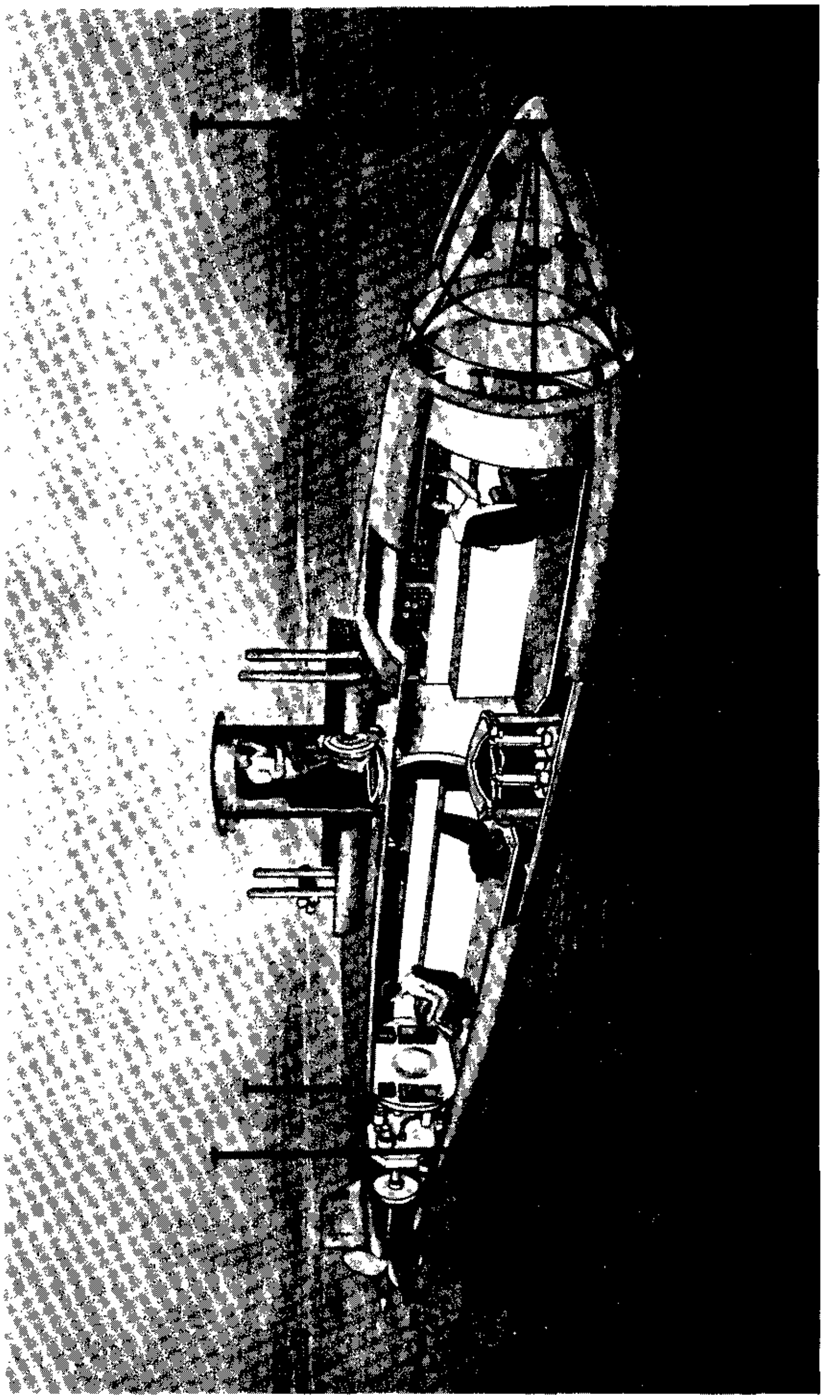

Fig. 1. Artist's conception of submarine docking position.

