SURVEYING OFFSHORE CANADA LANDS
FOR MINERAL RESOURCE DEVELOPMENT

WORKSHOP ON OFFSHORE SURVEYS

DECEMBER 1970 (REVISED)

DEPARTMENT OF ENERGY, MINES AND RESOURCES,
OTTAWA, CANADA

SURVEYING OFFSHORE CANADA LANDS
FOR
MINERAL RESOURCE DEVELOPMENT

An Abridged Report on the Findings

of the

WORKSHOP ON OFFSHORE SURVEYS

Convened to Study

the

Technical and Legal Aspects of Surveying

for

Mineral Resource Development

on

Offshore Canada Lands

Held at the Surveys and Mapping Branch
of the Department of Energy, Mines and Resources
615 Booth Street, Ottawa, Ontario, Canada
from
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THE WORKSHOP

The workshop was organized by the Department of Energy, Mines and Resources, 588 Booth Street, Ottawa, Ontario, and was held in the Surveys and Mapping Branch, 615 Booth Street, Ottawa, Ontario.

The following participating agencies were represented at the workshop:

DEPARTMENT OF ENERGY, MINES AND RESOURCES

- Surveys and Mapping Branch
- Marine Sciences Branch
- Resource Administration Division

DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT

- Northern Economic Development Branch

DEPARTMENT OF TRANSPORT

- Marine Works Branch

CANADIAN PETROLEUM ASSOCIATION

The following agencies co-operated in the workshop:

DEPARTMENT OF NATIONAL DEFENCE

DEPARTMENT OF EXTERNAL AFFAIRS

DEPARTMENT OF FISHERIES AND FORESTRY

THE CANADIAN OVERSEAS TELECOMMUNICATION CORPORATION

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INTRODUCTION

DEVELOPMENTS LEADING TO THE WORKSHOP

EXPANSION OF OFFSHORE EXPLORATION

Oil and gas exploration activity on Canada's Continental Shelf has increased dramatically during the last decade. There is every indication that this trend will continue. It is estimated that some fifty exploratory wells will be drilled off the east coast alone during the next three years. As illustrated by the maps in this Part I, the area of the Canadian Continental Shelf is equal to about 40% of the land area of Canada and some five hundred and fifty million acres are now under exploratory permit. By the end of 1969 exploration expenditures reached eighty-five million dollars (see Figure 1), and present estimates indicate that the total will exceed one billion dollars by 1980.

SURVEYING PROBLEMS

Where rights are granted for the exploration and development of minerals or oil and gas on land, the surveys needed are comparatively simple matters and in general are adequately covered in existing Acts and Regulations. The same cannot be said for surveying at sea, although the same survey regulations apply whether on or offshore.

The technical problems involved in offshore surveying vary greatly with the distance from the shore, the shape of the coast, the depth of the water, the presence of sea ice and other factors not encountered in surveying on land. In addition the Canadian situation is unique because the Canadian shelf is much wider than that of other countries and geophysical work and exploratory drilling is being started hundreds of miles from the coast. In other countries offshore oil and gas developments have generally been much closer to shore or, as in the Gulf of Mexico, have been gradually extended seaward from oil and gas fields along the shore. These types of development permit the use of the same accurate short-range survey systems that are used on land. On the Canadian shelf work sometimes starts beyond the design-range of any currently used survey system. This leads to questions about how the surveying for mineral resource development should be done at sea and the applicability of the present survey regulations.

PRELIMINARY STUDIES

Surveying in the offshore thus poses serious technical and legal problems both for the operating oil companies and for the resource management agencies in the federal government. In an effort to deal with some of the issues involved, the Department of Energy, Mines and Resources sponsored a joint Government-Industry Meeting in Ottawa in May, 1969. Following this meeting the Canadian Petroleum Association, in June 1969, proposed to the Hon. J.J. Greene, Minister of Energy, Mines and Resources, the formation of a Task Force of senior government officials to review the Acts, Regulations and Instructions governing surveys for exploration and production and to examine their relevance and practicability in the offshore.

As a result of this proposal, a study group was formed under the chairmanship of Mr. S.G. Gamble, Director, Surveys and Mapping Branch, Department of Energy, Mines and Resources. The study group report, submitted on October 3, 1969, concluded with the following four recommendations:

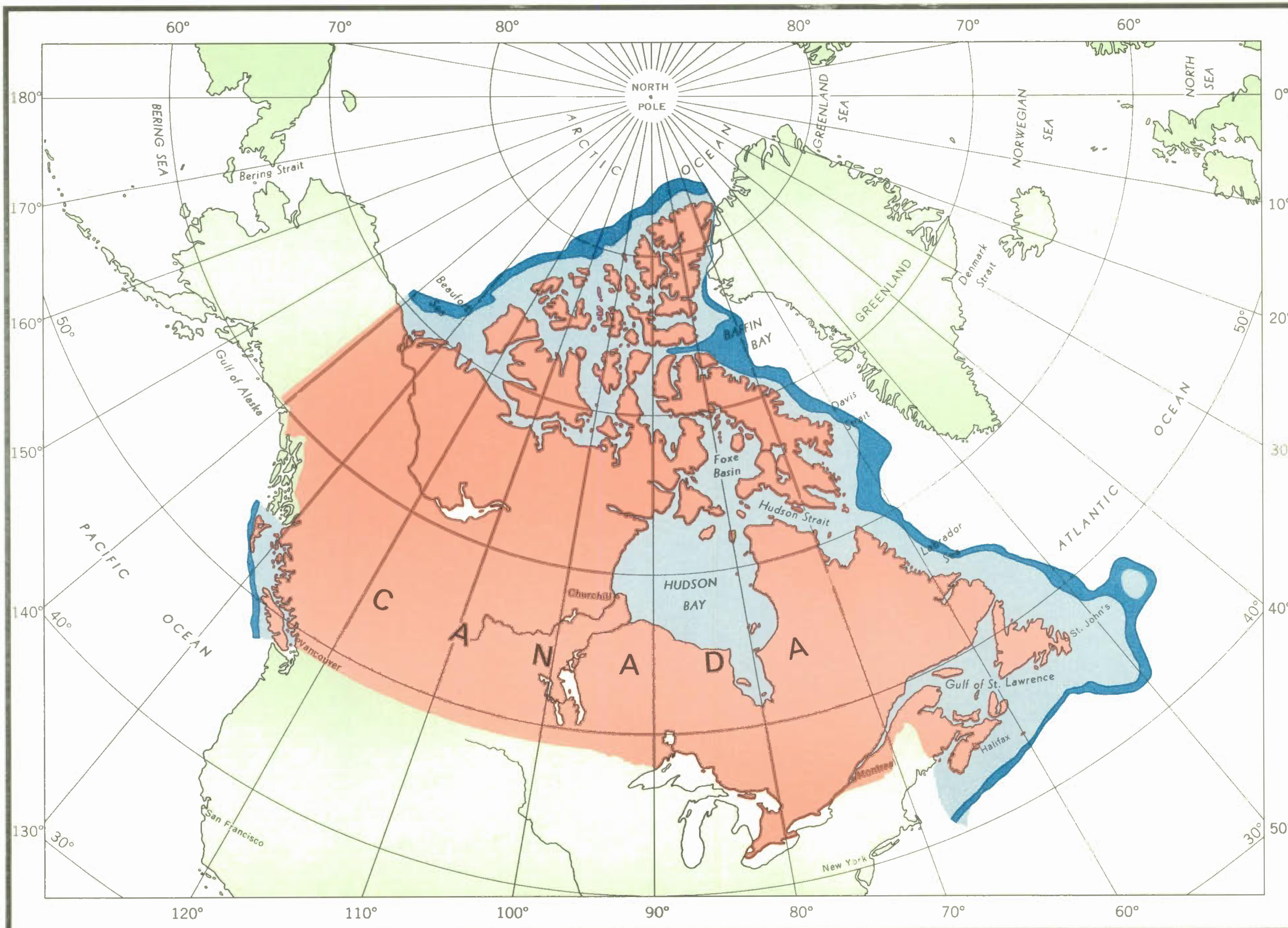
(1) That the Department of Energy, Mines and Resources initiate a study to specify the methods of positioning, or combinations of methods, which will be initially acceptable for federal administration of offshore resources. Amendments would be made in the light of research findings by appropriate agencies, both federal and other, and as new systems are developed or existing systems improved.

(2) That the Department make an assessment of the adequacy of existing geodetic control on Canada's coast, having in mind the present and the forecast levels of exploratory activity in each area, and the density and suitability of available control stations. This should be followed by the provisions of such additional control as is found to be necessary to meet the requirements for adequate shore control.

(3) That it be accepted in principle that the Federal Government be responsible for the extension of shore control seaward if this becomes essential.

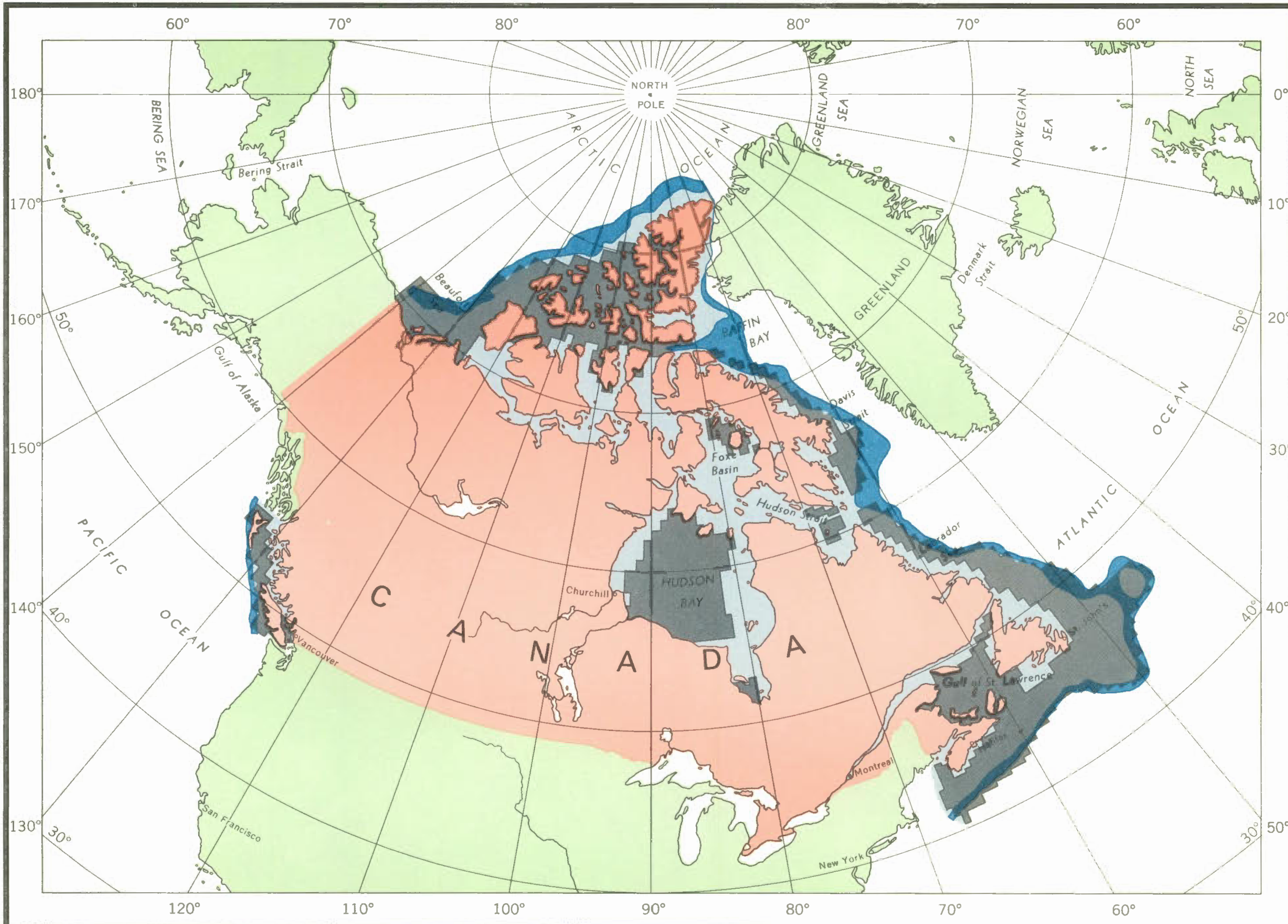
(4) That the Surveyor General together with mineral resource agencies of the Department of Energy, Mines and Resources and the Department of Indian Affairs and Northern Development review the Acts, Regulations and Instructions pertaining to offshore exploration and production, and recommend any amendment action considered advisable.

Another Government-Industry meeting was held in Calgary on October 14, 1969, at which these recommendations were discussed and at which it was decided that a joint study be made in the form of a six-week workshop on offshore surveying.



APPROXIMATE AREAS UNDER CONSIDERATION IN THIS REPORT SHOWN IN BLUE TINTS

CANADIAN OFFSHORE LANDS FOR WHICH FEDERAL OIL AND GAS EXPLORATORY PERMITS HAVE BEEN ISSUED (DEC. 1969) ARE SHOWN IN BLACK TINT



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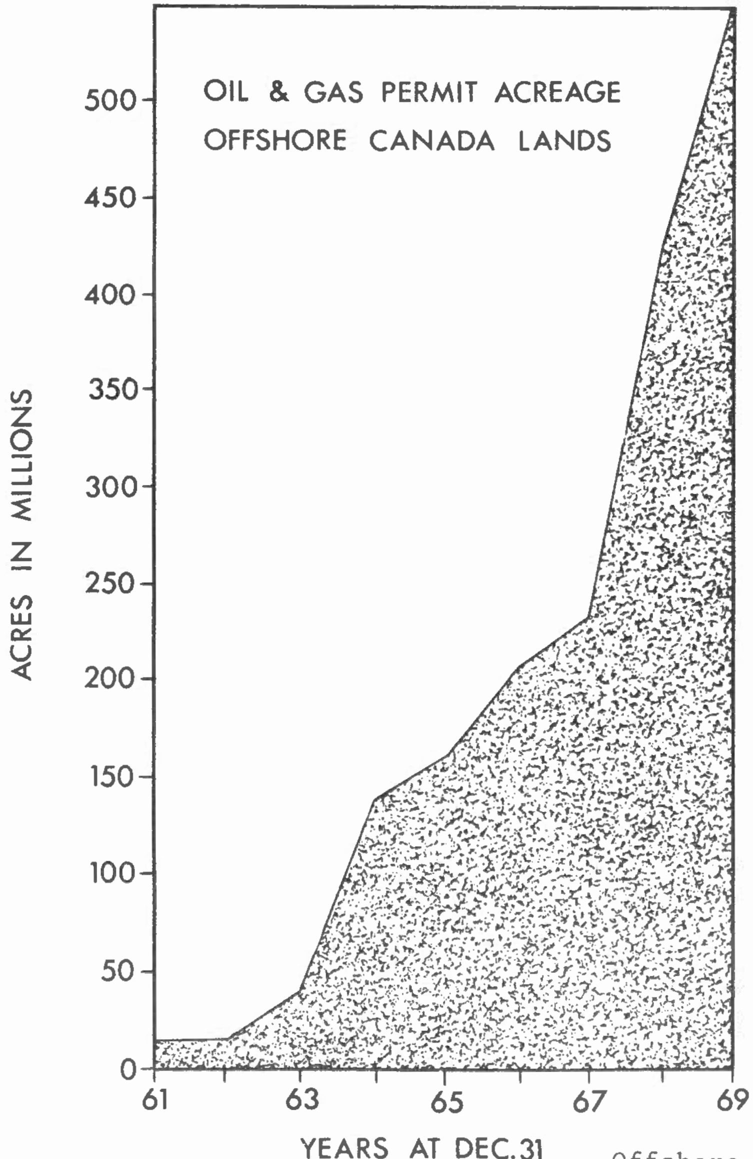

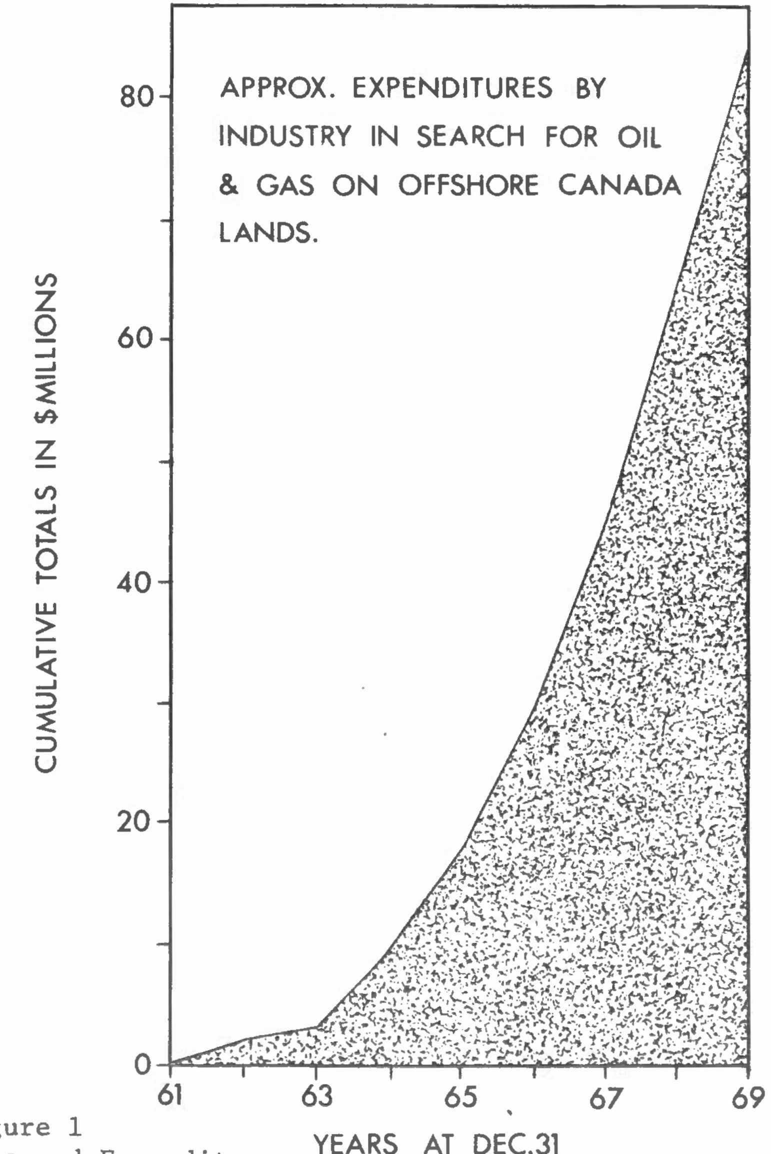

Figure 1
Offshore Permits and Expenditures

Offshore exploration activities by the oil and gas industry are directly related to the expenditures incurred. These expenditures, in turn, are directly related to the number of acres held under permit and to the number of years they have been held. The two graphs illustrate the sharp rise in both permit acreage and expenditures in recent years over all Canada Lands in the Offshore. The 550 million acres presently under permit is an area well in excess of the combined area of the three prairie provinces; and, it is expected that total expenditures on offshore Canada Lands will have passed $1 billion by 1980.

THE WORKSHOP

COMPOSITION

The Workshop was held in the Surveys and Mapping Building, Ottawa, January 12 to February 20, 1970. It was composed of representatives from the Canadian Petroleum Association; the Departments of Energy, Mines and Resources; Indian Affairs and Northern Development; and Transport. The following agencies also co-operated, the Departments of National Defence; External Affairs; and Fisheries and Forestry, and The Canadian Overseas Telecommunication Corporation (see Part 3, Appendix A for list of members and participants with qualifications and affiliations).

