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DEFENCE RESEARCH AND DEVELOPMENT CANADA (DRDC)
RECHERCHE ET DEVELOPPEMENT POUR LA DÉFENSE CANADA (RDDC)

The History of Defence Science in the Canadian Arctic

DRDC Arctic-Related Activities: 1947 to 2012

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Edited by Stéphane Blouin
DRDC – Atlantic Research Centre

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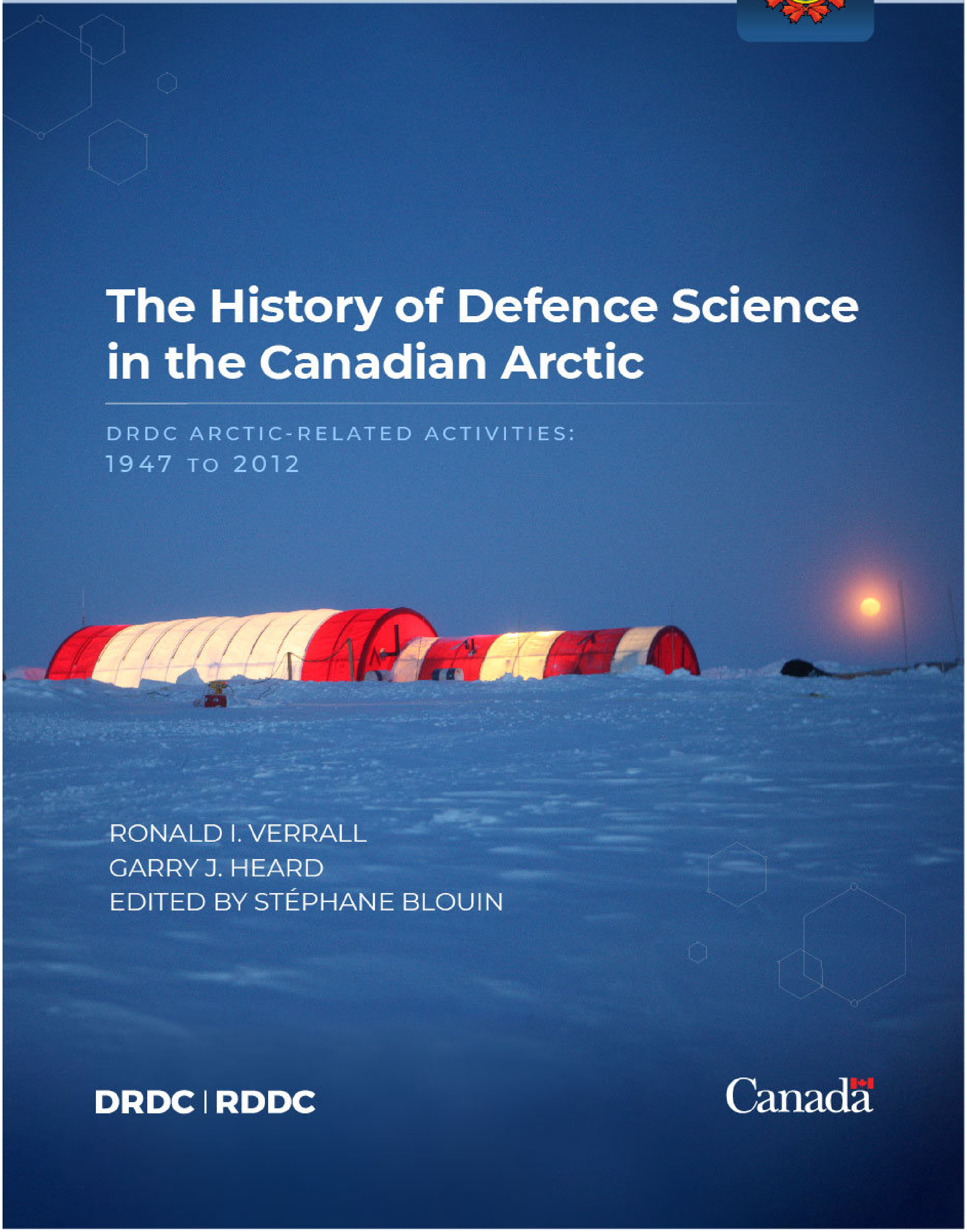

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Editor’s Note

This book was completed in 2012 after which it was passed through a lengthy review including external reviewers. Unfortunately, although the book was approved, it fell into a dormant state and a period of 10 years passed without the book being published.