In the event of an emergency, the vehicle position is known to within a few hundreds of feet at all times by acoustic pin-pointing of the energy source location. The two surface vehicles are from 0 to 30 miles distant and within 0 to 10 hours from the sub's position at any time during each traverse. A complete heliportable service module system is maintained at the base camp and could go quickly to the area where the sub was stopped, if an emergency developed.

To the surface crew, an emergency situation exists if the seismic source stops firing. This may or may not be true on the submarine itself. For example, any adjustment to the seismic system necessitating shutting the source down would not constitute an emergency. In any event, when the source stops the sub is manoeuvred to rest against the underside of the ice and a surface unit sent to its location. Once the vehicle has arrived within the acoustic fix area, a circle of 2,000 feet diameter, an underwater telephone is lowered through a hole in the ice and voice contact made with the sub crew. The steps required in dealing with the emergency are then worked out between the surface and submarine crew.

If the problem is something that can be resolved on board then the surface crew would stand by until this had been achieved. If it is a problem that requires outside assistance then a hole would be augered near the submarine. The sub would be positioned so that the cylinder could lock on to the hatch, either by using its own power or, if necessary, be put into position by a team of divers.

The main hazards to be anticipated are fire on board, flooding or hull rupture.

FIRE: The sub is equipped with an auxiliary bib oxygen system which the crew would immediately put on as soon as the warning system indicated fire. The main oxygen supply is cut off to starve the fire and standard fire fighting procedures can then be used.

FLOODING: The hull is sealed completely except for the shaft area and although there is an inflatable collar on the inside of the shaft entry to the hull, leakage might still develop. There are salt water warning systems in the bilges and a hatch by which the after section of the sub can be inspected. Should flooding develop the submarine is brought up to the bottom of the ice by blowing tanks or if necessary dropping shot ballast. The crew will pressurize the after compartment to equalize with sea water pressure at that level and effect repairs.

HULL RUPTURE: The most serious of submersible accidents are related to hull rupture due to exceeding their rated depths.

The Narwal will be operating approximately 100 feet below sea level, some 900 feet above its rated depth and there is no particular reason to expect any situations to arise where hull rupture is imminent. Despite this very remote possibility, should the sub start down, there are some 5,000 lbs. of shot ballast built into the keel section of the submarine which can be released by the pull of a lever at the pilot's station. Sufficient compressed air is available to blow all ballast tanks at the maximum rated depths. With an additional 5,000 lbs. buoyancy a sub of this size will rise immediately to the under side of the ice.

If all attempts to resolve submarine problems fail and it becomes necessary for the crew to abandon, then the central section has been designed so it can be pressurized as a lock out chamber and the energy source removed from the hull; the crew can then don scuba gear and exit the hull through this port.

### O.M.I. Arctic Navigation System

The primary difficulties encountered in precise navigation of a submerged submarine are the restraints imposed by the sea water column on electromagnetic signal propagations. Because of the high levels of attenuation, only the very low frequencies can be used. Frequencies on the order of 9-10 KHz in standard sea water are attenuated about 1db per foot. In air they are attenuated about 4db in 620 miles i.e. per 1000 KM. With the transmitter not too distant an 86db system would permit the submarine to operate in excess of 50 feet in standard sea water. Two additional considerations contribute to the possibility of operating to depths of 100 feet. Firstly, the sea water under the ice to a depth of 150 feet is not standard but considerably less saline, resulting in less attenuation, and secondly, with the very high stability of both the transmitters and the receivers because they are each locked to atomic standards, a very narrow bandwidth, such as 10 Hertz, can be used and receiving system gains in excess of 120db can be realized.

A second restraint imposed by the sea water column is that of the difference in propagation velocity and therefore wavelength of the in-water signal from that in air. This puts a requirement on the navigation system of correcting out the propagation changes in the vertical sea water column above the antenna with each computation of position. In the Arctic System described herein, it is proposed to utilize an upward looking high resolution sonar to continuously monitor the sea column length and provide the system with a suitable correction factor for use not only by the real time displays, but also in the data processing system.