OBJECTIVES

The objectives were to make a thorough study of surveying systems and survey regulations for offshore mineral development and to recommend feasible and acceptable surveying systems for effective development of offshore mineral resources.

TERMS OF REFERENCE

The final terms of reference were developed within the Workshop during the first week when senior officials from the oil industry and from federal agencies concerned with the offshore spoke to the Workshop.

The Workshop determined that it should confine itself to a study of present and potential capabilities of available positioning systems for the Canadian continental shelf and margin, to consideration of the problem of monumentation or marking of offshore surveys and to a review of existing survey regulations in the light of these findings.

PROGRAM

Thirty guest lecturers spoke on a variety of related subjects. A full list of the lecturers and their subjects is contained in the detailed workshop program a copy of which is appended to this report. (See Part 3, Appendix B).

The six week program was divided into four sessions:

Session I occupied the first week and served to introduce all aspects of the problem to the workshop.

Session II occupied the next two weeks and during this period the Workshop studied position-fixing at sea. Nineteen different position-fixing systems were studied in detail. The results of this study are given in Part 3 "Offshore Positioning Systems".

Session III occupied the next two weeks and was devoted to a study of all possible devices that might be used to monument surveys at sea. In addition to studying the effectiveness of devices as monuments, the Workshop studied the effects of currents, waves, ice, corrosion and fishing operations on the devices. The results of these studies are given in Part 3 under Offshore Monumentation.

Session IV, the last week of the workshop, was spent reviewing the regulations, developing recommendations, preparing material for inclusion in the final report and establishing an editorial committee (see Appendix A).

The editorial committee prepared the first draft of the report, consolidated the subsequent comments of all Workshop members and undertook the preparation and printing of the final report.

PART 2

THE FINDINGS OF THE WORKSHOP

THE FINDINGS OF THE WORKSHOP

SUMMARY AND CONCLUSIONS

COASTAL CONTROL

Geodetic control along the coast is essential for the establishment and maintenance of an orderly system of surveys on the adjoining continental shelves.

The minimum spacing of such control should be 30 kilometres (kms) and the minimum accuracy should be third order*. However, since surveys on the shelves will be extrapolated from the existing control and errors may be magnified, a higher order of coastal control is desirable and new work should be second order if the increase in cost is not prohibitive.

Existing coastal control is adequate in all areas except along the southern shore of Hudson Bay and the coast of British Columbia.

There is also a need for a high order scientific test range for investigation of the velocity of electromagnetic surface-wave propagation over sea water and sea ice, or a combination of both. The most practical area for such a range appears to be the Gulf of St. Lawrence and the southeasterly coasts of Nova Scotia and Newfoundland out to Sable Island. An unconstrained re-adjustment of existing control networks would probably be adequate for this purpose. (For a more detailed consideration see Part 3 Coastal Control).

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* The orders of control referred to are defined in "Specifications for Control Surveys" published by the Surveys and Mapping Branch in 1961 and, briefly, are as follows:

Maximum Anticipated Errors in Adjusted Horizontal Control

First order	1 in 50,000
Second order	1 in 20,000
Third order	1 in 10,000
Fourth order	1 in 5,000

POSITIONING SYSTEMS

Positions on the continental shelves should be determined by surveyed connections to coastal control and related to the 1927 North American Datum.

For purposes of this report the continental shelves are divided into two zones, the Line of Sight Zone and the Coastal Zone. These are roughly defined as follows:

> Line of Sight Zone - The area of the shelf extending from the shore to the limit of unobstructed direct radio transmission and within which positions can be determined using microwave or optical systems.
>
> Coastal Zone - The area of the continental shelf and margin beyond the Line of Sight Zone. A problem area including the Tail of the Grand Banks and the Flemish Cap is referred to as the Remote Coastal Zone.

LINE OF SIGHT SYSTEMS. Within the Line of Sight Zone there are many commercially available survey systems that will permit fixed or floating platforms to be connected directly to coastal control. Second or even first order accuracy can be achieved in positioning fixed platforms. Within this zone many of the techniques used by surveyors on land can be used to position and check points at sea.

Beyond the Line of Sight Zone the range of some line of sight equipment can be extended by using an airborne line crossing mode of operation. This is costly and at present the extreme range appears to be about 500 kms. If further research shows that this range can be sufficiently extended the system could maintain the same high accuracy everywhere on the shelf, even in the Remote Coastal Zone.

MEDIUM AND LOW FREQUENCY ELECTRONIC RANGING SYSTEMS. There are a number of Two-Range Electromagnetic Surface Wave positioning systems now being used successfully to position ships and floating platforms on the Canadian shelves. These systems provide measured connections to shore but are generally designed for ranges of less than 600 kms, well under those needed to reach the extremities of the Remote Coastal Zone. It is possible however to boost some of these systems beyond design limits to enable them to reach these areas. They could then be used with some difficulty to determine positions. These systems are very costly both to purchase and to operate. They are virtually essential however to the exploration process in the Coastal Zone since they give continuous position fixing of the vessel in which they are installed.

The accuracy of these systems is variable dependent on the particular system, the range, and the land configuration available to give good geometry offshore. In addition the positioning accuracy depends on the assumed and actual velocities of the propagation of the wave front through the sea water surface. The Marine Sciences Branch is presently studying these velocities and hopefully can provide a means of significantly improving the positioning accuracy of these systems especially at long distances from the shore. With good geometry the radius of the standard error circle can be held theoretically to fourth order standards throughout the shelf with the exception of the Remote Coastal Zone. This accuracy can only be achieved if there is an unobstructed salt water path along the ranging lines; even intervening sea ice will seriously reduce the accuracy.

ELECTRONIC SYSTEMS FOR MARINE NAVIGATION. There are a number of electronic systems operated by the United States and by Canada as aids to marine navigation. Canadian systems such as Decca Navigator (Main Chain) and Loran A and United States systems such as Omega, Navy Navigation Satellite System and Loran C may be of varying use in offshore exploratory work. The latter two United States systems, although not under Canadian operational control, may be of real value in that they appear to be the only means available at this time to achieve fourth order accuracy in the Remote Coastal Zone at the Tail of the Grand Banks and Flemish Cap. The satellite system also provides an effective means of independently checking positions determined by two-range systems anywhere in the Coastal Zone. Loran C might serve for this purpose too in most of this Zone along the east coast where there is Loran C coverage. Both the satellite and Loran C systems are on the Mercury

Datum. The accuracy with which positions can be converted to the 1927 North American Datum is not certain but some reasonable approximation can be made by employing a trans-location technique in which a shore control station is positioned by the system. The accuracy achievable by this technique has not been sufficiently investigated but is estimated to be better than ±40 metres (m) if fixes are taken continuously for at least a day at points less than 600 kms apart.

ASTRONOMY. Astronomic observations give positions related to the actual and irregular geoid rather than to the ellipsoid of reference for the 1927 North American Datum. A positional accuracy of ±30 m relative to the geoid can be achieved for a stable instrument site but this could easily be more than a kilometer different from the 1927 North American Datum position because of the deflection of the vertical. It is possible to estimate the difference of deflection of the vertical between two points using gravity observations. It might be possible by a differential method to achieve 1927 North American Datum positions from a stable production platform to ±100 m. As yet not enough research has been done on this and it should be investigated further. It might also be possible to position a floating platform using expensive gyro-stabilizing equipment.

MONUMENTATION AT SEA

Permanent monumentation of surveys at sea, while highly desirable, is not considered practical at the present time. The cost of establishing and maintaining permanent, stable, and useful markers solely for the purpose of marking positions is considered unrealistic in terms of the present needs.

When permanent or long-life structures are erected offshore for other purposes they should be used for the period of their existence to support position markers which can serve as legal monuments when needed and can help in fixing other points in their vicinity.

CONTROL MONUMENTS. Extending accurate monumented control seaward is not considered essential at this time. The presently available medium and low frequency electronic ranging systems permit the positioning of points anywhere on the shelf directly from coastal control. Accuracies of better than ±100 m can be achieved everywhere on the shelf except in the Remote Coastal Zone where this rises to ±250 m. This accuracy is considered adequate for exploratory surveys. Research into electronic surface wave propagation may reduce these error figures. The presently available United States Navy Satellite System can also give positions of fixed or semi-submersible platforms to about ±40 m anywhere on the shelf.

In general, it appears more reasonable and practical to accelerate our investigation of surface wave propagation velocity with the goal of improving the accuracy of available positioning systems rather than to extend accurate monumented control seaward.

MONUMENTATION OF OIL AND GAS SURVEYS. It is impractical to establish permanent markers at sea for surveying conducted in the exploratory (or permit) stage. At this time monumentation of shore stations involved is considered adequate to enable the operator to return to points fixed by the positioning.

Permanent markers at sea for marine geophysical operations are not essential. In the case of the expendable exploratory wells presently being drilled in the Canadian Offshore, where the seafloor is usually left without obstruction upon the abandonment of the well, there are no practical or reliable methods currently available to establish permanent bottom markers at the well site, desirable though they may be. In the case of exploratory wells that are suspended for whatever reason, the well equipment that projects above the seafloor is itself a permanent marker during the period of suspension at least.

At the production (or lease) stage however the legal location of producing wells becomes critical and monumentation is considered essential. But at this time substantial structures associated with production have to be erected. These also have to be maintained and protected for the productive life of the wells and have a design life of some twenty years. At the present stage of technology these structures are fixed to the bottom and have decks that project well above the ocean surface. They thus provide an ideal base for legal monumentation. Future developments undoubtedly will permit underwater completions. At that time consideration will have to be given to monumentation of legal surveys for such operations.

MONUMENTATION OF ADMINISTRATIVE AND JURISDICTIONAL BOUNDARIES. If these boundaries are defined exactly in terms of geographical coordinates on the same datum as the system used to define rights within the boundaries, the need for monumentation becomes much less critical. It would then be possible to control and police development close to the boundary by using positioning systems presently available and by requiring that development be located no closer to the boundary than the expected inaccuracy of the positioning system. In critical cases a developer may use a more accurate positioning system at greater costs to exploit resources close to the boundary. In the extreme case it would be possible to have sections of the boundary permanently marked but this would be very expensive.

CANADA OIL AND GAS LAND REGULATIONS

The survey provisions of these regulations were set up for land and were designed specifically to defer costly legal surveys until production was achieved. The same philosophy is considered equally valid for the offshore. It is only at the production stage, when a well starts to produce a valuable product, that a legal survey is required to determine beyond doubt the ownership of rights in the production.

During the exploratory stage, the onus is on the permittee to locate his exploratory work to the accuracy he deems necessary to protect his interests, keeping in mind that ultimately a legal survey will determine the positions of any producing wells.

It is important therefore that a permittee know at all stages the exact requirements for a legal survey. The Surveyor General's specifications for such surveys should be published without delay. These become the yardstick against which the permittee can judge all his exploratory positioning systems. It should be noted however that a legal survey is not required to be the most accurate survey but it is legally definitive.

One minor change in principle is considered necessary in the case of abandoned or suspended exploratory wells offshore. It is recognized that it might become necessary to return to an abandoned well and that it is always necessary to return to a suspended well. To ensure this capability it is essential to have a documented record of the positioning of the abandoned or suspended well and to have this reviewed to ensure that the positioning could be duplicated to recover the well should the need arise. This would not constitute a legal survey in terms of the regulations.

Further detailed conclusions about specific sections in these regulations are listed in the Regulation Review in this report.

SURVEYOR GENERAL'S SPECIFICATIONS FOR OFFSHORE LEGAL SURVEYS

The present instructions for Territorial Oil and Gas Land Surveys need to be modified to provide for surveys in the offshore. In reviewing these instructions it was concluded that consideration should be given to increasing the accuracy specifications for offshore surveys because these will be extending outward from control with little or no means of distributing the errors inherent in the control, or of controlling the errors in the positioning systems being used.

At this time it would be feasible to require that coastal control used be third order or better everywhere except on the west coast where the present control is of less than fourth order accuracy.

The present instructions require that the minimum accuracy of connections to control be fourth order. This order is just attainable throughout the shelf at the present time. If research into the velocity of propagation of electromagnetic surface waves shows that significantly better accuracies can be achieved, consideration should be given to upgrading the minimum required accuracy.

The present requirement, that all connections to control on land be independently checked to indicate the quality of the survey and to allow adjustment of residual discrepancies, is equally or more important at sea.

Since no development well has been drilled in Offshore Canada Lands there has not, as yet, been a legal survey at sea under the Canada Oil and Gas Land Regulations. This appears to be an appropriate time to introduce the metric system and to adopt the Universal Transverse Mercator Co-ordinate System. The latter is already used for federal mapping on land and by the Canadian Hydrographic Service for its offshore surveys.

CANADA MINING REGULATIONS

Priority dictated that the Workshop devote most of its attention to surveys for oil and gas development offshore. It did however review briefly the submerged claim staking procedures and resulting survey requirements contained in the Canada Mining Regulations. It was concluded that these were unworkable in the offshore for the orderly development of offshore minerals.

THE DOMINION LAND SURVEYOR

The Workshop was asked by the Canadian Petroleum Association to consider the following questions:

1(a) Where are competent Dominion Land Surveyors to come from in sufficient numbers?

(b) Should a recommendation go to the Board of Examiners for Dominion Land Surveyors that a special breed of Marine D.L.S. be created to handle offshore surveys?

(c) Should the D.L.S. Syllabus include examinations in offshore positioning and geodesy?

2 Should the D.L.S. be empowered to determine what constitutes acceptable control points for legal surveys?

The Workshop considered and answered these questions as follows:

1(a) It seems reasonable to assume that competent surveyors will develop in response to industry's demand for service. These surveyors could come from two sources, from the ranks of existing D.L.S.'s who will have to gain experience in offshore surveys and from experienced offshore surveyors who will have to acquire the necessary legal survey knowledge. In the meantime consideration should be given to amending Section 10 of the Canada Oil and Gas Land Regulations to read:

10. For the purposes of these Regulations, no person other than a Dominion Land Surveyor, or, in the case of offshore legal surveys, any other surveyor authorized by the Surveyor General, shall make a legal survey of Canada Lands.

(b) The Workshop did not have time to study all the implications of creating a new breed of Marine D.L.S., but felt that this deserved very careful consideration. It concluded that the D.L.S. Board of Examiners should study this problem jointly with the Dominion Hydrographer.

(c) The Workshop agreed that the D.L.S. syllabus should definitely include examinations in offshore positioning and geodesy.

2 The Workshop felt that the authority for final determination of acceptability of control points for legal surveys must be centralized. This authority cannot therefore be passed to the individual surveyor.

ADVANCING TECHNOLOGY

The technology of offshore surveying and undersea resource development is advancing very quickly. The rapidly increasing pace of oil and gas exploration on the Canadian continental shelf is such that new techniques are constantly being applied. It is impossible to predict with certainty what techniques will be used to actually produce undersea wells when oil is found. This will depend largely on the location of each discovery with particular reference to water depth and ice conditions. The legal survey of development wells is of necessity affected by the production technique since the production structure must carry the legal monumentation. To cope with this constantly evolving technology it is essential to re-evaluate periodically the assumptions and conclusions of this Workshop.

RECOMMENDATIONS

The Workshop prepared specific recommendations dealing with the following:

COASTAL CONTROL

1. Accelerating the assembly of a comprehensive control file, classified as to order, of all available control points on the coast whenever they are judged to be of third order or better; and,
   - (a) second order control at 30 km spacing along the southern shore of Hudson Bay,
   - (b) an unconstrained re-adjustment of geodetic nets around the Gulf of St. Lawrence for scientific purposes,
   - (c) the upgrading of control on the west coasts of Vancouver and the Queen Charlotte Islands, preferably to second order standards.

TECHNICAL INVESTIGATIONS

2. The maximum range of Aerodist.
3. The Theoretical capability of determining 1927 North American Datum positions from astronomic observations by correcting for plumb line deflection using gravity contours.
4. The accuracy of the U.S. Navy Navigation Satellite system in a trans-location mode for positioning fixed platforms at sea.
5. The accuracy of Loran C used in a precision two range mode.
6. Further investigations into the velocity of electromagnetic surface wave propagation including areas of ice coverage, to improve the accuracy of long range electronic positioning systems.

ADMINISTRATION

7. Administrative and jurisdictional boundaries being defined exactly in terms of Latitude and Longitude on the 1927 North American Datum when these boundaries are established in the offshore.

8. Amending the Canada Oil and Gas Land Regulations to provide specifically for surveys of wells in the offshore.

9. Submerged staking procedures under the Canada Mining Regulations being replaced by a geographically defined grid system for defining terminable grants on the Canadian shelf.

10. Specifications for offshore legal surveys:

(a) Coastal control to be at least third order, but higher order control to be used if available and feasible.

(b) Survey connections to control to be made to at least fourth order accuracy but a higher order to be required if this becomes practical; or, a lower order to be permitted in special cases where survey technology and equipment cannot meet such requirements.

(c) All connections to control to be independently checked as required on land.

(d) Survey dimensions to be expressed in metres and plane coordinates to be on the Universal Transverse Mercator System.

11. (a) The availability of competent Dominion Land Surveyors to undertake the required offshore legal surveys.

(b) Additions to the syllabus for examinations for Dominion Land Surveyors on subjects covering offshore positioning and geodesy.

(c) Special qualification for Marine Legal Surveyors.

ANNUAL REVIEW

12. An annual review to re-evaluate the assumptions and conclusions of the Workshop in the light of new developments.

REGULATION REVIEW

The Workshop made a careful review of the CANADA OIL AND GAS LAND REGULATIONS in light of its findings about surveying and monumentation capabilities in the Canadian offshore. The following is a summary of the conclusions made by the Workshop in this review.

POSITION OF A WELL

On land, surveys are made to locate wells which are defined in the regulations as being an opening in the ground. A more practical point to position in the case of an offshore well is considered to be the drill stem at the drilling platform. For all practical purposes this can be considered to be coincident with the opening in the ground in the case of a fixed platform. For a mobile drilling unit the position of the drill-stem relative to the well head must be measured by the drilling engineer.

SURVEYS OF ABANDONED AND SUSPENDED EXPLORATORY WELLS OFFSHORE

The essential characteristics of these positional surveys were identified as being:

(a) Sufficient to enable a return to the well.

(b) Sufficient to determine the geographic position of the well using acceptable methods.

(c) Impractical of permanent monumentation at or near the well in the foreseeable future.

In line with this it was agreed that there was no need for a legal survey of abandoned or suspended exploratory wells, but that the plan submitted under Section 13 should be accompanied by a full report of the fixing system used together with a record of all system parameters and that all shore stations from which the well was fixed be permanently marked and described in the survey report.

SURVEYS OF DEVELOPMENT WELLS OFFSHORE

The Workshop recognizes legal surveys as both practical and necessary in the case of offshore development wells.

It is highly likely that any offshore production on the Canadian continental shelf, for the next few years at least, will be associated with permanent fixed drilling platforms which can serve as the base for monumentation of a legal survey and can in turn be used as a platform for controlling further surveys in the vicinity. The Workshop recognizes that underwater well completions are inevitable and that consideration will have to be given to their monumentation.

Since several wells may be drilled from a single platform it was agreed that a single legal survey should be sufficient for all wells drilled from one platform. It was further recognized that it is impractical to require the submission of an approved plan of legal survey before drilling a development well.