This book covers the period from 1947 to 2012. The reader will find incomplete stories of some of the projects and will note that there is a discrepancy in the timeline presented.

Defence Research and Development Canada (DRDC) has continued working in the Arctic in the past 10 years, but the story of the projects undertaken in that interval will have to be told in a future history document. Some of the projects described in the present history book have long since been completed, but their stories are not finished here. In particular, the Northern Watch Technology Demonstration Project (TDP), Project Cornerstone, Suffield’s Vehicle Mobility project, and other newer projects have all yielded interesting results that will have to wait to be described.

Summary

In the period between 1947 and 2012, Defence Research and Development Canada (DRDC) and its predecessors conducted a wide variety of research activities in the Canadian Arctic. This book attempts to summarize the Arctic work done by nine separate Establishments in that time period, as well as by some early expeditions run by Defence Research Board (DRB) Headquarters. This history has been written in an attempt to provide general information to new employees who are preparing for their first Arctic experiences and to give background material to managers and Canadian Armed Forces personnel with an interest in Arctic activities. Hopefully it will also inform the general public of DRDC's valuable contributions to a better understanding of our Arctic regions and to our claims of sovereignty.

Résumé

De 1947 à 2012, Recherche et développement pour la défense Canada (RDDC) et ses prédécesseurs ont mené une vaste gamme d'activités de recherche dans l'Arctique canadien. Le présent livre renferme le résumé des travaux réalisés au cours de cette période dans l'Arctique par neuf établissements distincts et par les membres des premières expéditions dirigées par le Bureau chef du Conseil de recherches pour la défense. Cette histoire a été écrite dans le but de donner des renseignements généraux aux nouveaux employés qui se préparent à vivre leurs premières expériences dans l'Arctique et de fournir de la documentation aux gestionnaires et au personnel des Forces armées canadiennes qui participent aux activités liées à l'Arctique. Nous espérons qu'elle permettra également de sensibiliser le grand public au rôle important que joue RDDC pour mieux faire connaître nos régions arctiques et nos revendications en matière de souveraineté.

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Acknowledgments

This turned out to be a very popular project. Everyone we asked for help was supportive and generous. The general feeling seemed to be, “Well, it’s about time something like this was written. How can I help?” And, at the very least, everyone knew someone else who “might be of help.”

First of all we thank David Hazen of DRDC for proposing the project and providing funding.

Secondly, we would like to thank LCol Paul Dittmann for the epigraph at the beginning of the book. In two pithy sentences he summed up what we tried to say in the rest of the Introduction.

Also, we would particularly like to thank Janice Lang who provided us with pictures, contacts, and much help on the Headquarters research and on Defence Research and Telecommunications Establishment (DRTE), Defence Research Northern Laboratory (DRNL), Communications Research Centre (CRC), and Defence Research Establishment Ottawa (DREO). She was a fount of ideas for what might be included, and she was actively involved for the duration of this project. There are at least two major items that we would have missed had it not been for her diligence.

Larry Maynard was extremely helpful with information about DRTE, Prince Albert Radar Laboratory (PARL), and the work done by CRC in support of the Defence Research Board. He provided us with many more anecdotes than we could use.

John Strickland was a great source of information on the satellite link into Eureka (NU) and the subsequent microwave link from Eureka to Alert (NU).

Stu McCormick knew how to contact many of the old-timers, and occasionally he had to tell us sadly that they could no longer be contacted. The web site that he manages, “The Friends of CRC,” was a gold mine of information about DRTE, DRNL, and PARL. Stu also put us on to D.J. Goodspeed’s book *A History of the Defence Research Board of Canada*, which was excellent for the history up until about 1957.

John Brebner provided us with great digital images of the Prince Albert lab and of the Alouette satellite.

We would like to thank Lloyd Gallop and Mike Vinnins for information regarding the Icepick Sonobuoys. Maureen Yeremy and Karim Mattar, as well as Lloyd Gallop and Janice Lang, provided background and pictures regarding the Radarsat-1 work on shoreline delineation.