The navigation system is a time based system using rated caesium beam atomic clock standards. A time differential technique using the low frequency transmitting stations, such as Omega, is employed for gross positioning. At a master stationary position on the ice a minimum of two different low frequency transmitters are monitored. As long as these transmitting stations are atomic clock controlled then variations in times of reception of the signals from these stations will be due to variations in the propagation paths of the transmitted signal for whatever reasons. Since it can be safely assumed that within the modest distances of approximately 50 miles to the other receiving points then the same propagation path errors will be common to all the local caesium clock controlled receivers. The time differences of the same event being received by the slave stations in relation to the master station therefore represent ranges when converted to distance using the speed of light. Using 4 such master and slave units set outside a 40 mile by 40 mile area, then the control for the area within is established. The vehicular atomic clock receivers are rubidium frequency standard with a short term stability and lesser expense and size as compared to the caesium clock receivers which have long term stability and greater size. Because of the short term characteristic of the rubidium clocks they must be up-dated against one of the caesium clocks periodically. A 5th such clock will be installed in the helicopter used to transport the crew back and forth between the submarine and the base camp or the service equipment in the case of an emergency or a long tracked vehicle move. Since the helicopter will be at the exit or entry point of the submarine at each crew change, that is, within a 12 hour period, then the submarine clock can be re-rated at this time along with the rubidium clocks in the tracked vehicles. The travelling master clock will also be used to tie the positioning system on the surface of the ice to absolute geodetic points at the nearest land fall.

On board the submarine and other moving vehicles, the same far distant, low frequency signals will be received and corrected in the same fashion as those on the surface of the ice at the master stations. The crew will have available to them a plot of their progress made along track and their position left or right of track. The sensitivity of the navigation system is one nano-second or .9 feet, however propagation path unknowns will increase this noise envelope to $\pm$ 3 feet over the surface of the ice and probably $\pm$ 50 feet under the surface of the ice.

## Seismic Energy Source

The Seismovac Monopulse pneumatic rebound Seismic Source has been described by Goldberg (1972). Figure 2 is a diagram from this paper.

The principle of operation is as follows:

A cylinder contains a sliding piston which is initially positioned at the open end of the housing. A partial vacuum is created inside the cylinder, and a clamp holds the piston in place against the external hydrostatic pressure. At the firing instant the clamp is released and the pressure differential accelerates the piston inward.

As the piston accelerates inward, its velocity increases and the internal pressure rapidly increases as the gas inside the cylinder is compressed. At some point this com-

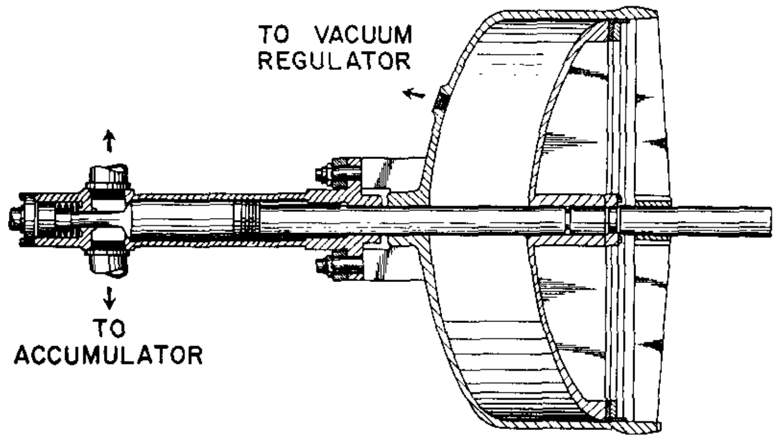


**Fig. 2.** Seismovac Monopulse source (Goldberg, 1972).

pression causes the internal pressure to equal the external pressure, and the piston velocity is at a maximum. Due to inertia the piston compresses the gas to well over the external pressure, and generates a positive pulse of acoustic pressure many times greater than the initial negative wave. The large internal pressure causes the piston to rebound as if driven by a spring. A second downstroke is prevented by restraining the motion of the piston. The signature of the signal is considered to be stable, and is relatively free of following pulses. The frequency spectrum is all in the useful seismic range, between 10 and 100 Hz. The output and frequency content can be varied by changing the initial pressure differential. A sample section from the Gulf of Mexico is shown on Figure 3.