EXPLORATION REPORTS

The Workshop noted that Section 54 requires the submission of maps showing geological and geophysical data with respect to permit area boundaries. The value of such maps in the offshore is dubious if the positioning accuracy cannot be assessed by later users. To ensure that such assessment is possible these maps should be accompanied by a report on the positioning system used in the course of collecting the data.

ACCESS TO OFFSHORE PLATFORMS

Permanent production platforms will carry legal survey monuments that have to be used in surveys of other nearby platforms. Provision should be made to ensure that surveyors can use the platforms in their positional surveys. It is therefore recommended that the following new section be added to the survey part of the regulations to provide for access to offshore production platforms.

> "A person authorized by the Minister may enter upon a permit area, lease area or development platform for the purpose of making legal or other positioned surveys."

SURVEYS OF PIPELINES AND OTHER OIL AND GAS FACILITIES OFFSHORE

No provision exists in the regulations for surveying of installations and facilities for the gathering, storing, processing, transmission or other handling of oil and gas in the offshore. Since it is important to know where these facilities are, provision should be made for their survey and the proposed survey plans and final plans should be subject to review by the Surveyor General.

PART 3

OFFSHORE TECHNIQUES AND APPENDICES

OFFSHORE SURVEYING TECHNIQUES AND APPENDICES

COASTAL CONTROL

In order to make economic and effective use of any of the ranging survey systems considered to give positions of offshore points to the required accuracy, they should originate from control of at least third order accuracy. Shore stations for offshore survey systems must be located with careful and detailed consideration of local topography. Also, they must be located in such a way as to give satisfactory angles of intersection (cut-angles) between the measured lines. It is thus unlikely that monumented control will be in appropriate locations for shore stations for offshore positioning systems. Therefore, a spacing of control monuments of 30 km or less is a reasonable requirement in order that excessively long tieing traverses will not be required. These accuracies and spacing requirements are met on nearly all the coastal regions of Canada. The exceptions are:

(a) the southern shores of Hudson Bay (and James Bay) where second order control exists but at 140 km spacing.

(b) The west coasts of Vancouver Island and the Queen Charlotte Islands where coastal control is of fourth order or lower.

In much of northern Canada, the third order control was put in previous to the adjacent first order framework and has not been adjusted into it. In the Arctic Islands the basic control is Shoran trilateration classed as second order. In many cases, when the coastal traverses closed to acceptable standards, no closure adjustments were made. Thus, in many cases it would be possible to upgrade the existing coastal control appreciably by re-adjustments, if the requirement should arise in some specific area.

In view of the fact that errors in shore control may be greatly magnified when used to extend control hundreds of miles off shore, it is recommended that any further control surveys made to put in shore control for offshore survey should be done to second order standards.

A summary of the relative accuracy and spacing of the existing coastal control is given on page 30.

ZONES

Distance from shore and thus from coastal control has a marked effect on the choice of equipment that can be used to position points at sea and also on the accuracy with which these points can be fixed. It is therefore reasonable to define zones within which some generalizations can be made.

In the preliminary report of the study made by the Atlantic Oceanographic Laboratory, entitled "Navigation at Bedford Institute", an attempt was made to determine accuracy requirements for navigation in certain arbitrary zones, and to assess the Institute's capability to achieve this requirement in each zone. Four zones were identified, the Inshore or Line of Sight Zone, 0 to 30 kms from shore; the Coastal Zone, 30 to 150 kms from shore; the Offshore Zone, 150 to 1000 kms from shore and the Deep Sea Zone, beyond 1000 kms from shore.

Since the Workshop was considering only the continental shelf and margin and since the 150 km line between the Coastal and Offshore Zones seemed to have no real significance in the Workshop considerations, it was decided to divide the shelf into two zones. (See Figure 2)

THE LINE OF SIGHT ZONE

The Line of Sight Zone is defined as extending from the shore to the limit of unobstructed direct radio transmission from the shore and within which positions can be determined using microwave or optical systems or future systems which might have similar characteristics. The width of this zone is influenced by shore topography and may be as great as 50 kms.

THE COASTAL ZONE

The Coastal Zone is defined as the area of the continental shelf and margin beyond the Line of Sight Zone. It is therefore basically the area of concern, being out of sight of land.

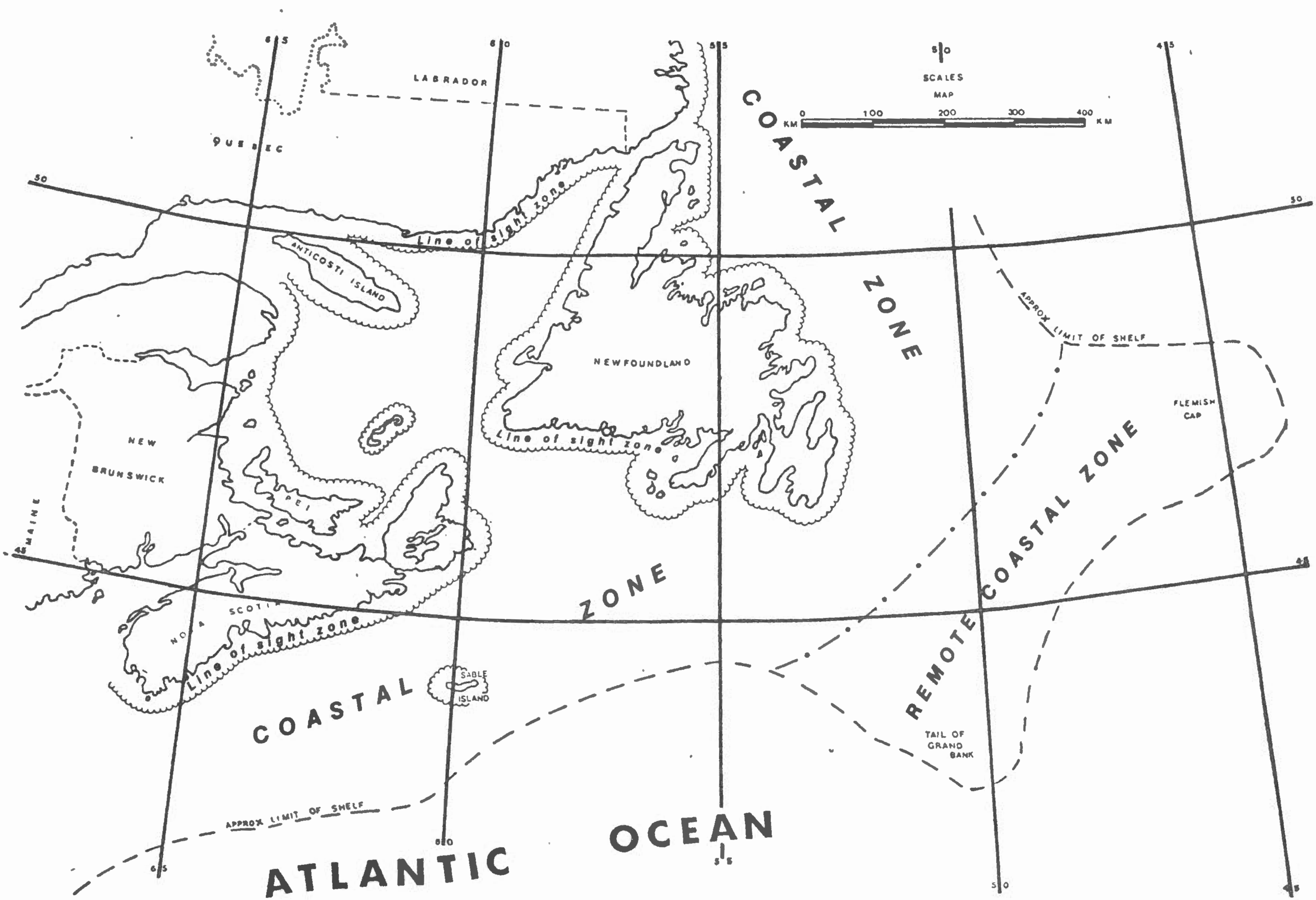


Figure 2
Zones in the North Atlantic

RELATIVE ACCURACY AND SPACING OF MONUMENTS DEFINING THE 1927 NORTH AMERICAN DATUM ALONG THE CANADIAN SEA COAST

The tabulated accuracy figures for the basic Geodetic Control are derived from both internal consistency of measurements as shown from mathematical adjustments and, more important, an assessment of checks and closures indicated when old work is compared with measurements made by new, more accurate techniques, and keeping in mind net distortions caused by forced closures. They are an attempt to evaluate absolute accuracy of distances between either adjacent points on a net or points separated by a few hundred miles.

AREA	BASIC CONTROL		SHORE STATIONS		REMARKS
	Spacing (km.)	Std.Dev. (ppm.)	Spacing (km.)	Std.Dev (ppm.)	
Nova Scotia, S.E., Shore	30-250	20	15	90	The basic control is stretched by about 20 parts per million (ppm) on the mainland. Sable Island is positioned by second order Aerodist giving a standard deviation with respect to mean adjacent shore control of about 4 m. perpendicular to shore and 15 m. parallel to shore.
S.&E. of Nfld.	15-150	50	10-15	90	
Gulf of St. L.	30	25	*		* Some 3rd order breakdown in southern part. Two sets of coordinates for P.E.I.
Lab. Coast	200	25	10	90	
Hudson St.-Ungava	40	8	10	90	Coastal Control not adjusted into the subsequent high order Geodetic triangulation.
Hudson Bay - North	50	8	10-15	90	Coastal Stations not adjusted into the subsequent high order Geodetic triangulation. There is some evidence that the 1927 datum is too narrow by about 30 m. across the N. end of Hudson Bay.
Hudson Bay - South (inc. James Bay)	--	--	140	45	2nd Order aerodist.
Arctic Islands	250	20	10-15	90	Coastal control needs re-adjustment.
Beaufort Sea	140	10	10-15	90	Coastal control can be upgraded by re-adjustment.
Pacific Inshore	50	20	1-5	500	The basic control is compressed by about 6 ppm. near Campbell River.
Pacific Offshore	250	20	8	500	

The Workshop has also identified within the Coastal Zone what might be termed a "problem area". This is the area off the southeast corner of Newfoundland and includes the Flemish Cap and the Tail of the Grand Banks and is referred to in this report as the Remote Coastal Zone. In all other areas of the continental shelf the Coastal Zone extends no more than 370 kms from the shore and reasonably well proportioned triangles can be made from the shore to the limits of the shelf. In the Remote Coastal Zone however the shelf extends up to 700 kms from the nearest land. Added to this the coastal configuration makes it impossible to have well proportioned triangles extending from the shore to points at the edge of the shelf except by adding very substantially to the lengths of the sides of the triangles, and extending the range of the presently used survey systems well beyond their design limits.

OFFSHORE POSITIONING SYSTEMS

In any discussion of offshore positioning, aids to navigation must be clearly distinguished from aids to survey. The first are intended to provide a "fix" with sufficient accuracy to permit a vessel to follow a selected course or to avoid dangers. The second are designed to provide a fix for survey ships, or other platforms, with the best possible accuracy which, in the case of hydrographic and geophysical surveys, must obviously be greater than that required for navigation. A navigational aid does not usually have the necessary qualities to allow accurate surveys to be carried out, whereas an aid to survey, in principle, may always be used in navigation although supplying information of superfluous accuracy.

Survey and research ships, operated by the Department of Energy, Mines and Resources, have been using electromagnetic surface-wave positioning systems since 1955. In more recent years, these positioning systems have been used in this Department to position helicopters, fixed-wing aircraft, motorized toboggans and other vehicles engaged on offshore surveys in the Canadian Arctic. Departmental experience with such radio positioning systems has been gained on three oceans and on the Great Lakes. In addition, the Department's survey and research units have made extensive use of electronic distance measuring systems to extend geodetic control throughout Canada.

Several commercial companies have used electronic positioning systems to control offshore geophysical exploration surveys and to fix the position of exploratory oil wells which have been drilled on the Canadian continental shelf. In some cases, e.g., on the west coast, the exploratory wells have been close enough to land to be positioned by land survey methods.

MICROWAVE LINE-OF-SIGHT SYSTEMS

Land survey methods using "line-of-sight" electronic survey systems such as Tellurometer and Geodimeter, permit precise positioning offshore when it is possible to site the instruments on accurate control stations on land and on stable platforms offshore. To take advantage of such systems it is usually necessary for the offshore platforms to be within 50 km of the coastal control. However, using airborne line-of-sight electronic distance measuring systems such as Aerodist, in the line-crossing mode, it may be possible to accurately position a stable platform at distances in excess of 500 kms from land.

Several electronic range measuring systems using microwaves provide continuous positioning of a survey vehicle but are restricted, by their radio frequency, to the line-of-sight zone.

MEDIUM AND LOW FREQUENCY RANGE MEASUREMENT SYSTEMS

In proceeding offshore beyond the line-of-sight it becomes necessary to use another family of survey positioning systems. In order to achieve longer ranges it is necessary to use lower frequency electromagnetic surface-waves transmitted by more powerful stations. Electronic surveying systems are classified as "two-range" systems when distances are measured and "hyperbolic" systems when differences in distances are measured.

The position of the survey vessel will lie on the intersection of two circular lines of position when using the two-range system and on the intersection of two hyperbolic lines of position when using the hyperbolic system. In the two-range systems, such as Decca Lambda, it is necessary to carry a transmitting station on the survey ship and the systems are limited generally to one user. When using a hyperbolic system the transmitting stations are on land and several ships can use the system simultaneously. Both these methods are in use in offshore surveys but because of the configuration of many of our coastal regions and the extent of the continental shelf it sometimes is necessary to increase the transmitted power and use higher transmitting masts in a two-range system in order to achieve acceptable accuracy and maximum range. This is necessary when surveying such areas as the Remote Coastal Zone.

The precision achievable with electronic systems, which are tied to the coastal control, decreases with distance beyond the line-of-sight. Field tests have demonstrated that these systems provide accuracy which is acceptable for hydrographic and geophysical surveys over the whole of the continental shelf, however, further tests are necessary to determine whether the value used for the velocity of propagation of electromagnetic surface-waves can be improved. Any improvement in the value used for the velocity of propagation will reduce the Standard Error. This is especially important when positioning sub-surface markers, buoys, wells and other installations in the Remote Coastal Zone.

The velocity of radio transmissions in air depends on temperature, pressure, humidity and the nature of the surface over which the transmissions are passing. Raydist, Toran, Lorac, Decca Lambda, Decca Hi-Fix etc., all use frequencies in the 100 KHz to 2000 KHz band and in addition to being sensitive to normal changes in atmospheric and surface conditions along the transmission paths, are seriously affected by the presence of sea ice. Some tests have been carried out in Arctic Canada to determine errors caused by varying sea ice conditions and positioning data required for hydrographic and geophysical surveys have been adjusted as a result of these tests. There is a need for further investigation with a view to enhancing the value of the systems for extending coastal control seaward.

The use of reference buoys, in conjunction with electromagnetic surface-wave range measurement systems of determining position offshore, is essential. When the positioning system including the shipboard receivers and display units is fully operational, the measurement display units should continue to show the correct values regardless of the movement of the master station in the ship. However, lanes may be slipped or lost due to equipment malfunction; phase shifts, due to skywaves which may be either out of phase with the surface wave or stronger than the surface wave; radio transmissions on nearby frequencies or atmospheric noise generated by thunderstorms.

To avoid steaming back to the coast to re-set the receiver display units in relation to the shore stations and/or control points, when measurements are in doubt, buoys are moored at convenient locations in the area of operation and system coordinates established for them. The buoy positions are established under good operating conditions. Several buoys are used and checked at least daily,so that the danger of re-setting shipboard receivers at buoys that have been moved by fishermen, or natural causes, is eliminated.

The positioning systems discussed above are either portable or semi-portable and are tied to local geodetic control on the mainland or islands. These systems obviously come under Canadian operational control.

ELECTRONIC SYSTEMS FOR MARINE NAVIGATION

There are several systems available for use offshore that have been developed as navigational systems. The Decca Navigator (Main Chains) and Loran "A" are operated by the Canadian Department of Transport. Loran A provides coverage of the east and west coasts. Decca Navigation covers part of the east coast. The accuracy attainable using these systems is adequate for general navigation but would not be suitable for surveys other than those of a reconnaissance nature.

Loran "C", Omega and the United States Navy Satellite Navigation Systems are owned and operated by the United States Government although a Loran C Station at Cape Race, Newfoundland, is operated through a cooperative arrangement, by the Canadian Department of Transport.

Loran "C" in the two-range mode has been tested by the United States Coast Guard using sophisticated receivers. Accuracy comparable to that attainable using Decca Lambda at extreme range has been reported. However, this requires further investigation and would seem to warrant the attention of the Marine Sciences Branch.

The United States Navy Navigational Satellite System is available but, because only four satellites are presently in orbit, positions can be determined only at intervals of approximately 100 minutes. This system has been evaluated in Canada by government and industry. Results to date indicate that, as long as the system is available, positions can be determined with sufficient accuracy to provide an independent position check every two hours on most continuous electronic positioning systems now in use. Furthermore, it is capable of providing a position in any weather, in any season, day or night.

The Satellite System provides a position relative to the Mercury Datum rather than to the 1927 North American Datum. By taking satellite fixes at coastal control points, the difference between geographic coordinates based on the two datums can be determined. This difference is applied to the satellite fix to adjust it to the 1927 North American Datum. The magnitude of this difference depends on local differences between the verticals on the two ellipsoids and the quality of the local control. Further research is required to develop corrections which will allow satellite fixes offshore to be readily adjusted to the same datum as fixes obtained by other offshore positioning systems.

ASTRONOMY

Since astronomic positioning can give accuracies with respect to an absolute datum much better than most long range hydrographic surveying methods, and considering also the successes of Professor W. Von Arx in astronomic observing at sea, the feasibility of using astronomic positioning for legal surveys at sea must be examined. It appears that the accuracy of positioning a production platform on the 1927 North American Datum depends mainly on the unknown accuracy which can be achieved in computing the change in deflection of the plumb between two stations from gravity surveys.

Astronomic observations could be made from a semi-submersible platform using an expensive gyro-stabilized table but the accuracy is unknown.

PHOTOGRAMMETRY

Two photogrammetric methods were considered using high oblique photographs and analytical methods. Both were discounted as being impractical and giving results of insufficient accuracy. Any photogrammetric method would involve night photography using lights. In an extremely clear atmosphere at 150 miles, a minimum of 50,000 candle power would be needed to produce a dot about 60 microns in diameter on the photograph. This is possible with a regular automobile-lamp of 500 watts and 13° total field. However, extremely clear atmospheric conditions exist over the shelf for only a few days in a year. The power requirement under ordinary atmospheric conditions would likely be much greater and render any photogrammetric method impractical. The two methods considered would produce results with an expected error of at least ±200 m.

GENERAL

Available detail about most of the above systems is given under System Summaries. There is no doubt that there are enough systems available with an existing or potential capability for providing acceptable surface positioning for offshore mineral exploration and development. These positioning systems can be combined with acoustic methods to determine the position of seafloor installations anywhere on the Canadian continental shelf.

Several other systems were investigated but because of insufficient information they have not been included in this report. With one exception, XR Shoran, none of these incorporated any features not found in the nineteen studied in detail.

ACCURACY OF ELECTROMAGNETIC RANGING SYSTEMS

To assess the accuracies of a measured distance by the various electromagnetic ranging systems it is necessary to assume an error model. It was assumed that for each ranging device the errors in measured distance could be divided into two independent random groups; those independent of length, and those directly proportional to length. The standard deviation σ (in metres) of the measurement will then be given by:

$$\sigma = \sqrt{r^2 + (fL)^2} \text{ where:}$$

r is the standard deviation in metres, of the combined factors which are independent of length.

f is the standard deviation of the combined factors which are dependent on the length expressed as a ratio.