The DREP section was particularly long and involved. The book *Alpha and Omega* edited by Bob Chapman contains a section on Arctic Acoustic research written by Al Milne. This history was used extensively in the DREP Acoustics section of this book. John Ganton, Harold Grant, Jon Thorleifson, Mervin Black, Steve Taylor, Borge Haagensen, Jim Kennedy, and Chris Gibb all provided details regarding DREP’s work in the Arctic. Bruce Kaye found a large archive of DREP photographs—pictures that had been missing since DREP’s migration to the east coast in 1998. Peter Holtham and Ron Kuwahara were particularly helpful in the DREP Magnetics section. They provided ideas, and for some topics they even suggested much of the text. They donated pictures, and they corrected the first draft once it was finished. Capt(N) Don Smith helped with the details of the ARCSSS Project.

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We would like to thank Helen Verrall for editing the book, for repairing the punctuation and the grammar, and for telling us that "such-and-so" was quite confusing, and that it would read better if written "this way."

Stephane Blouin who took up the cause to get this book finally published after the authors were no longer working at DRDC. Stephane earned his credit as the Editor by spearheading the effort to bring the document up to present day style and standards. He ensured that there were no roadblocks to publication and spent many hours proof-reading and modifying the content as required.

Paul Melchin of the DRDC Editorial Office who went above and beyond to produce the book in the present style and helped develop the index and forematter for the book.

A second mention for Janice Lang and the staff of DRDC VisDoc Team for updating the cover graphics.

Finally, a heart-felt "Thank You!" to the indigenous people of Canada and Greenland. From the beginning of our efforts in the Arctic we were helped, guided, protected, and led by indigenous participants in our field work. Their skills were essential to our work in the Arctic and we've had many great encounters over the years. One particularly good event happened at Gascoyne Inlet where a family of hunters took shelter with us for a few days. It was a great experience and we both learned a lot about each other. Friendships were formed that we tried to maintain, but were difficult with the distance and time lapse between meetings. Our work is about learning more from and protecting the home lands of our northern peoples and we appreciate their support whenever we visited.

We thank you all.

Foreword

This book is a history of the scientific research conducted by Defence Research and Development Canada (DRDC) and its forebears in the Arctic. It captures details of the type of work, the environment, and some of the basic results of the efforts in a wide range of ground breaking and highly innovative—even audacious—activities in underwater acoustics, geography, oceanography, biology, glaciology, physics, and military technologies.

Almost since the creation of the Defence Research Board (DRB) in 1947, it and its successors, have undertaken a wide variety of highly novel and productive research activities in the Canadian Arctic. While the results of these activities have been passed on to and used by the appropriate parts of the Canadian Armed Forces (CAF), they are not generally well known to either our current CAF members or even ourselves, and certainly not to the general public. This is partly due to the cyclical nature of interest in the Arctic, but also to security concerns about much of the work and simply the passage of time.

The authors, having experienced first hand both the wonders of working in Canada's High Arctic and the frustration of seeing the results of that work effectively lost to the newer generations of both scientists and military planners, felt compelled to bring to light both their own work and that of the hundreds of other dedicated researchers who have ventured north under the auspices of the Department of National Defence (DND). Going through their own records, departmental archives, and other sources, including direct contact with several of the original investigators, they have brought to light extensive information on many of those investigations. Among them: DND scientists were among the earliest explorers of northern Ellesmere Island; built northern laboratories, radar facilities, and rocket ranges to study the ionosphere over the pole; developed new tools, clothing, equipment, and operating principles for doing both science and military operations in the Arctic; and carried out pioneering studies in underwater acoustic and electromagnetic detection of submarines and ships in the Arctic channels and ocean basin.

This book admirably captures the spirit of those scientific investigations and the people who supported and carried them out. This strong support and morale extended to all involved in the field expeditions regardless of whether they themselves were participants in the trials. The vast majority of those who spent many weeks in difficult conditions during the field work were prepared—even keen—to repeat the effort whenever possible due to a strong belief in the value of the work coupled with the amazing opportunity to see and help defend a stunning part of Canada that many will never get the opportunity to visit.

In addition to providing an overview of the history of DRDC Arctic research, this book is a "how-to" field guide for future researchers. It describes the sorts of things that were attempted in an effort to provide knowledge and capabilities for the CAF, it describes the often extreme logistical efforts and the innovations that were required, and it highlights the perseverance that is needed, even today, to operate in the harsh Arctic environment where there is little support and infrastructure.

About the Authors

The authors have worked in the Arctic many times and both have worked at the east and west coast laboratories—Defence Research Establishment Pacific (DREP) and the Atlantic Research Centre, which was formerly known as the Defence Research Establishment Atlantic (DREA).