These data were obtained with one 24″ source at a depth of 15 ft. There is usable information to below 2.0 seconds.

The source to be mounted in the submarine will be 36″ in diameter, and the increased operating depth to 100 ft with the resultant larger pressure differentials, should result in an effective seismic source.

The firing cycle is 12 seconds which will allow 1200% coverage at 5 knots.

### Seismic Instrumentation

A set of DFS V digital floating point binary gain instruments will be mounted on the rear bulkhead of the cabin. This set is essentially a miniaturized version of the DFS IV's, with the important advantages of less bulk and weight, and lower power requirements. Twin tape decks will ensure continuous data acquisition. A flatbed single channel sequential recorder will complete the onboard instrumentation. The system has been ordered for delivery to coincide with the sea trials to commence in the fall or early winter of 1975.

### The Seismic Streamer

The streamer comprises:

five 50 metre isolation sections

twelve 50 metre live sections with acceleration cancelling hydrophones.

Depth recording and waterbreak sections.

This will give a maximum source-detector distance of ½ mile. The streamer has an O.D. of 1.1″ and is connected to the submarine through the propeller drive shaft via a specially designed plug equipped with an hydraulic jettisoning device in case of an emergency.

The streamer will be initially balanced with slight positive buoyancy so that when the sub is at rest the streamer will rise to the bottom of the ice. It is not envisioned that it will be touched during the survey except to replace dead sections. This will be done by removing the complete streamer,