L is the measured length in metres.

The positional accuracy attained, with respect to the mean shore control, by making range measurements with standard deviations defined above will depend on the geometry of the fix and the accuracy of the shore control used. Error ellipses were computed by the Geodetic Survey of Canada using the GALS electronic computer adjustment program to show the effects of various ranging accuracies, geometric configurations, and shore control accuracies. If the shore control is appreciably better in accuracy than the ranging measurement a rough approximation of "a" the longer dimension of the error ellipse (semi major axis) is given by:

$$a = \operatorname{cosec} \beta \sqrt{\sigma_1^2 + \sigma_2^2}$$

where σ_1 and σ_2 are the standard deviations of the two ranges and β is their angle of intersection. If $\sigma_1 \approx \sigma_2$ this becomes

$$a = \sqrt{2}\sigma \operatorname{cosec} \beta.$$

A graph of this function is given for various ranges (see Figure 3).

In assigning accuracies to the various systems many sources were drawn on. Whenever thorough test reports by users were available their values were accepted in preference to manufacturers claims. If independent authorities quoted different values the larger values were used. For those systems for which no user test reports were found, accuracy claims by manufacturers and consultants (who appear to be quoting manufacturers) were critically examined. In this the Workshop was guided by the extensive first hand users experience with a large variety of ranging instruments by several members of the Workshop in both industry and government, and by

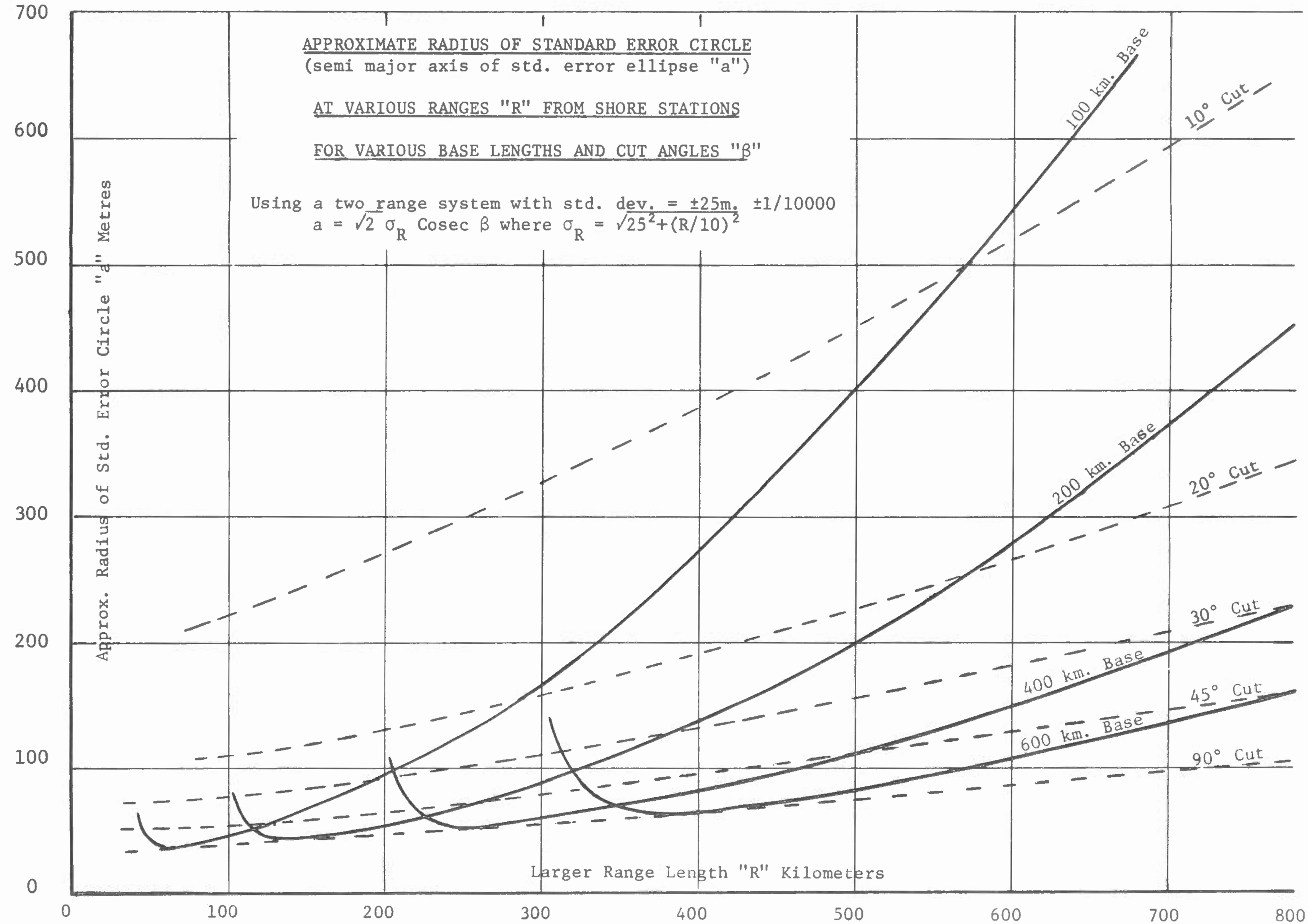


Figure 3
Approximate Radius of Standard Error Circles

consultants who came to the Workshop. Finally, after assigning accuracies to range distances and control points and computing the positional error figures for specific geometries, it was confirmed that they were reasonable in the light of actual experience by Workshop members who used different survey systems to position a point or had re-fixed the same point at different times by a single system.

EFFECTIVE PROPAGATION SPEED. One of the most difficult accuracy factors to assess was that for the effective propagation speed for ranging systems using the electromagnetic surface wave, which is the effectively detected wave in the LF, MF and HF band. For these systems it is the only significant factor in the value of "f". The value of the velocity is dependent on the frequency of transmission and the conductivity of the surface which is in turn dependent on the salinity and temperature of the water and the temperature and pressure of the air, the proportion of ice cover and possibly waviness in the interface. It is also considered to be slightly dependent on the length of the range and it should be noted that this length dependence is not allowed for in the error model. All the surface wave propagation systems dealt with, lay in two narrow bands around 2 MHz and 100 KHz. Each of these frequencies was considered separately.

In field operations it is normal practice to adopt a single effective propagation speed and to consider it constant regardless of the length being measured or of any of the other factors affecting velocity. For each frequency band, the results of many tests over several years were studied to see what range of values had been assumed and estimates were made of the proportional error that could be expected as a result of the adoption of a single value for any survey.

It was noted that values determined using Decca Lambda have ranged from 299,572 km/sec to 299,667 km/sec, and that a nominal value of 299,650 km/sec has been used for the 100 KHz band for many years. It was considered that some value in the neighborhood of 299,620 km/sec would be a better estimate and that for all practical purposes such a value could be considered to have a standard deviation of 1:10,000. The effective velocities that have been determined and used for equipment in the 2 MHz band, range from 299,631 km/sec to 299,684 km/sec. It is considered that a value of about 299,660 km/sec could be reasonably assumed to have a standard deviation of 1:10,000.

These estimates are only valid if there is no ice coverage and if no portion of the range is across land or close to land. Experience in the Arctic has shown that the velocity is very different when ice is present and that attenuation is very much greater than over water. The random nature of the values, inferred by expressing them with a standard deviation, is not a short term phenomenon. It could be expected to vary greatly from area to area as salinity and water temperatures change, and from spring and fall as water and air temperatures change etc. It is therefore reasonable to suppose that the standard deviation might be decreased by calibration procedures and by measuring ambient conditions. There was not enough experimental data to give even rough empirical estimates as to how to apply corrections for measured ambient conditions.

TERMINAL ERRORS. The value of "r" is the root mean square of many errors independent of length, e.g. uncertainty in the exact location of electrical centres, instrumental errors, resolution errors, terminal induction and ground transmission effects, and induction effects which might be caused by completely independent operations adjacent to or along the line of a range measurement.

ERROR ELLIPSES. The error figures computed by the GALS electronic computer adjustment programme give the standard deviation of a position using:

(a) the relative accuracy of the control points as expressed by the standard deviation.

(b) the expected standard deviation of the range measurements which is used to find a weight for the measurement.

(c) the geographic location of the points.

From this the accuracy of the fix (which is different in different directions) is described in terms of the magnitude of the standard error and the direction in which it is a maximum and the standard error and direction in which it is a minimum. These maximum and minimum standard deviations are used as the semi major and semi minor axes of ellipses in the appropriate orientation. It should be kept in mind that the 95 percent probability level is twice the standard deviation.

FIGURE 4. These figures show accuracies typical of a Pacific coast operation using a system such as Hi-Fix and shore control of poor quality. The large difference in accuracy perpendicular to and parallel to the direction to the control is very evident when the angle of intersection is small. Also shown is the improvement which might be achieved by using better shore control.

FIGURE 5. These figures show accuracies typical of Decca-Lambda in the best configurations for positioning in the Remote Coastal Zone, stretching its range to the maximum. The dotted ellipses show the appreciable improvement which would occur on the Flemish Cap if the accuracy of the velocity of propagation can be improved from 1:10,000 to 1:20,000. It is also evident that it is the terminal error which predominates at the more usual range of the system.

FIGURE 6. These figures show accuracies typical of Decca-Lambda using a short base for positioning the problem area. A comparison with Figure 5 demonstrates the large improvement in accuracy as the base line is lengthened.

FIGURE 7. These figures show what are believed to be realistic accuracies for Loran-C in a two range mode with the geometry which would be used in the problem area. The slightly smaller dotted ellipses show the accuracies which may be attained when more accurate clocks are installed in a year or so.

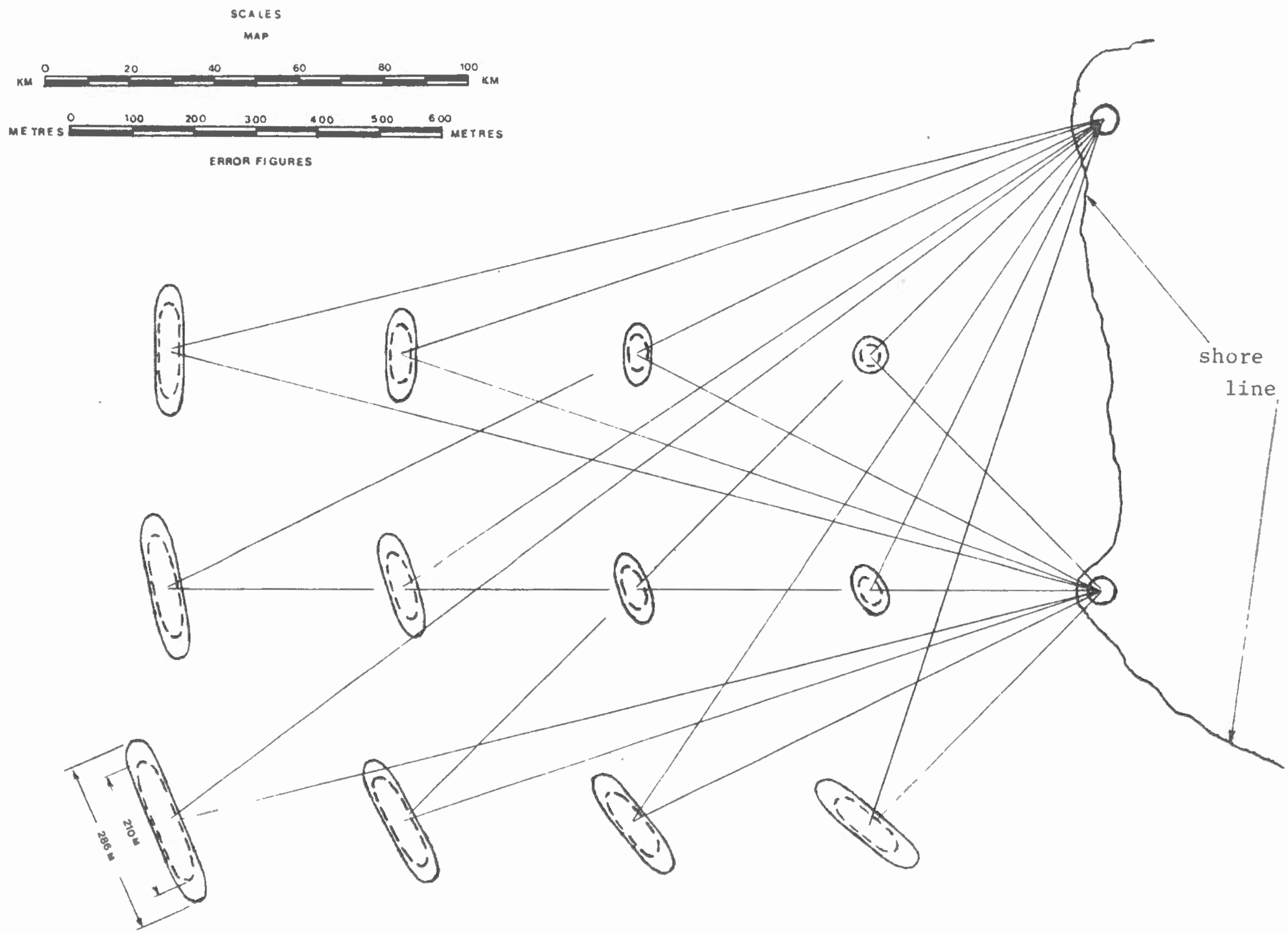


Figure 4

A GRID OF TYPICAL STANDARD ERROR ELLIPSES

with respect to the 1927 N.A. datum as defined by the mean of a pair of shore control stations from which ranges with a std. dev. of ± 15m. ± 1/10000 are measured.

The ellipses with solid outline are derived from shore control with a relative accuracy of 1/2000.

The ellipses with dotted outline are derived from shore control with a relative accuracy of 1/11000.

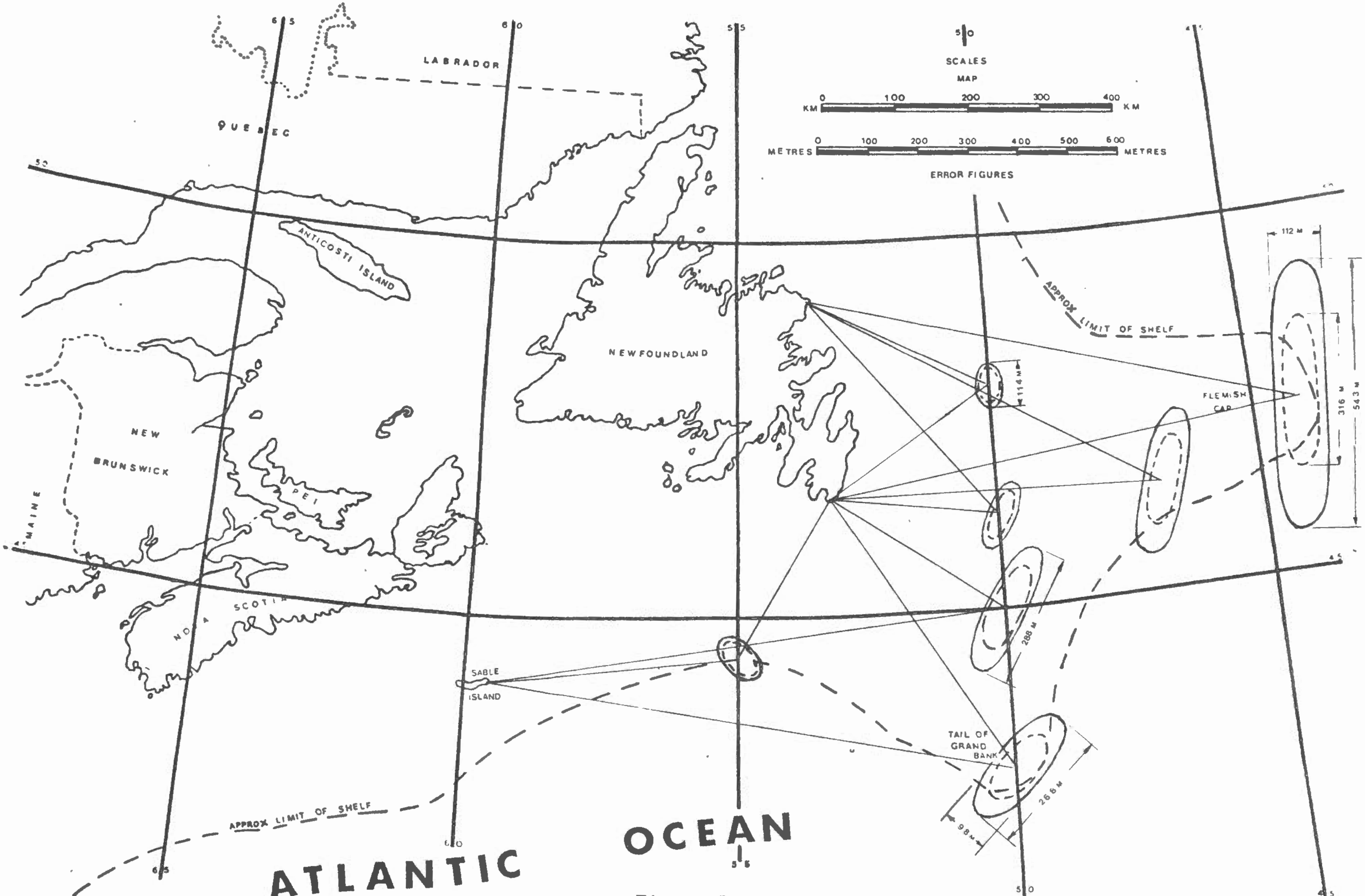


Figure 5

TYPICAL STANDARD ERROR ELLIPSES FOR POSITIONS

with respect to the 1927 N.A.Datum as defined by the mean of the pairs of third order control stations used.

The ellipses in solid outline are those using a two range system with std. dev. = ±25m. ±1/10000.

The ellipses in dotted outline are those using a two range system with std.dev. = ±25m. ±1/20000.

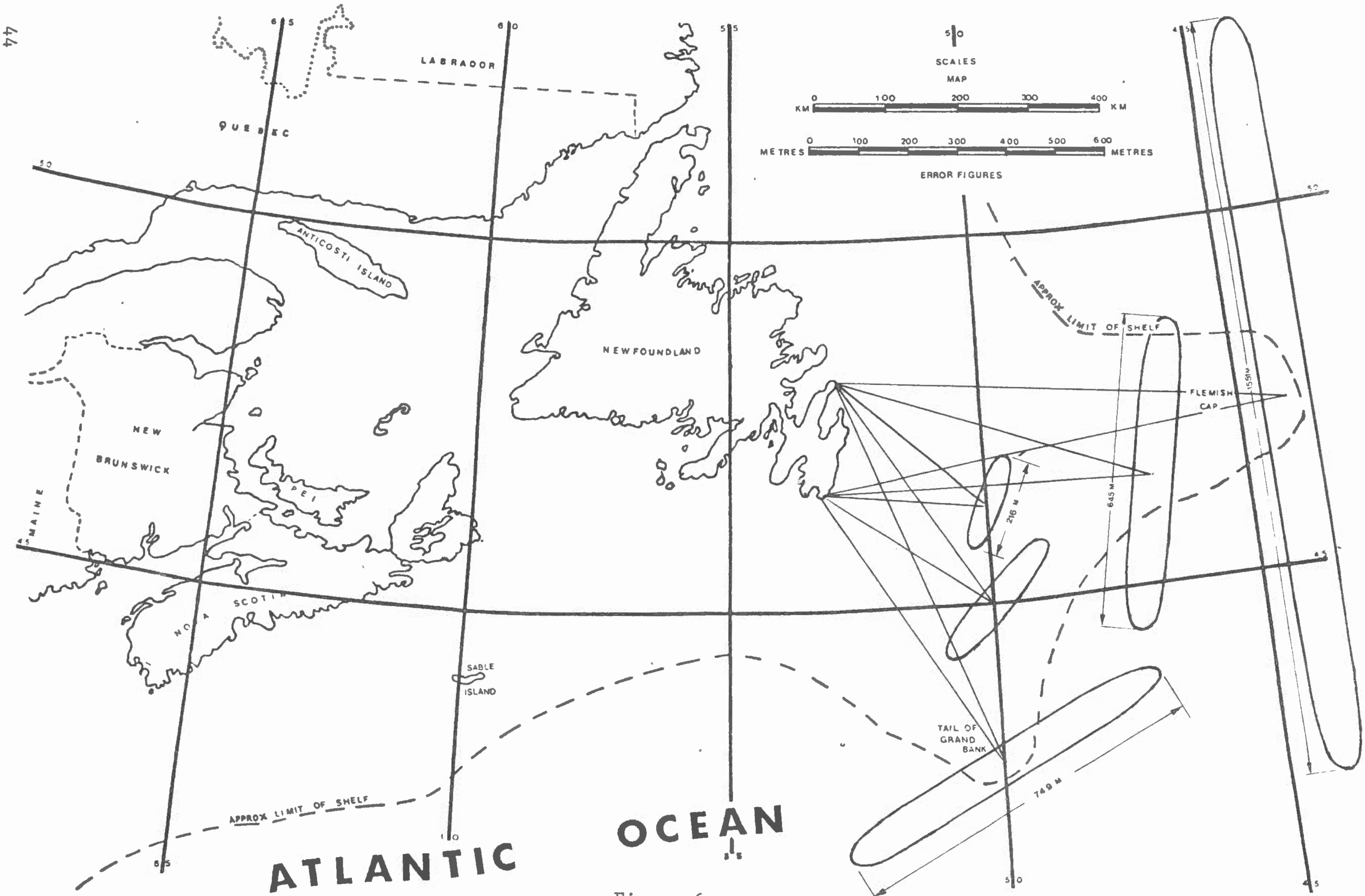


Figure 6

TYPICAL STANDARD ERROR ELLIPSES FOR POSITIONS

with respect to the 1927 N.A. datum as defined by the mean of the pair of third order control stations used and using a two range system with std. dev. ±25m. ±1/10000

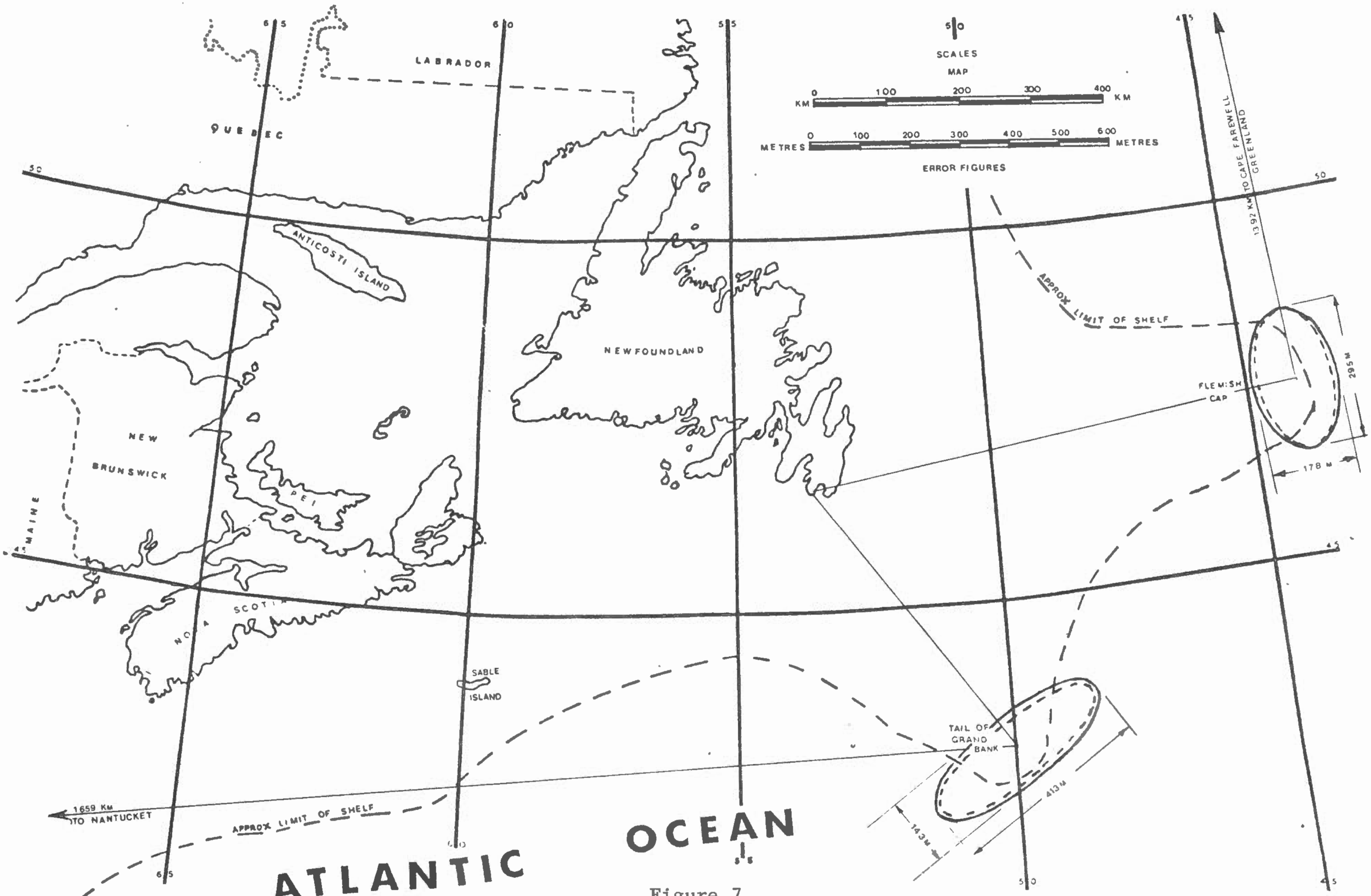


Figure 7

TYPICAL STANDARD ERROR ELLIPSES FOR POSITIONS USING LORAN C IN A TWO RANGE MODE

with respect to the Mercury Datum as defined by the mean of the pairs of stations used, assuming a relative accuracy of 10 ppm.

The ellipses in solid outline result from assuming a std.dev. for ranges= ±50m.±1/10000

The ellipses in dotted outline result from assuming a std.dev.for ranges= ±30m.±1/10000

SYSTEM SUMMARIES

Pages 46 to 66 of this report contain the Workshop's assessment of the following survey positioning systems. The information is expressed in terms of description, availability, cost, range, accuracy, restrictions, user experience and special features of each system. Unless otherwise stated accuracies are expressed as standard deviations for a single range measurement. The methods of assessing accuracies and for converting ranging accuracies to position accuracies are described in "Accuracy of Electromagnetic Ranging Systems" page 35.

Line of Sight Systems

Tellurometer

Geodimeter

Motorola RPS

Cubic Autotape

Hydrodist

Aerodist

Hiran

Medium and Low Frequency Systems

Minifix (Decca)

Hi-Fix (Decca)

Raydist

Rana H

Lorac

Decca Lambda

Toran

Navigation Systems

Loran C

Omega

U.S. Navy Navigation Satellite System (NNSS)

Astronomic Positioning at Sea

TELLUROMETER

Description. A precise distance measuring system using electromagnetic waves over the direct path followed by micro-waves. It is comprised of two electronic units, one master and one remote, which permit determination of the distance between them.

Availability ....on demand

Cost ....$10,000 to $25,000

Range ....to 50 kms (line of sight)

Accuracy
- MRA II ± (3 cms + 6 ppm)
- MRA III ± (3 cms + 6 ppm)
- MRA IV ± (1.5 cms + 3 ppm)

Restrictions
- Single user
- Not continuous fixing
- Calm sea may render instrument useless
- MRA III, IV - narrow beam width restricts use to relatively stable platforms
- Requires simultaneous use of theodolite or other ranging device
- Ambiguities possible
- Manned shore stations
- Requires meteorological data
- Affected by sea ice

Special Features
- First order accuracy

User Experience ....extensive in Canada

GEODIMETER

Description. A precise distance measuring system using modulated light waves over the direct path followed by the waves. It is comprised of one electronic unit and remote reflectors which permit determination of the distance between the electronic unit and the reflectors. Two types of light source are used:

Incandescent		Laser	
Availability	on demand	Availability	on demand
Cost	$12,000	Cost	$25,000
Range	to 10 kms	Range	30 kms (day and night)
Accuracy	±1.0 cm ± 1 ppm	Accuracy	±1.0 cm ± 1 ppm

Restrictions

- Single user
- Not continuous fixing
- Needs good visibility
- Narrow beam - needs stable platform
- Requires simultaneous use of theodolite or other ranging device
- Ambiguities possible
- Requires meteorological data

Special Features

- First order accuracy
- Sea ice no problem
- One operator

User Experience ....extensive in Canada

MOTOROLA RPS

Description. A pulsed ranging system operating on a frequency of 9300 MHz using a ship board transmitter-receiver to measure the ranges to two transponders of known positions. By the process of trilateration, the position of the ship is determined continuously in x, y coordinates.

Availability ....on demand

Cost $81,000

Range ....up to 50 kms (line of sight)

Accuracy
- ± 5 m dependent on geometry (positional accuracy)

Restrictions
- Range/Range, single user
- External radar interference
- Cannot be monitored for pattern variation
- Ambiguities possible
- Requires careful site selection
- Affected by sea ice

Special Features
- All weather
- Continuous positioning
- Unmanned shore stations
- One operator
- Built in digitizer and visual display (position plan indicator)

User Experience ....limited to Canadian Hydrographic Service

CUBIC AUTOTAPE

Description. A precise ranging system using modulated 10 cm electromagnetic waves to continuously and simultaneously determine distances along the radio line of sight. It comprises two responders located at known positions and a mobile interrogator which usually displays the two distances in metric units.

Availability ....on demand

Cost $90,000

Range ....50 kms (line of sight), range/range system

Accuracy • ± (2 m ± 10 ppm)

Restrictions
- Single user
- Not complete area coverage
- Ambiguities possible
- Requires careful site selection
- Affected by sea ice

Special Features
- Continuous positioning
- Unmanned shore stations
- One operator
- Can be interfaced with printer

User Experience .....extensive in USA, limited in Canada to the Canada Centre for Inland Waters

HYDRODIST

Description. A tellurometer system designed specially for use at sea. The master unit is carried aboard ship and measures ranges to two remote units of known positions.

Availability ....on demand

Cost $25,000

Range ....50 kms (line of sight)

Accuracy

- ± 2 m

Restriction

- Single user
- Not complete area coverage
- Ambiguities possible
- Requires careful site selection
- Manned shore stations
- Affected by sea ice

Special Features

- Continuous positioning possible using four operators

User Experience ....extensive in Canada and elsewhere

AERODIST

Description. This is an air-borne tellurometer system which can be used in the line crossing technique to give first order position determinations in a trilateration network.

Availability ....rental basis only - one company in Canada

Cost ....3 remote system $2,000/day + $100/hr. flying time

Range ....400 kms

Accuracy
- ± 10 ppm

Restrictions
- Single user system
- Not continuous fixing
- Requires relatively stable platform
- Ambiguities possible
- Requires careful site selection
- Manned shore stations
- Line crossing technique only
- Minimum length of line 75 kms
- Requires meteorological data

Special Features
- Sea ice no problem
- First order accuracy

User Experience ....extensive in Canada and Australia

HIRAN

Description. An air-borne line crossing system similar to Aerodist but operating at a frequency of 200 MHz and using pulsed timing.

Availability ....rental basis - one company in USA

Cost ....$5,000 per month + cost of aircraft and personnel

Range ....800 kms

Accuracy

- ± 10 ppm

Restrictions

- Single user system
- Not continuous fixing
- Requires relatively stable platform
- Ambiguities possible
- Requires careful site selection
- Manned shore stations
- Line crossing technique only
- Minimum length of line 150 kms
- Requires meteorological data

Special Features

- Sea ice no problem
- First order accuracy

User Experience ....extensive in USA

MINIFIX (DECCA)

Description. A miniaturized version of Hi-Fix using automatically operated shore stations.

Availability ....on demand

Cost ....$120,000 + $15,000 per user

Range ....Range/Range 150 kms (over saltwater)
....................Hyperbolic 50 kms (restricted by pattern geometry)

Accuracy

- Range/Range ± (1:10,000 + 15 m)
- Hyperbolic 10 m to 50 m (positional accuracy in area of good geometry i.e. angle of interesection 30°)

Restrictions

- Range/Range, single user
- Daylight operation
- Useless over sea ice
- No land path system
- Ambiguities possible
- Requires careful site selection
- Requires ground mats
- No lane identification

Special Features

- Continuous position
- Unmanned shore stations
- Can be interfaced with printer, plotter, and left/right indicator
- Range/Range and hyperbolic

User Experience ....extensive in Canada

HI-FIX (DECCA)

Description. A transportable electronic positioning system especially designed for hydrographic surveys. Three transmitter-receiver stations are required for either range/range or hyperbolic positioning. It is a continuous wave phase comparison system in the 1700 to 2000 KHz band. The lane width is in the order of 80 m. Special charts, having either the hyperbolic or concentric circle patterns, are required.

Availability ....on demand

Cost ....$110,000 + $10,000 per user

Range ....Range/Range 250 kms (over saltwater)
....Hyperbolic 150 kms

Accuracy

- Range/Range ± (1:10,000 ± 15 m)
- Hyperbolic 10 m to 100 m (Positional accuracy)

Restrictions

- Range/Range, single user
- Daylight operation
- Useless over sea ice
- No land path system
- Ambiguities possible
- Requires careful site selection
- Requires ground mats

Special Features

- Continuous positioning
- Unmanned shore stations
- Cable interfaced with printer, plotter, left/right indicator
- Lane identification available
- Range/Range and hyperbolic

User Experience ....extensive in Canada and elsewhere

RAYDIST

Description. A portable electronic positioning system similar to Hi-Fix but operating in frequencies from 1.5 to 5 MHz. By using a combination of hyperbolic and circular patterns the range/range system may be used simultaneously by up to three ships. Charts having the hyperbolic and/or circular patterns are required.

Availability ....six months delivery

Cost ....$50,000 (miniaturized), $80,000 (high power)

Range ....150 kms (miniaturized), 400 kms (high power)

Accuracy
- ± (1:10,000 ± 15 m)

Restrictions
- Range/Range - three users
- Daylight operations
- Useless over sea ice
- Receivers very responsive to ships movement
- Subject to radio interference due to range of frequencies
- No land path system
- Ambiguities possible
- Requires careful site selection
- Manned shore stations

Special Features
- Continuous positioning
- Can be interfaced with printers and plotters
- Three users per system in Range/Range mode
- Several radio patterns can be generated
- Lane identification
- Range/Range and hyperbolic

User Experience ....extensive use by U.S. Coast and Geodetic Survey
................................limited Canadian experience

RANA H

Description. A transportable electronic positioning system using continuous wave phase measurement in the 2000 KHz band. At least two pairs of shore stations generate two intersecting hyperbolic patterns and special charts with these patterns are needed. Rana H is presently obsolete but Rana HS 5 is now being developed.

Availability ....six months delivery

Cost ....HS 5 $250,000

Range ....150 to 400 kms (depending on power)

Accuracy
- ± (1:10,000 ± 15 m)

Restrictions
- Daylight operation
- Expected to be useless in sea ice
- Subject to radio interference due to number of frequencies used
- No land path system
- Ambiguities possible
- Requires careful site selection

Special Features
- Continuous fixing
- Unmanned shore stations
- Separate baselines can be used to provide good geometry
- Land identification
- Range/Range and hyperbolic
- Not restricted to narrow range of frequencies

User Experience ....extensive French experience (Rana H)

LORAC

Description. A transportable electronic positioning system similar to Hi-Fix but operating normally only in a hyperbolic mode. Special hyperbolic charts are needed. It can also be used to measure long range by using aircraft line crossing techniques.

Availability ....on demand

Cost ....$60,000 + $10,000 per extra receiver

Range ....250 kms (Lorac A) 400 kms (Lorac B)

Accuracy
- ± (1:10,000 ± 15 m)

Restrictions
- Daylight operation
- Useless in sea ice
- No land path system
- Ambiguities possible
- Requires careful site selection
- Hyperbolic only
- Manned shore stations

Special Features
- Continuous fixing
- May be used in airborne line crossing techniques
- Lane identification
- High power
- Interfaced with printer and plotter

User Experience ....extensive U.S. experience

DECCA LAMBDA

Description. A transportable electronic positioning system specially designed for long range hydrographic surveys. Three transmitter-receiver stations are required for either range/range or hyperbolic positioning. It is a continuous wave phase comparison system operating in the 100 KHz band. The lane widths are in the order of 350 m. Special hyperbolic or concentric circle charts are required. By increasing the power and antenna height, ranges of 800 kms have been consistently achieved by the Canadian Hydrographic Service off Canada's east coast.

Availability ....12 months delivery

Cost $250,000

Range ....800 kms

Accuracy • ± (1:10,000 ± 25 m)

Restrictions
- Range/Range, single user
- Daylight operation
- Reduced accuracy over sea ice
- No land path system
- Ambiguities possible
- Requires careful site selection
- Requires ground mats
- Manned shore stations
- High maintenance and operating costs
- Lane identification of limited usefulness

Special Features
- Continuous positioning
- May be interfaced with printers
- Range/range or hyperbolic

User Experience ....extensive

TORAN

Description. A transportable electronic system for continuous long range positioning at sea. It is a continuous wave phase comparison system operating in the 1400-2000 KHz band. It generates two sets of hyperbolic patterns from two pairs of shore stations and uses a mobile phase comparison receiver to determine position within the hyperbolic pattern. Special charts are needed. It can be used in a ranging mode.

Availability.....................on contract if included with seismic survey
..not known if it is available separately or if it can be purchased

Cost.............................$20,000 - $30,000/month to rent (estimated)
.............................$200,000 - $250,000 to purchase (estimated)

Range.......................................up to 700 kms (manufacturers)
...............................user experience up to 800 km (Australia)

Accuracy

- ± (1:10,000 ± 25 m)

Restrictions

- Daylight operation
- Reduced accuracy over sea ice
- No land path system
- Ambiguities possible
- Requires careful site selection
- Requires ground mats
- Manned shore stations
- High maintenance and operating costs
- No lane identification

Special Features

- Continuous positioning
- May be interfaced with printer and plotters
- Separated baselines can be used to provide good geometry
- Range/Range or hyperbolic
- Multi-user system

User Experience ....very limited in Canada

LORAN C

Description. A United States Coast Guard world wide electronic navigation system operating in the 90-110 KHz band and using permanent shore stations. The hyperbolic pattern is developed by measured time differences between master and slave stations. To improve accuracy there is matching within the pulses. A range/range system has been successfully tested by the U.S. Coast Guard and apparently, accuracies acceptable for long range offshore surveys, have been achieved.