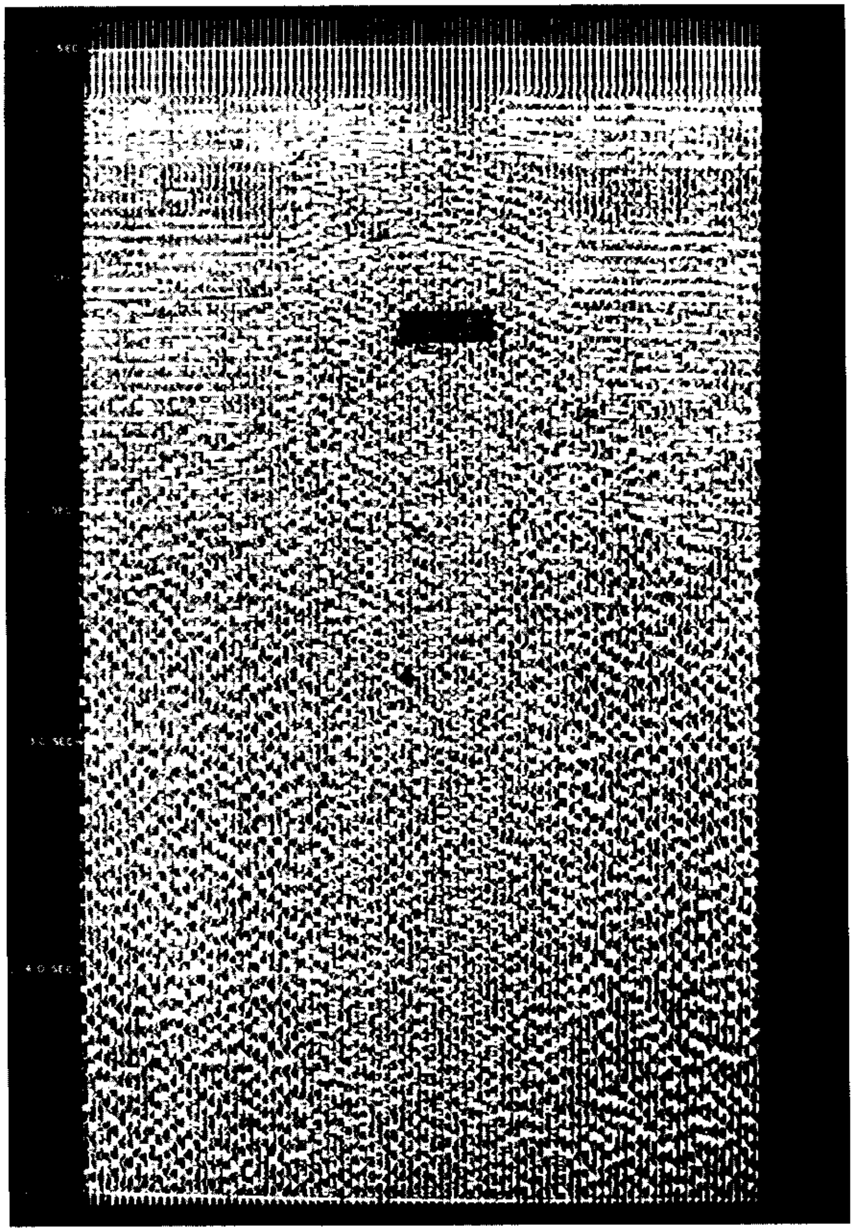

**Fig. 3.** Seismovac Monopulse section from the Gulf of Mexico.

replacing it with the spare and repairing the faulty streamer at camp.

### Surface Support System

There are three surface support service modules that are fully transportable by either helicopter or tracked vehicle. One of the service modules in the field and the spare in camp have large diesel generators to be used for recharging the batteries at the end of each work cycle, otherwise the systems are identical. They are complete with the ice augers, a means of putting the cylinder through the ice and latching onto the submarine, mooring devices, underwater communication equipment and divers. The spare system remains at base camp except for emergencies, breakdown of one of the field modules or where a helicopter move is dictated by the grid pattern.

### 1975 Preparation

A pneumatic rebound source will be taken to the Arctic in 1975 for simulation tests, with both source and hydrophones at operational depths under the ice. Water current measurements, tests of navigation and positioning equipment will also be carried out.

The construction of the submarine is slated to begin in early 1975. The submersible will be trucked from its place of construction at Dominion Welding & Engineering, Maple, Ontario to West Palm Beach, Florida, some time in the early fall of 1975.

The sea trials and crew training will commence immediately after the subsystems have been installed with a view to undertaking actual seismic system tests in November or December of 1975. Arrangements have been made to reoccupy some marine seismic lines in northern offshore Florida. At that point in time a direct comparison of data quality will be available. Following this stage it is planned that the submarine and supporting personnel will move to the western end of Great Slave Lake to finalize the under ice operations. Production surveying is expected to begin about April 1st, 1976. The submarine will be transported to a prepared air strip and camp at the location of survey commencement. It will then be lowered into the water through a hole previously cut in the ice. The batteries will be installed and the survey commenced.

### Method of Operation

The normal cycle for the submarine will be 9 hours of traversing, one hour of crew change, another 9 hours of traversing and 12 hours of battery charge. During this 31 hour cycle some 100 statute miles of seismic data will be acquired.

The basic and most efficient survey traverse for the submarine is 40 miles along dip and 10 miles along strike as indicated in Figure 4. This can of course be modified to a 45 x 5, a 35 x 15 or any similar variation as required. The suggestion of a basic 5 x 8 mile survey grid has come up and obviously this fits very well with the 40 x 10 mile traverse.

With the submarine moored to the surface module through the cylindrical trunk, the batteries are charged, the crew changed and tapes, supplies, scrubbers etc. replenished. Meanwhile the second service module is positioned at the exit point, a 42″ hole is augered through the ice and the acoustic and underwater telephone systems are emplaced. The sub then commences its traverse and the entry point module remains on location until it is obvious that the submarine is within the reach of the exit point station. The entry point service module then moves to its next location and prepares to receive the submarine back from the previous exit point.