Availability ....on demand

Cost $125,000/receiver

Range ....2000 kms

Accuracy
- ± (1:10,000 ± 50 m), will soon improve to ± (1:10,000 ± 30 m)

Restrictions
- Accuracy reduced over sea ice
- Canada does not have operational control
- Ambiguities possible
- Manned shore stations
- High maintenance cost
- Back up receivers advisable
- Limited coverage

Special Features
- All weather
- Continuous positioning
- Lane identification
- Ideal for remote coastal zone
- Range/Range or hyperbolic
- Multi-user system
- Can be used in conjunction with Loran D

User Experience ....extensive in the U.S. (USCG, USNOO, and USC&GS)

OMEGA

Description. A world-wide electronic navigation system being developed and operated by the United States Coast Guard and expected to be fully operational by 1972. This is a very low frequency system (10 KHz) which tests indicate will not provide the order of accuracy required for offshore surveys. Attempts to use this system to obtain accurate velocity information during satellite passes have proved futile.

Availability ....on demand

Cost $10,000/receiver

Range ....world wide

Accuracy
- 3 kms by day, 6 kms by night (Positional accuracy)

Restrictions
- Severely limited by atmospheric conditions
- Canada does not have operational control
- Ambiguities possible
- Internal oscillator drift
- Navigational system

Special Features
- World wide when fully developed
- Useable under water
- Continuous positioning
- Sea ice not a problem

User Experience ....extensive in Canada and USA

THE U.S. NAVY NAVIGATION SATELLITE SYSTEM (NNSS)

System General Description. The N.N.S.S. provides the means to determine the Latitude and Longitude of the observer's position anywhere on earth approximately every 2 hours by sampling the transmitted data from artificial polar satellites orbitting the earth.

The principle is based on measurement of the Doppler shift of V.H.F. (400 mc/s) radio signals transmitted by the moving satellite. At present four satellites, in polar orbits some 600 nautical miles above the earth, are in use for this system. Their tangential velocity is 16,500 miles per hour, and they take 107 minutes to complete one orbit. The operational life of polar satellites has varied between 2 and 5 years. Four additional satellites are available to replace or add to the present satellites in orbit.

Four ground tracking stations situated in the continental United States and Hawaii monitor the orbits continuously. The results are processed in a computing centre at Point Mugu, California. After evaluating the influence of all known forces on the satellite, a new orbit for the next 16 hours is extrapolated and injected once every 12 hours into the satellite, by over-writing the previous information in its core memory.

Satellite Receivers. In order to utilize the above system a satellite receiver and a general purpose computer must be purchased. At the present time there are three manufacturers of satellite receivers i.e. I.T.T. Federal, Magnavox and Honeywell. It is estimated that 150 receivers have been sold to industry and government agencies throughout the world.

System Cost. A complete satellite receiving system will generally consist of the following items:

(1) A satellite receiver	$35,000
(2) General Purpose Computer (8K memory)	30,000
(3) High speed tape reader and punch	5,000
(4) ASR 35 7 channel teletype	5,000
Total Capital Cost	$75,000

Note: Present systems are not yet available under rental agreement.

Repeatability. A stationary observer equipped with a satellite receiver can obtain and repeat his position relative to the Mercury Datum within a circle of 100 meters at a 95% confidence interval/level. At a stationary platform it is desirable to record 20 selected satellite passes in order to derive the best mean position co-ordinates. Mean positions derived in the above manner are found to vary only by several meters when the process is repeated for the same station at a later date.

A moving observer with poor knowledge of ship velocity and heading can expect position errors in the order of 1000 meters, when taking a position from a single satellite pass.

Relative Accuracy. The method presently adopted to determine the difference between geographic coordinates on the 1927 North American Datum and those obtained by satellite fixes on the Mercury Datum requires the observer to take satellite fixes at a known control station and then apply this datum shift to the area of operation. The magnitude of this difference depends on local differences between the verticals on the two ellipses and the quality of the local triangulation.

Disadvantages and Limitations of the Satellite System

1. The satellite system is not a continuous navigation system. The intervals between acceptable satellite passes at Latitude 40° - 50° can range from a few minutes to 8 hours.

2. The velocity and heading of a moving observer relative to the earth's surface must be known since both these quantities are input parameters for the computation of the satellite fix. Errors in the order of 1000 meters can be introduced by entering a one knot error in the north-south velocity component.

3. The satellites, the tracking stations, and the input orbital parameters are wholly operated, controlled and financed by the U.S. Government. There is no guarantee that the present system will remain available to other than U.S. users.

Advantages of the Satellite System

1. The satellite receiver system is less expensive than most other positioning systems for remote offshore survey operations. Establishment of a fee by the U.S. government could increase the cost.

2. The satellite system provides an independent position check approximately every 2 hours for most continuous electronic positioning systems.

3. The system operates day and night under all weather conditions, at all seasons and is world wide.

4. It is a superior alternative to any other long range positioning system.

Summary. The satellite system is a useful survey tool in offshore exploration and production activities. Further development of the system in the translocation mode will increase its usefulness in all aspects of surveying. At the present time it is the only way to achieve fourth order accuracy in the Remote Coastal Zone.

ASTRONOMIC POSITIONING AT SEA

A fixed oil platform at sea could be positioned to the same degree of accuracy, on an astronomic datum, as a land station with a standard deviation better than 35 meters. A semi-submersible or other floating platform might be positioned using Von Arx's techniques with a gyro-stabilized platform. The accuracy of determining differences in deflections from gravity surveys at sea must be studied as this will be the limiting factor in relating the astronomic position to the 1927 North American Datum.

The astronomic coordinates of a point are determined by measuring the direction to stars at known times with an instrument which refers to the local vertical. Positional accuracies are determined in the main by the accuracy of timing, verticality, and star position. It is the problem of verticality that is a major concern at sea. From experience on land using first-order techniques and instruments, it appears that the absolute accuracy of the mean of observations made on two nights is truly represented by its standard deviation of a few tenths of a second in position (about 10 m). This absolute accuracy is indicated because different observers, using quite different instruments, can remeasure the coordinates years later, disagreeing normally by only a few tenths of a second and only very rarely by as much as one second. These accurate astronomic coordinates refer, however, to an astronomic datum which differs from the Geodetic datum by the difference between the local vertical and the vertical defined by the spheroid of reference. This difference is known as the deflection of the plumb. In prairie country the deflections are commonly a few seconds and vary from place to place by perhaps a second in 25 kms. In mountainous terrain deflections of 20 seconds are common and changes of 40 or more seconds across a 15 km wide valley may be expected. In relatively flat country where gravity anomalies are present a change of deflection of 3 or 4 seconds in a distance of 10 km may be expected. It is evident from limited measurements by Von Arx of Woods Hole that similar variability may be expected at sea. A change of deflection of about 130 seconds was measured across the Puerto Rico Trench (about 100 km). The accuracy to which astronomic observations can be made at sea is unknown. It seems reasonable to assume that, at a fixed production platform, accuracies comparable to those on land could be achieved. From a semi-submersible platfrom which will be rocked by the waves through an angle of one degree even in very calm weather and more commonly through several degrees, it would be impossible to observe without a gyro-stabilized platform. The platform which Professor Von Arx has been using for astro observations on board a ship under way is a Sperry MK.19, much modified to improve its accuracy. The modified version costs about $100,000 and delivery would take at least ten months. It appears from Von Arx's reports that accuracies of observations might approach those attainable on land. It should be noted that Von Arx is successfully using, as a level sensing device, a small thin pool of oil because the common spirit level and the electrolytic level are useless on board ship. In view of the fact that a semi-submersible platform moves much less than a ship, it might be possible to use a less sophisticated gyro platform. The Askania platform which is used to support a shipboard gravimeter at the Bedford Institute is not modified to give the extra accuracy attained by Von Arx but it might suffice for preliminary tests.

Although an astronomic position is permitted in the Canada Oil and Gas Land Regulations to fix a grid it is evident from the variability in the deflection of the vertical that many inconsistencies in grid definitions, with respect to the 1927 North American Datum might arise, particularly as oil wells are likely to be drilled on gravity anomalies where the deflection will be more than usually variable. Inconsistencies in the order of several hundreds of meters could occur between adjacent grid areas if they were positioned by independent astronomic fixes. There remains the possibility of computing the change in deflection between two astronomic observation stations by using gravity data. If the position of one is known on the 1927 North American Datum, the position of the other could then be computed on that datum. This computation, involving Stokes theorem, is complicated and the accuracy attainable and the density of gravity survey required have not yet been thoroughly investigated. It might be possible to check this on land using the results of exploratory gravity surveys already made. A thorough study of the accuracies attainable should be made. If accuracies of one second or better could be obtained for differential deflections the astronomic method could, theoretically, give positions for stable platforms to a standard deviation of about 40 m. It seems reasonable that differential deflections might be computed with a standard deviation of 3 seconds, in which case the standard deviation of the position referred to the 1927 North American Datum would be about 100 m. To position a semi-submersible platform, there would be the additional requirement to use a very expensive gyro-stabilized platform for observing. The accuracy attainable is unknown.

OFFSHORE MONUMENTATION

Monuments, which may be posts, stakes, pegs, mounds, pits, trenches or any other devices used to mark a boundary or the location of a point, provide a system of horizontal control over visual markers, the positions and characteristics of which are recorded. One essential feature of this system is that the monument location can be re-occupied for the purpose of checking or extending the control network.

The feasibility of establishing a similar monumentation system over Canada Lands Offshore has been studied in detail keeping in mind the present Canada Oil and Gas Land Regulations, national security, economic limitations and the capability of our present technology to provide permanent fixed and re-occupiable markers in the offshore environment. With respect to the latter we have examined the possibility of using as offshore monuments towers, buoys, transponders (both active and passive), reflectors, abandoned wells, submarine cables, wrecks, physical features (both surface and sub-surface) and potential field anomalies (gravity and magnetic).

With the exception of development platforms each type of monument considered fails one or more of three basic criteria,i.e. permanence, accuracy or re-occupiability. Destruction by fishing gear seriously affects the life span of most types of monuments considered. Corrosion is another serious barrier to the long life of any monument. Short term protection can be provided in the form of inert or galvanic coating and by increasing cross-sectional areas to provide for metal loss. Long term protection can only be given by cathodic processes in which a permanent power supply is required to maintain a potential difference or in which the sacrificial metal of an anode is constantly replenished.

With respect to the Canada Oil and Gas Land Regulations it appears that there is no urgent requirement for an offshore monumentation system prior to the establishment of a permanent development platform.

It would be desirable to have permanently monumented control throughout the Continental Shelf but economic considerations preclude the establishment of such a system.

TOWERS

There are 2 types of towers that might be used for survey monuments out of sight of land. These are (a) permanent towers fastened to the bottom of the Continental Shelf, (life expectancy 20 to 50 years) (b) floating towers moored to the bottom (life expectancy 2 years).

Permanent towers, equipped for helicopter landing have been built in Canadian coastal waters for lighthouse purposes and elsewhere in the world for oil production at sea. An adaptation of these would be suitable for permanent referencing. They have the advantage of permanence, can be used whenever weather permits helicopter flight and are sufficiently stable for the rigid requirements of astronomic observation.

The cost of construction is very high and it is doubtful if this cost could be justified even considering shared use for aids to navigation and scientific purposes. Following is a brief summary of towers already built:

1. Prince Shoal Pier lighthouse built in 1963 in 28 feet of water at low tide (42 feet high tide) in the St. Lawrence River at the junction of the Saguenay River. The tower is designed for hurricane winds, severe ice pressures but moderate wave forces. The cost was $1,600,000. The equipment on board included in this cost was $150,000 and living accommodation for 4 people is provided. The design of this tower was adapted for the Cook Inlet oil production tower, Alaska, built in 1966-67 at a cost of $10,000,000 including equipment.

2. Buzzards Bay lighthouse built in 1961-62 at the Cape Cod Canal entrance in 61 feet of water. Cost $2,200,000. Designed for hurricane force winds and waves but not ice. The vibration of small waves that caused the failure of a Texas tower has given the U.S. Coast Guard concern for the safety of this tower. They have stopped their programme of replacing lightships by similar towers for two reasons (a) redesign for those vibration forces, the parameters for which are not well known, and (b) advance in cost since 1962.

3. Oil production platforms have been built off the United States coast of the Gulf of Mexico, off the coast of California and in many other offshore regions of the world. Representative cost figures for the Gulf Coast area are as follows:

    100' depth $ 750,000
    200' depth $1,250,000
    400' depth $5,500,000

Costs vary with depth and other design considerations such as the number of wells to be drilled, environment, oceanography etc. A platform is currently under construction for use by Shell Oil Co. in the Gulf of Mexico for a record water depth of 373 feet. The oil industry has preliminary studies of a production platform in 300 feet of water on the Grand Banks. The estimated cost of the tower installed without the equipment is $10,000,000.

Two types of floating towers have been built in Canada:

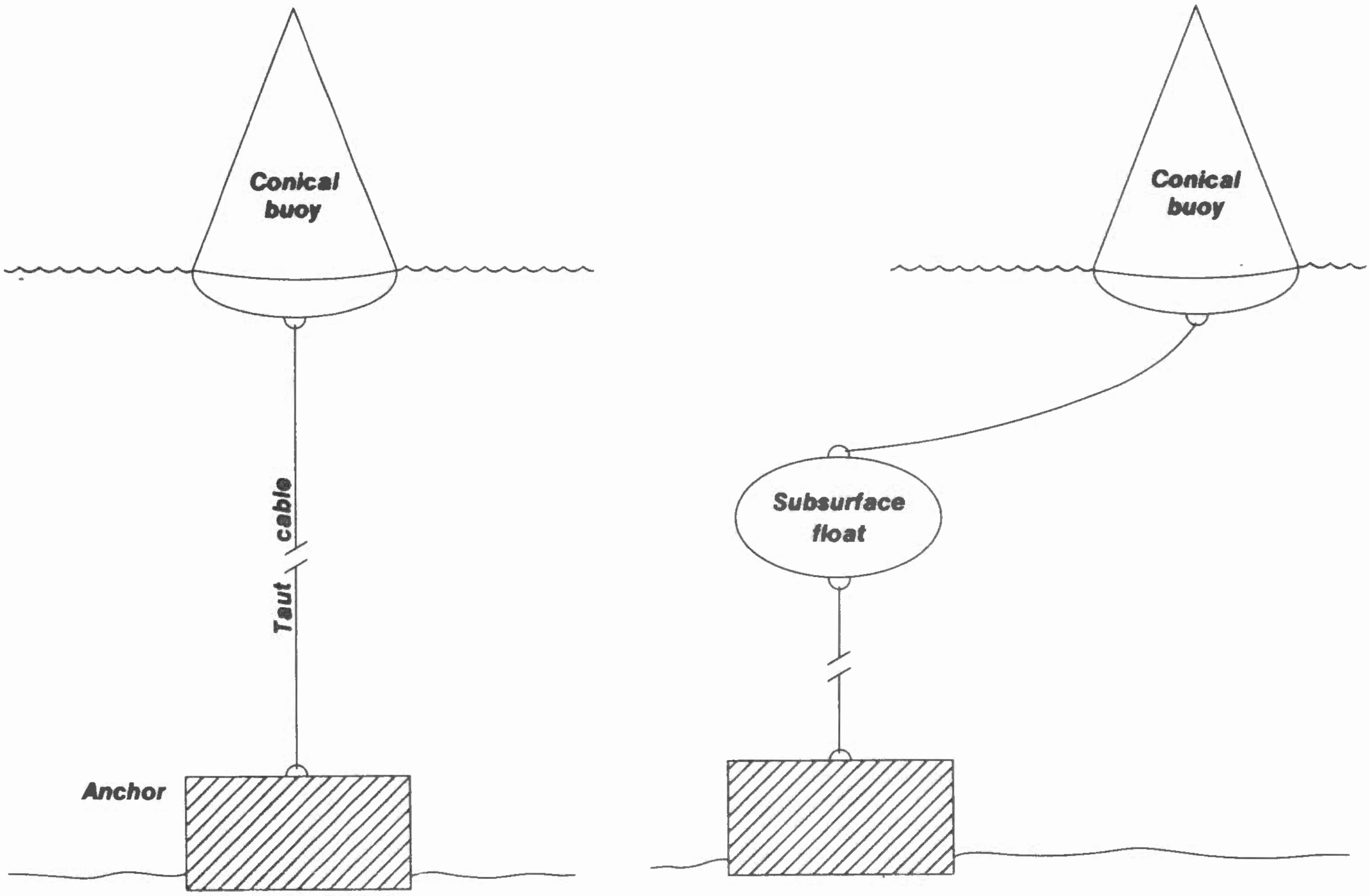
1. Scientific stable platforms in Lake Superior, Gulf of St. Lawrence, and off Halifax. These were in relatively shallow water where divers could assemble moorings. The cost varied between $50,000 and $150,000 installed. In Lake Superior the towers were removed in the fall and replaced in the spring to protect them from ice. Off Halifax the tower remained for 2 years before it was destroyed by a storm. These towers have no helicopter platform and can be boarded only in a calm sea.

2. Semi-submersible oil drilling units of the SEDCO 135 type costs $12,000,000 to $14,000,000 to build and $20,000 to $30,000 per day to operate. They are usually on one well location for periods of only one to three months. The stability permits accurate location. Astro observations may not be possible however.

BUOYS

There are many types of buoys, with different characteristics. Basically they are moored in two ways, conventionally, which involves moorings of 2 - 3 times the water depth, and taut line which has the shortest mooring consistent with keeping the buoy visible. (See Figure 8(a)(b)(c))

A relatively long life, i.e. 2 years or more, can be obtained with moorings approximately 2 - 3 times the water depth, but obviously this permits a greater movement of the buoy and hence a less accurate position. Greater accuracy can only be obtained by a taut line mooring and here life is measured in terms of months even with weak currents and good weather. (See Figure 9)



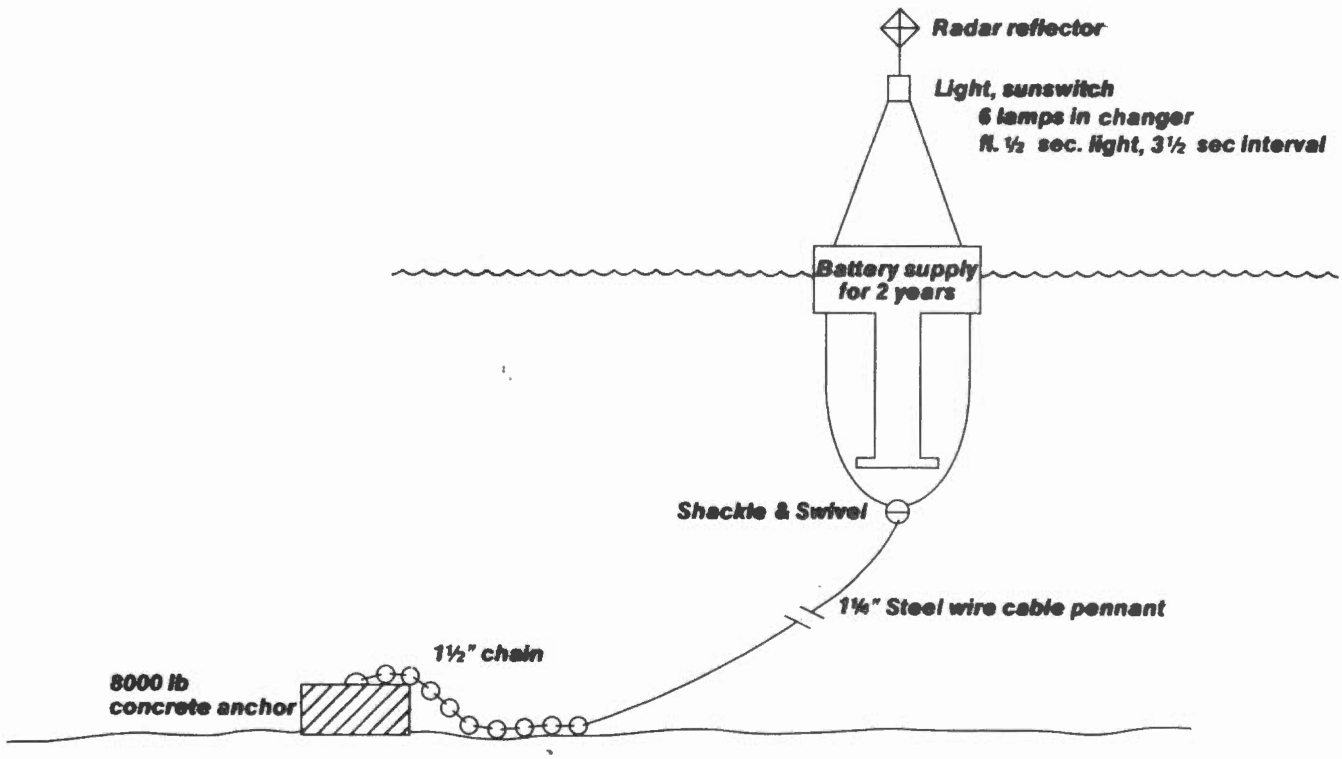
Taut Buoy Wire System

(a)

Subsurface Buoy System (Modified Taut Wire)

(b)

Figure 8
Buoy Moorings



Conventional Mooring
(c)

Figure 8
Buoy Moorings (Continued)

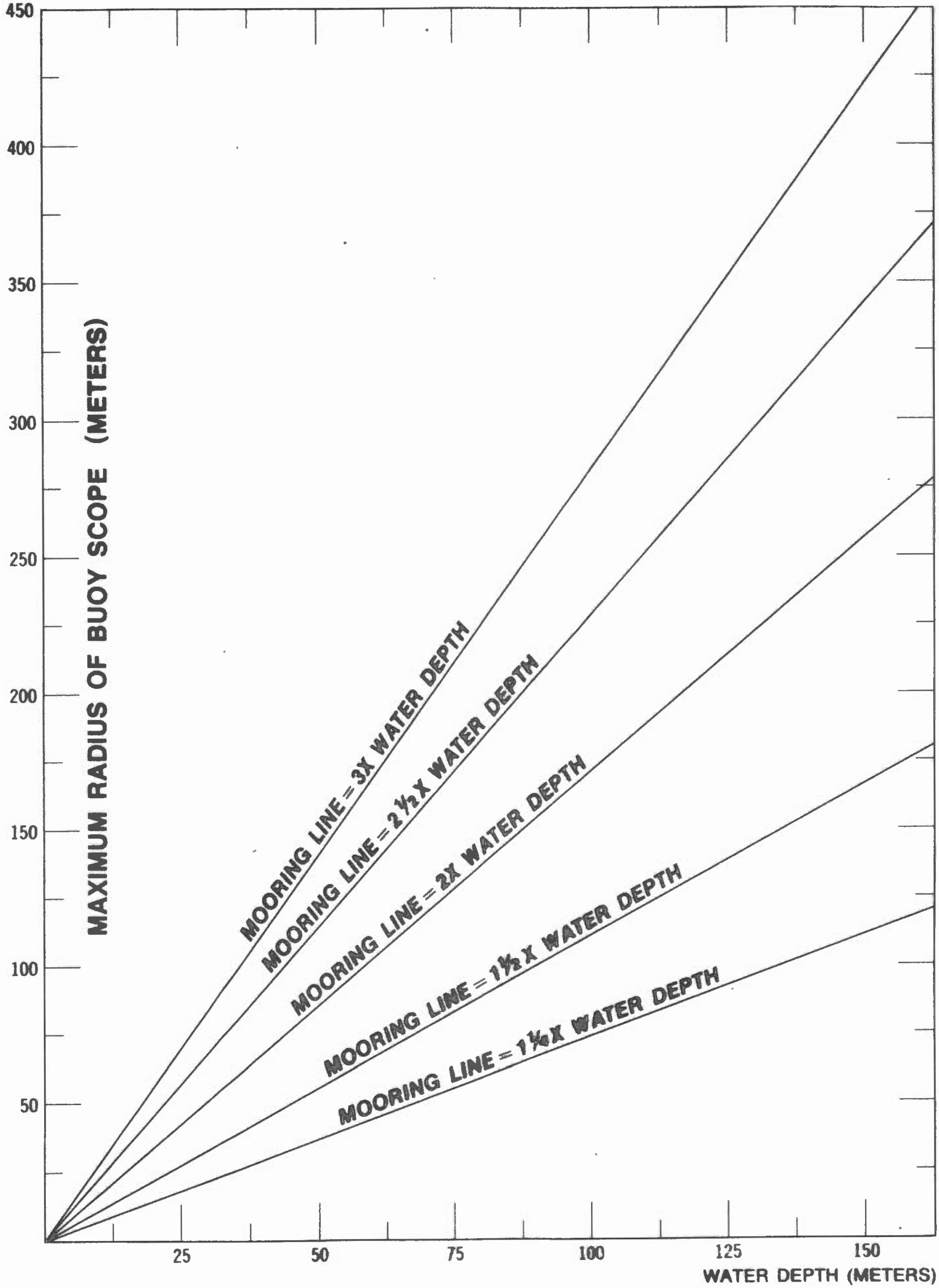


Figure 9
Graph of Buoy Scope

Maintenance at sea is normally a matter of replacement as the moorings determine the life of the buoy on station. Under these circumstances the complete buoy system has to be raised and a new system laid. Present buoy laying technology makes it impossible to lay this new system on the same spot. We therefore have virtually a new monument and would have to reactivate a positioning system to fix the buoy again.

Buoys are recoverable under normal conditions of sea and weather and are easily identifiable.

Further drawbacks to the use of buoys as monuments are that they are liable to drag their moorings in heavy weather, particularly taut line moored buoys, and this movement may not be readily noticed. They are susceptible to icing up and toppling. They may be moved off station by floating ice, or frozen in and crushed. There is also the possibility of movement or even removal by fishermen operating in the area.

The greatest depth at which the Department of Transport (DOT) has had experience is about 60 fathoms. Periodic checking is required in any buoyage system. DOT work on a 1 - 2 year replacement and approximately a four month check. Checking and replacing involves ship time at a cost of about $2,500 per day. Buoy costs vary from approximately $1,000 for a small conical buoy to approximately $10,000 for a large (ten-ton) buoy. Normally, three buoys are required to keep two permanently on station.

A buoyage system would be of doubtful accuracy and would be extremely expensive. On a practical basis, it requires a permanent accurate positioning system. DOT has found that Navigation Decca has an accuracy of about ± 1,500 feet, which is not acceptable for surveys. In addition there would be costs of $15,000 per station based on 1½ ten-ton buoys per station, and maintenance costs of approximately $40,000 per annum per station including estimated ship costs.

TRANSPONDERS

Transponders are divided into two types, active and passive. The active type gives a continuous underwater signal which can be detected by sonar. The passive type is keyed by sonar and responds. The life of active transponders depends primarily on the life of the power pack while the passive type is dependent on the number of interrogations, and also on the battery shelf life. It is unlikely that the life of the total system can be assured beyond 5 - 7 years because of corrosion, regardless of the power source. Transponders can be coded to provide definite identification to avoid confusion or ambiguity in any array.

Distances at which these devices may be detected by sonar depend on acoustic noise but generally are in the one mile range. To achieve such ranges the transponder ideally should be buoyed above the seabed. Proximity to seabed and greater depths decrease range and accuracy.

Surface vessels must be fitted with sonar to detect these instruments. Positioning the vessel over the transponder presents problems.

Maintenance of these instruments would involve replacement and this would entail the use of divers or submersibles, or redropping and refixing, the latter naturally involving the reactivation of a positioning system.

In all forms these transponders are liable to be moved by fishermen.

The Department of National Defence has indicated that should such a system be considered, they would favour a type of transponder that could readily be deactivated.

A typical cost figure for a coded transponder and bottom release system would be $3,500 per unit. (1 year life power pack)

In summary, these transponder locations are not occupiable, are of variable life with the power unit cost increasing substantially to achieve a life of useful duration, are subject to movement and at the present stage of technology are not of guaranteed reliability. A power supply has been built, at a cost of more than $1,000,000, which manufacturers claim will last 20 years.

WELLS

Producing wells in the offshore environment (in depths to 400 feet) are generally associated with permanent surface platforms and have excellent characteristics for use as survey monuments. These have already been covered under the section on Towers. The following remarks therefore, apply only to abandoned exploratory wells.

Abandoned offshore wells have some characteristics that are desirable as survey monuments but at the same time there are factors that make them very difficult to use and therefore, are considered essentially useless as survey monuments.

Long life, stability and permanence of position are all desirable features for any survey monument and abandoned wells would provide these in excellent fashion. In addition there would be no maintenance to such a well.

Identification and re-occupiability are two essential criteria of any marker to be used as a survey monument and these are extremely difficult to obtain with abandoned wells. The present manner in which most wells are abandoned at sea leaves no physical evidence on the bottom of a well having been drilled. The casing is usually sheared off from ten to twenty feet below the mudline and all equipment recovered. Within a short time, the hole fills in with sand etc. and leaves not even a scar for detection. Therefore if any visual means, e.g. T.V. camera etc. were to be used to relocate an abandoned well, some physical object would have to be left there at the time of abandonment that would be easily detectable. In order to do this an entirely new abandonment procedure would have to be developed and this does not seem feasible at the present time. In addition anything left on the bottom would be subject to destruction by icebergs and fishing draggers.

The only other feasible method of finding an abandoned well would be by possible magnetic detection of the well casing. This might be accomplished by towing a magnetic sensing head near the sea floor over the well. This at best would give only a relative position for one instant and one could never be positive as to the position of the sensing head relative to the well itself. (See Appendix C for a more detailed appraisal of the method.)

Both the above methods, (visual and magnetic detection) are considered to be cumbersome and difficult to use and have the added objection that one can never be certain of the observer's position relative to the marker.

In view of the foregoing, abandoned wells are difficult to find, are not occupiable, and in some cases may not be identifiable and therefore are not considered to be useful as survey monuments at sea.

CABLES

Cables were considered from two standpoints. First as electronically detectable line markers along the ocean floor so that intersecting lines would define a point and secondly as a means of providing a permanent power source to active bottom transponders.

As line markers, cables are unsuitable because the shielding needed to protect them makes them virtually undetectable unless a break occurs. They are also very prone to movement and to breakage wherever there is a dragging operation or where icebergs ground. Icebergs near Greenland rested on a cable in a depth of 230 metres, broke the cable and prevented repairs for a period of 6 months.

Some protection is afforded, at great cost, by burying the cables. In fact, buried cables have not experienced breaks to date. The cable companies have not devised a means of recovering buried cables.

Cables are inordinately expensive as a means of providing permanent power to acoustic transponders. In fact with installation at $13,200 per kilometer and maintenance at $100,000 per break, the costs are prohibitive. It should also be noted that cheaper power sources are now available that will outlast the probable effective life of the exposed mechanical components of acoustic transponders.

WRECKS

It is well known that the Canadian Continental Shelf is strewn with sunken ship wrecks of various sizes and at various depths. At present, the approximate locations of most of these wrecks are classified military information. It is believed that this security restriction could be overcome, in specific instances, if these wrecks could be useful as boundary reference marks.

At first glance, it might appear that such sunken wrecks would serve admirably for such purposes if situated near the points being referenced. As they would be in position, there would not be any construction or maintenance expenditures.

On closer examination, the matter is not quite so simple. In many cases, these known locations of wrecks are based on dubious information such as the last reported "dead reckoning" position of the vessel before it sank. It has been found that the final resting place of such ships is often far from such positions. Consequently, it is quite likely an extensive search with special acoustical equipment would have to be undertaken to pinpoint the actual position of a particular wreck. In all probability, such acoustical equipment would have to be utilized each time reference was being made to the "monument" thereafter, although such a search would be facilitated by the previously determined coordinates of the wreck.

As some sunken ships are subject to a certain amount of shifting due to underwater currents, and others are eventually covered over by silting, or break up, only those ships of substantial size and in a reasonably good state of preservation could be classed as being permanent enough to be considered for monument purposes.

The use of sunken ships as survey monuments can be disregarded. Limited use has been made of wrecks, as positioning aids, during offshore mineral exploration surveys. They have been used for example to check for movement of transponders.

POTENTIAL FIELD ANOMALIES

In recent years, the Marine Sciences Branch has been making continuous measurements of the earth's gravity field in conjunction with offshore bathymetric surveys. These measurements are recorded and contoured presentations showing their variability on a sea level datum are prepared in a manner similar to that of bathymetric charts.

Magnetics. Factors affecting the accuracy and repeatability of magnetometer measurements can be divided into three broad classes:

1. Instrument system errors which are probably less than five gammas.
2. Approximately predictable time varying changes in the magnetic field which are generally of the order of twenty-five gammas.
3. Unpredictable transient disturbances called magnetic storms. The intensity of these variations may exceed several hundred gammas.

It is evident that due to the numerous error sources the exact position of a point even on large-amplitude, high-frequency magnetic anomalies is not sufficiently well defined to serve as a survey monument.

Gravity. The accuracy and repeatability of shipborne gravity meter measurements are affected by instrumental and environmental factors. At the present time, the accuracy of shipborne gravimeter measurements is approximately two to three milligals under carefully controlled surveys with good navigation.

As gravity anomalies are generally of less gradient than a few milligals per mile, contours of anomalies are not sufficiently definitive to serve as survey markers or monuments.

PHYSICAL FEATURES

The Canadian Oil and Gas Regulations, Section 13(1)(b) refers to the use of a topographical feature that is identifiable on a map that has been published by, or on behalf of, the Government of Canada. Offshore, submerged topographical features are normally shown only on Nautical Charts. These are maps which have been designed as Aids to Marine Navigation and due to the inherent variables of chart usage and need, no two charts may even be exactly similar in character and scope although the work conforms to the same general standards. The variety of submarine relief is presented in a clear and practical manner so that dangers as well as features which may be useful as aids when navigating by echo-sounding, or other sonar apparatus, are identifiable. In deep water, depth soundings are widely spaced but they are more closely spaced on the Continental Shelf and in shoal water. Depth contours are used to bring out more clearly the features of value to navigation.

Physical features do not appear to be useful as monuments but may serve as reference marks when relocating or recovering abandoned wells, wrecks, acoustic reflectors or other apparatus on the sea floor. They fall into two categories:

1. Bottom features are shoals, banks, canyons etc. which have been identified during the course of hydrographic surveys and are shown on Nautical Charts. Bottom characteristics are shown by appropriate abbreviations.

2. Sub-bottom features are usually rock formations which are covered by a layer of sediment although, in some areas, sunken wrecks which have become covered by sediment over the years may exist. These features are frequently detected during the course of hydrographic surveys, because the echo-sounding signals penetrate the sediment cover and are reflected back to the survey ship and recorded in the same manner as bottom features. However, these sub-bottom features are not normally shown on Nautical Charts.

ACOUSTIC REFLECTORS

On the continental shelves, underwater positioning systems using an array of reflectors could be very useful in positioning a vessel.

Distances measured to acoustic reflectors are affected by many factors. Some of these are the quality of the transmitting-receiving equipment, the transmitting medium itself which affects the velocity of sound, the signal frequency and target characteristics, the ship's speed and the bearing of the target.

To detect a reasonably-sized target the transmitting-receiving equipment must be highly directional and operate at high frequencies. This results in higher signal-to-noise ratio. Attenuation increases with frequency and reduces the effective range of the equipment. Frequencies from 5 to 40 K Hz are commonly used in echo-ranging.

The transmitting medium, which in this case is sea water, has undergone considerable study as to its effect on the propagation of underwater acoustic signals. This information is readily available and is discussed at length in various texts. Conditions vary from one locality to another and for accurate measurements of range, careful calibration for the determination of the various parameters affecting propagation must be carried out for every array of reflectors.

The reflected signal is affected mainly by size, shape, attitude or position of the target in relation to the transmitted signal and range from the signal source. These factors all combine to determine the target strength.

Target strengths of objects like cylinders and submarines vary with orientation. Spheres make good targets when they can be used because their target strengths are relatively independent of orientation. Highly compressible spheres such as gas bubbles, have greatly increased target strengths.

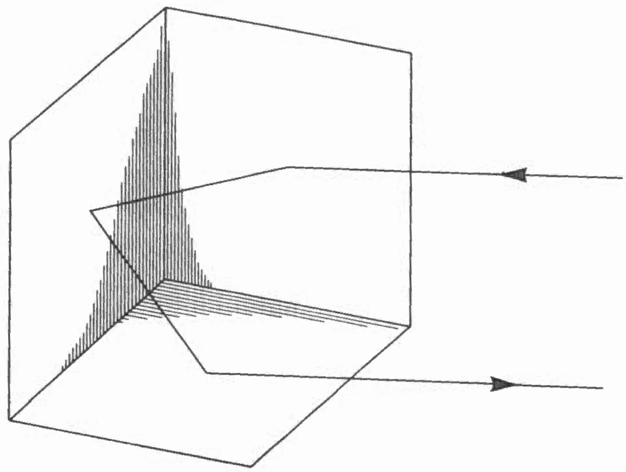
The greatest target strengths are obtained from flat surfaces which are perpendicular to the acoustic signal path. Corner reflectors and triplane reflectors (see Figure 10(a)(b)) give an almost constant reflected signal regardless of the direction from which the signal is received. Considerable increase in target strength is obtained by constructing the triplane target so that its reflecting plates contain an air space.

The triplane type target has undergone a series of tests as to effective ranges compared with other targets of various shapes and would appear to be the most effective considering the size of target required. Most targets of this type use plane surfaces 6 feet to a side, and may be detected at ranges to 1,000 meters. The cost of such reflectors including anchoring system is from $1,000.00 up.

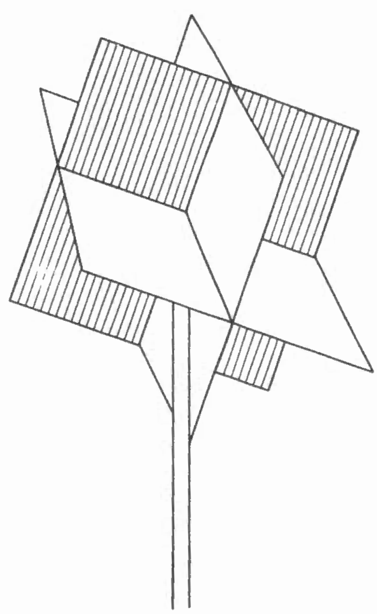
Since it is necessary that the target be distinguishable, it must be held off the bottom to separate it from the background reflections. The usual height is about twenty feet from the seabed. This necessitates the use of buoys, anchors, and cables, leading to some of the disadvantages of the use of reflectors.

There does not seem to be any doubt that a system of reflectors accurately positioned near the ocean floor, could be used to position a surface or a sub-surface vehicle. The problems are similar in many ways to those of buoys and, in addition, the target cannot be located visually.