The submarine in Figure 1 is shown moored under the surface of the ice. The system of mooring is as follows; when the sub gets within underwater telephone range of the exit hole it is instructed to position itself immediately down current from the exit hole. A small hole is augered, a precise distance up current from the exit hole and a mast lowered. The submarine pilot opens the clam shell at the forward end and the hatch on the top side which puts the ice snubbers in place and exposes the midship transverse thruster. By opening the forward clam, the fore and aft, vertical and lateral thrusters at the bow are exposed as well as an arm with a clamp attached. The operator also has lights forward to illumi-

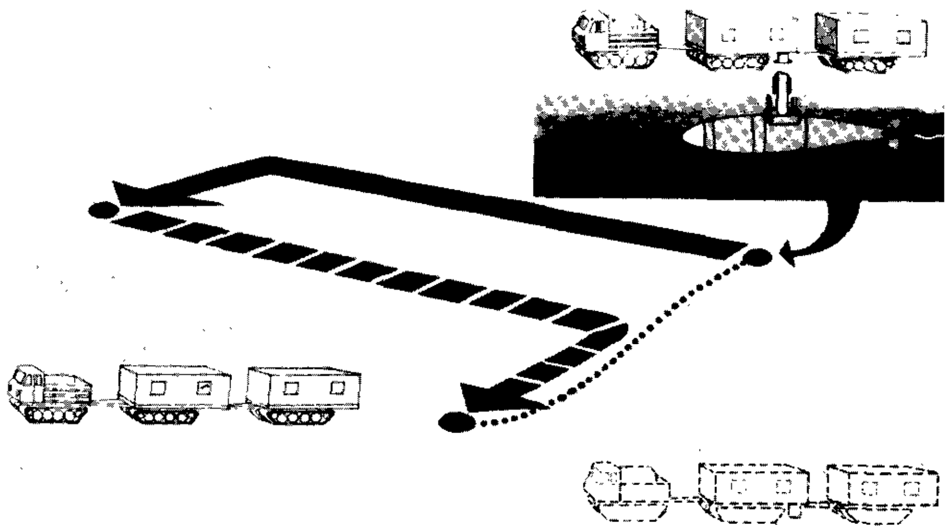

Fig. 4. Basic survey traverse plan.

nate the last part of his docking procedure. The submarine then proceeds up current on its thusters until the mast is grabbed and then the midships transverse thruster is used to slowly position the boat with its hatch precisely under the cylinder that has been lowered from above the ice. Once the hydraulic seal has been made, the water is pumped from the cylinder and access to the submarine achieved. The two other masts aft are to hold the submarine so that no torque is applied to the cylinder. The replacement of people, supplies and recharging of the batteries is straight forward from this point.

## Conclusions

The system described is expected to produce seismic data of at least comparable quality to that achieved by conventional means.

It has however, two big advantages:

1) High productivity
2) A regular control grid

In the first operational season sorties will be made under the ice pack in the northern part of the Sverdrup Basin to determine some of the difficulties that may be expected in this type of work. There is no reason to believe that the submarine could not be used to achieve a radial, flower petal type pattern from a series of locations on the Arctic pack. It may be possible to modify the present approach by using helicopters so that a rectangular grid could be obtained. The ramifications of success in this direction are obvious, it opens up not only the northern part of the Sverdrup Basin but also the Beaufort Sea and such other prospective areas for hydrocarbons as offshore Alaska. In addition to its under ice capabilities it may be that with present power developments such as fuel cells or small nuclear engines that the time endurance of Narwal can be increased sufficiently to make it competitive for surveying in the rough water areas of the world such as the North Sea and the North Atlantic.

In summary it is an exciting project with a very interesting future not only insofar as seismic surveying is concerned but also with regard to engineering studies as they may be related to pipeline routes or rig locations.

ACKNOWLEDGEMENT

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REFERENCE

Goldberg, S., 1972: The Seismovac Monopulse Pneumatic Rebound Seismic Source. Geophysics, 37, 174-177.