The maintenance of the system, once established, would be similar to that of buoys and transponders. They require regular series of checks on the stability of their positions. They would have to be repositioned after maintenance. They would be vulnerable to fishing draggers. They would lose target strength due to sea growth on reflecting surfaces and to some extent other deposits and chemical reaction. They would be subject to the limited life of the anchoring system (cables, buoys, etc.). All these things and the



(a)
Corner Reflector



(b)
Triplane Reflector

Figure 10
Acoustic Reflectors

present difficulty of accurately positioning them, give some indication of the problems which, although not insurmountable, would require serious consideration and study.

APPENDIX A

MEMBERS AND PARTICIPANTS

MEMBERS

Canadian Petroleum Association

R. Anderson, Senior Geophysicist, Amoco Canada
A. Hittel, A.L.S., Chief Surveyor, Shell Canada

Department of Energy, Mines and Resources
Surveys and Mapping Branch

W.V. Blackie, D.L.S., O.L.S., Legal Surveys Division, Workshop Coordinator
D.H. Browne, D.L.S., O.L.S., Legal Surveys Division
R.G. Snowling, D.L.S., Legal Surveys Division
P.I.R. Sauve, D.L.S., Legal Surveys Division
H.E. Jones, D.L.S., Geodetic Engineer, Geodetic Survey Division

Marine Sciences Branch

H. Blandford, Hydrographer, Master Mariner, Canadian Hydrographic Service
G. Ewing, Hydrographer, Geophysicist, Canadian Hydrographic Service
R.W. Sandilands, Hydrographer, Mariner, Canadian Hydrographic Service
G. Wade, Hydrographer, D.L.S., N.S.L.S., Canadian Hydrographic Service

Department of Transport
Marine Works Branch

F. Elliott, Engineer, Aids to Navigation Division

PARTICIPANTS

In addition to the full time members, representatives of several agencies participated while the workshop was dealing with matters in their special fields. Notable among these were:

Canadian Petroleum Association

D. Dawson, D.L.S, A.L.S., Chairman, Surveys and Mapping Committee
G. Turnock, A.L.S., Surveys and Mapping Committee

Department of Energy, Mines and Resources
Marine Sciences Branch

D. Wells, Metrology Section, Atlantic Oceanography Laboratory
P. Brunavs, Chief, Nautical Geodesy Section, Canadian Hydrographic Service

Resource Administration Division

M.D. Bell, P.Eng., Senior Conservation Engineer

Department of Indian Affairs and Northern Development
Oil and Mineral Division

R.R. McLeod, P.Eng., Administrator of Oil and Gas

WORKSHOP EDITORIAL COMMITTEE

W.V. Blackie
H.E. Jones
H. Blandford
M.D. Bell
A. Hittel

APPENDIX B

PROGRAM

for

a

WORKSHOP ON OFFSHORE SURVEYS

to be conducted by

The Department of Energy, Mines and Resources

in cooperation with

The Department of Indian Affairs and Northern Development

The Department of National Defence

The Department of External Affairs

The Department of Transport

The Department of Fisheries

and

The Canadian Petroleum Association

January 12 - February 20, 1970

Surveys and Mapping Building,
615 Booth Street, Ottawa

Workshop Director
Mr. A.C. Hamilton

Workshop Program Coordinator
Mr. W.V. Blackie

APPENDIX B

WORKSHOP ON OFFSHORE SURVEYS
INTRODUCTORY SESSION - 1 WEEK

JANUARY 12		
1:30 pm	*Formal Opening* *Overview and Objectives*	Guest speaker, Dr. C.M. Isbister Deputy Minister, EMR Mr. S.G. Gamble, Director, Surveys and Mapping Branch, EMR Mr. D.G. Crosby, Chief, Resource Administration Division, EMR Mr. H.W. Woodward, Chief, Oil & Mineral Division, Northern Economic Development Branch, DIA & ND
8:00 pm	*Informal social evening as guests of Mr. & Mrs. S.G. Gamble, 244 Irving Avenue*	
JANUARY 13		
9:00 am	*Oil Industry Procedures and Problems (including reference to experiences elsewhere)* *Discussion*	Mr. A. Hittel, Chief Surveyor, Shell Canada Mr. R. Anderson, Geophysicist, AMOCO, Canada
JANUARY 14	*Vested Interest and Legal Aspects*	Mr. A.F. Lambert, International Boundary Commissioner, EMR
9:00 am	*Law of the sea*	Mr. Legault, Legal Division, Dept. of External Affairs
10:30 am	*Fisheries*	Mr. C.R. Levelton, Director, Regional Operations, Fisheries Service, Dept. of Fisheries & Forestry
1:30 pm	*Navigation Safety and Marine Regulations*	Capt. W.S.G. Morrison, Superintendent, Marine Crews & Navigation Safety, Marine Regulations Branch, DOT
3:00 pm	*Security*	L/CDR B. Torrie, Mapping & Charting Establishment, DND

JANUARY 15 9:00 am	*Present Oil, Gas (and Mining) Regulations*	Mr. M. Bell, Resource Administration Division, EMR Mr. R.R. McLeod, Oil & Mineral Div., Northern Economic Development Br., DIA & ND
	Discussion	
1:30 pm	*Present Oil, Gas (and Mining) Land Survey Regulations*	Mr. R. Thistlethwaite, Surveyor General, Legal Surveys Div., EMR
	Discussion	
JANUARY 16	*Principles of systems evaluation*	Mr. A.C. Hamilton, Coordinator, Research & Training, Surveys & Mapping Br., EMR Mr. R. Groot, Geodetic Survey Div., Surveys & Mapping Br., EMR
11:00 am	*S&M Branch seminar: GALS. A computer program for the design, adjustment and analysis of survey networks. C.D. McLellan.* *Note: Group may break up into two, or three, subgroups for the discussion sessions.*	

WORKSHOP ON OFFSHORE SURVEYS
SESSION II - 2 WEEKS
POSITION DETERMINATION
Session Coordinators - H.E. Jones & R.G. Snowling

JANUARY 19 9:00 am	*Geodetic Methods* *Geodetic Methods and Control* *Discussion*	Mr. H. Klinkenberg, Chief, Computations & Research, Geodetic Survey
10:30 am	*Datums, Elipsoids and Geoid* *Discussion*	Mr. A. Peterson, Adjustment Section, Geodetic Survey
1:30 pm	*Astronomy and Geodetic Surveying* *Discussion*	Mr. H. Jones, Research Section, Geodetic Survey

3:00 pm	*E.D.M. and Geodetic Surveying* *Shoran, Hiran and Shiran* *Discussion*	Mr. S. Yaskowich, Electronics Section, Geodetic Survey
JANUARY 20	*Short Range (Precise, Fixed Marker) Systems*	
9:00 am	*Geodimeters, Tellurometers and similar Instruments* *Discussion*	Mr. D. MacDonald, Legal Surveys
10:30 am	*Aerodist and Hydrodist* *Discussion*	Mr. R. Colwell, Geodetic Survey
1:30 pm	*A.B.C., Autotape, Hoversight*	Mr. D.H. Browne, Legal Surveys
3:00 pm	*Photogrammetry*	Mr. R.E. Moore, Topographical Survey
JANUARY 21	*Decca Systems*	
9:00 am	*Introduction*	Mr. D. Wells, Atlantic Oceanographic Laboratory
	Evaluation	Mr. A. Hittel, Senior Surveyor, Shell Oil
	Evaluation *Discussion*	Mr. R. Anderson, AMOCO
1:30 pm	*Evaluation*	Mr. P. Brunavs, Canadian Hydrographic Service
JANUARY 22		
9:00 am	*Satellite Navigation Systems*	Mr. D. Wells, Oceanographic Lab.
	Evaluation	Mr. R. Stacey, Gravity Division, Observatories Branch, EMR Mr. A. Hittel, Senior Surveyor, Shell Oil Dr. E. Krakiwsky, U. of New Brunswick, Fredericton
	Back-up Systems	
1:30 pm	*Loran A and C* *Discussion*	Mr. J. Cianfaglione, Dept. of Transport
3:00 pm	*Lorac A and B* *Discussion*	Mr. G. Wade, Canadian Hydrographic Service

JANUARY 23		
9:00 am	*BIO Study on Navigation*	D. Wells, Atlantic Oceanographic Laboratory
	Rana	G. Wade, Canadian Hydrographic Service
	Hi-Fix, Mini-Fix	R.W. Sandilands, Canadian Hydrographic Service
	Raydist, XR Shoran	D. Wells, Atlantic Oceanographic Laboratory
	OMEGA	G. Wade, Canadian Hydrographic Service L.W. Sobczak, Polar Continental Shelf Project
1:30 pm	*Exploration and Production Drilling*	J. Cook, Shell Canada
JANUARY 26	*Re-Cap of January 19-23*	W.V. Blackie, G. Ewing, H. Blandford
	Jan. 27-28-29 Hydrographic Conference (Talisman Motor Hotel, Carling Avenue)	
JANUARY 30	*Syndicates and group discussion*	
1:30 pm	*Doppler Sonar*	R.W. Douglas, Bedford Institute
2:00 pm	*Group Discussion*	
4:00 pm	*R.P.S.* *Ground Wave Propagation Over Ice*	N. Anderson, Canadian Hydrographic Service

WORKSHOP ON OFFSHORE SURVEYS
SESSION III - 2 WEEKS
SEA SURFACE AND SUB-SURFACE MARKERS AND MEASUREMENTS
Session Coordinator - Mr. H.R. Blandford

FEBRUARY 2		
9:00 am	*Currents* *Discussion*	Mr. J. Warner, Nova Scotia Technical College
1:30 pm	*Sea Ice*	Mr. W. Markham, Meteorological Br., Dept. of Transport, Halifax

(Appendix B (continued))

FEBRUARY 3		
9:00 am	*Wave action Discussion*	Mr. H. Neu, Atlantic Oceanographic Laboratory
1:30 pm	*Corrosion Discussion*	Dr. J.H. Greenblatt, Defense Research Establishment (Atlantic)
FEBRUARY 4		
9:00 am	*Syndicates and group meeting*	
FEBRUARY 5		
9:00 am	*Syndicates and group meeting*	
FEBRUARY 6		
9:00 am	*Magnetic Methods*	Dr. S. Shrivastava, AOL, Bedford Institute
	Airborne and seaborne	Dr. P. Hood, GSC
1:30 pm	*Syndicates and group meeting*	
FEBRUARY 9		
9:00 am	*Underwater measuring devices (sounders and sonars etc.)*	Mr. R.W. Sandilands, Canadian Hydrographic Service
1:30 pm	*Sub-surface markers hardware and stability*	Mr. R.F. Brown, Defense Research Establishment (Atlantic)
FEBRUARY 10		
9:00 am	*Buoyage Systems*	Mr. K. Curran, P.Eng., Dept. of Transport, Halifax, M. Leaver, Captain, Dept. of Transport, Halifax
FEBRUARY 11		
9:30 am	*Review Session*	
FEBRUARY 12		
9:00 am	*Cable Operations and Cable Engineering Discussion*	Mr. G. Foley, Canadian Overseas Telecommunication Corp.
FEBRUARY 13	*Re-cap February 2-13*	Blackie, Blandford, Ewing

WORKSHOP ON OFFSHORE SURVEYS
SESSION IV - 1 WEEK
ASSESSMENTS, EVALUATIONS AND RECOMMENDATIONS

Note: Schedule for the week to be arranged during the re-cap exercises at the end of Sessions II and III.

Participants:

Surveys and Mapping Branch (EMR) Legal Surveys Division	W.V. Blackie, DLS, OLS, Chief Plans Examination D.H. Browne, DLS, OLS R.G. Snowling, DLS, Research and Development Officer P. Sauve, DLS
Geodetic Survey Division	H.E. Jones, P.Eng., DLS, Head of Geodesy Subsection
Marine Sciences Branch (EMR)	G. Ewing, Assistant Regional Hydrographer, Atlantic Region H.R. Blandford, Assistant Regional Hydrographer, Central Region G.E. Wade, DLS, NSLS, Hydrographic Surveyor, Central Region R.W. Sandilands, Hydrographic Surveyor Pacific Region
Resource Administration Division (EMR)	M.D. Bell, P.Eng., Senior Conservation Engineer
Northern Economic Development Branch (IA & ND)	R.R. McLeod, P.Eng., Administrator of Oil and Gas
Industry	A. Hittel, ALS, Shell Canada Ltd. R. Anderson, Senior Geophysicist, Amoco, Canada G. Turnock, ALS, Imperial Oil Ltd. D. Dawson, DLS, ALS, Mobil Oil Canada
Department of Transport Marine Works Branch	F. Elliott, Engineer, Aids to Navigation Division, Management Superintendent

APPENDIX C

MAGNETIC DETECTION OF ABANDONED WELLS

The magnetic anomaly produced by a vertical string of casing which is long compared to the water depth may be approximated fairly well by considering only the magnetic pole at the top of the casing, and ignoring the pole of opposite polarity located at the remote end. Moreover, because the earth's field dips at a high angle, which is more than 70° over most of the Canadian continental shelves, for the purposes of this exercise the field can be considered to be vertical without very much error.

The maximum anomaly produced at the surface of the ocean is given by the formula $\Delta Z_{MAX} = \frac{kAZ}{h^2}$ (which is an inverse square law relationship) where k and A are the effective susceptibility and corss-sectional area of the casing respectively, Z is the intensity of the earth's magnetic field, and h is the depth to the top of the casing. A typical value for Z would be 50,000 gammas.

An average value of k of steel would seem to be 15, which is a value derived from the values for the permeability of cold rolled steel and iron given on page 2645 of the 41st edition of the Handbook of Chemistry and Physics published by the Chemical Rubber Publishing Co., in 1960. However, there seems to be strong evidence (particularly from observations of the magnetic effects of casing in the Redwater oilfield of Alberta) that casing can give negative anomalies. This would indicate that the remnant (or permanent) magnetism of the casing can exceed that induced by the earth's field. This exercise therefore will only indicate approximately what the maximum amplitude of magnetic anomalies from oilwell casing is likely to be. The maximum anomaly values (ΔZ_{MAX}) for various depths (h) and cross-sectional areas of the casing (A) may be estimated from the accompanying graph. It would seem reasonable that A would probably not exceed 50 square inches, which would mean that ΔZ_{MAX} would not exceed 10 gammas over a great deal of those portions of the Canadian shelves which have substantial thickness of sedimentary rocks, i.e. the outer parts of the shelves, because of the depth of the water.

What is important is not the maximum anomaly so much as the area, which will approximate a circle, within which the anomaly is detectable. The anomaly

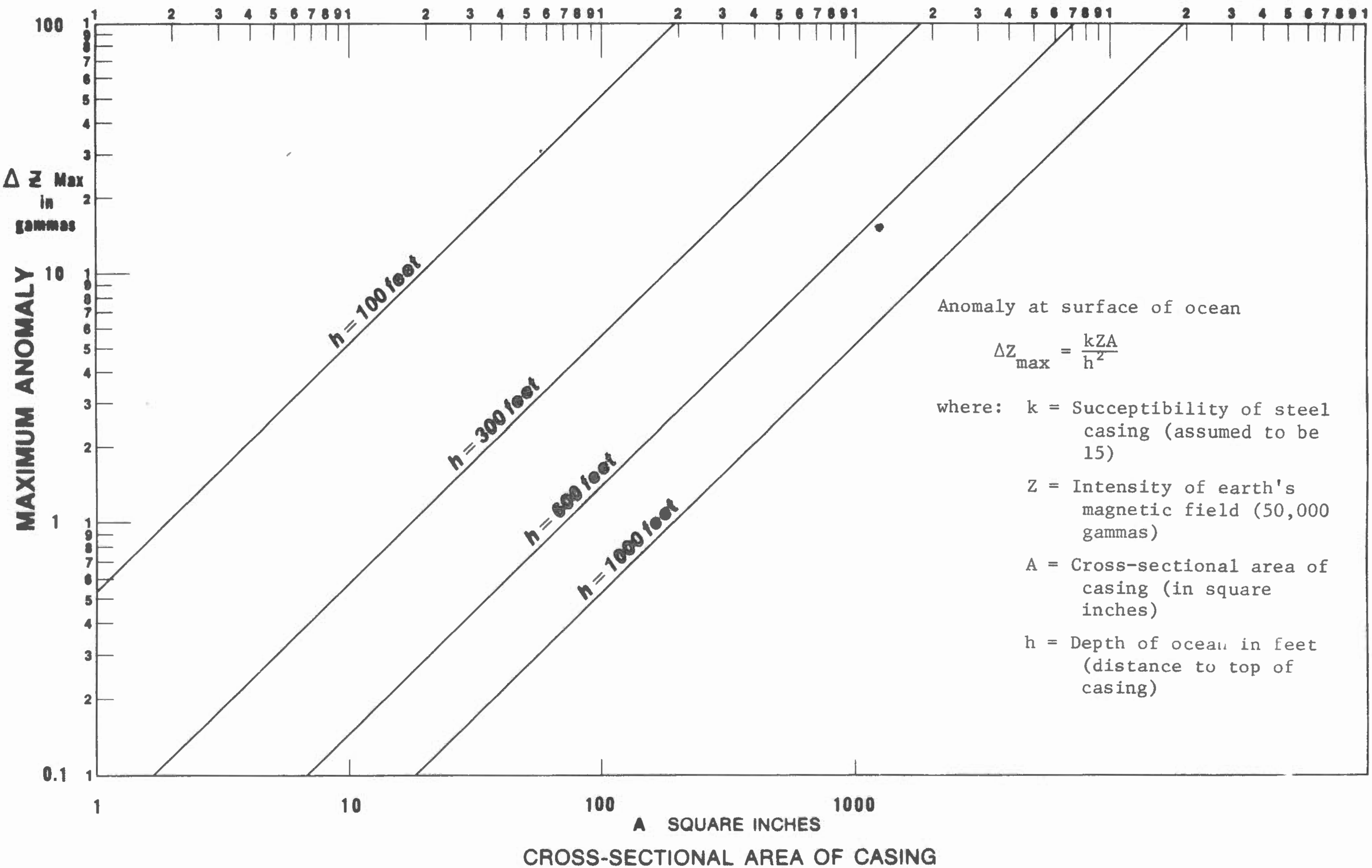


Figure 11
Magnetic Effects of Oilwell Casing

will fall to half its maximum value at a distance of about 0.75 h, i.e., 450 feet in the 100 fathom case, from the maximum value at the centre of the circle and to less than 10% of its maximum value in a distance of 2h which is quite a rapid rate of fall off.

From a consideration of the graph it would not appear feasible to try and locate the casing from a ship-towed instrument, because with the present generation of proton-precession magnetometers the anomaly would probably have to be at least 50 gammas in amplitude to be detectable, and it would probably require many hours of search unless an electronic navigation aid could first pin point the location of the anomaly fairly well. An airborne magnetometer survey system could do much better in detecting the anomaly, but there would still be the problem of marking the location for subsequent use.

There was little optimism about the practical feasibility of using casing as a magnetic marker except perhaps in special circumstances such as a line of wells being drilled when the search problem would be considerably simplified.

APPENDIX D

PRINCIPAL REFERENCES

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Decca Lambda Accuracy Tests - Canadian Hydrographic Service Preliminary Report, Brunavs (1970)

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A Technique for Finding Gravity Vertical at Sea, W.S. Von Arx, Deep Sea Research, 1969 Supplement to Vol. 16, Pergamon Press

Level Surface Profiles across the Puerto Rico Trench, W.S. Von Arx, Science Dec., 1966, Vol. 154

In addition to the above, numerous internal operation and project reports of the Marine Sciences Branch, the Surveys and Mapping Branch and of Oil Company surveys were valuable sources of technical data.