The late Ron Verrall was a leading Arctic researcher and was the mentor for his friend and colleague, Garry Heard. He joined DREP in 1971 with BSc and PhD degrees in physics. He was a key member of the Arctic Acoustics Group, participating in virtually all of the group's field trials for more than 30 years. He transferred to DREA/DRDC Atlantic in 1995 with the intent of helping to complete Project SPINNAKER and then building a kernel of Arctic field expertise at DREA to provide a nucleus for rebuilding a program when interest in the Arctic re-arose—as it did in the mid 2000s. Although Ron was an excellent scientist, his forte was Arctic operations—the equipment, supplies, logistics expertise, planning, and understanding of the environment that are so critical to doing science successfully in such a remote and physically challenging place. The success of the activities he was involved with—as well as those that followed after his retirement—owe much to his capabilities. Sadly, Ron died of cancer shortly after completing the draft for this book.

Garry Heard has also had a long association with DRDC's Arctic research activities—even predating his joining the organization in 1984: his PhD studies at the University of Victoria supported some of the early DREP electromagnetics investigations in the Arctic channels. Garry spent 10 years at both DREA and DREP in open ocean acoustics, becoming leader of the Surveillance Acoustics Group at DREA in 1998 and assuming leadership of the remaining Arctic acoustic activities transferred from DREP. He was instrumental in creating a small group of DREA and ex-DREP staff to carry on the Arctic work. When interest in the Arctic rose again around 2005, his group was well positioned to grow to support the Arctic-focused Rapidly Deployable Systems and Northern Watch Technology Demonstration Projects.

1 Introduction

> In more than half a century of research, DRDC and its predecessors have conducted scientific field operations in the Canadian Arctic. Not only have long-term arctic science operations demonstrated ownership and use of the land, but DRDC has also been the one military component consistently present in the Arctic.
>
> LCol Paul Dittmann, 3 Canadian Forces Flying Training School,
> *Journal of Military and Strategic Studies*, Spring 2009, Vol. 11, Issue 3.

During the last few years the Arctic has become more and more important to Canadians. Hardly a day passes without some mention of the Arctic in the media. The decrease in ice mass, the breaking-off of ice-shelves, the expected opening of a north-west passage, the anticipated search for oil in the High Arctic—these are all topics that are front and centre to politicians, bureaucrats, and the military, not to mention the average voter (in this publication, "High Arctic" mainly refers to the region above the Arctic circle). And every intelligent person who becomes interested in the Arctic recognizes his or her ignorance and searches for more information.

Since its inception in 1947, the Defence Research Board (DRB), which has evolved into the Defence Research and Development Canada (DRDC), has been interested in the Arctic and problems related to the Arctic. DRDC is a part of the Department of National Defence that is led by an Assistant Deputy Minister. Every year the various defence laboratories have spent a reasonable percentage of their budgets on Arctic matters. The principal client of DRDC is the military, and consequently this Arctic work has been, in large part, the gathering of knowledge that will help the military in all aspects of its Arctic operations.

It is therefore disturbing that many military officers and Canadian bureaucrats know nothing of this work. Conversations between lab scientists and military officers have indicated—over and over again—that the Arctic work of DRDC and its predecessors is largely unknown.

It is for this reason that this book has been written. It describes, in a broad-brush fashion, what the various labs have done in the last 65 years (or so)[1] to further Arctic knowledge and to show a Canadian presence in the Arctic. This book concentrates on the problems that were addressed (and are being addressed), what was done, who did it, and when. Detailed results, however, are beyond the scope of this work, although some references are given to steer the interested reader in the right direction.

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[1] Editor's note: This document was completed in 2012 and therefore covers only the period from 1947 to 2012.

2 DRB Beginnings

During World War II, the National Research Council (NRC) and the Department of National Defence (DND) worked hand-in-glove on war-related research for the military. Well before the end of the war, the acting head of NRC, C.J. Mackenzie, realized that the war's end would bring big changes to the nature of their work. He saw that there would still be a need for defence-related work, but he wanted to separate NRC from it. He wanted NRC to go back to the civilian-related projects that they had temporarily put on hold for the duration of the war. Consequently, he was a strong advocate for the creation of one or more organizations that would concentrate on defence research.

For their part, the Canadian military realized that science had played a big part in the war, and that long-term technological research would be extremely important in their future. However, organized scientific and technological research was an entirely new requirement for the military. There was no structure or mechanism in place to handle it, and they were not at all sure how "defence research" should be organized.

In August 1945, as the first definite step, the government approved a Committee on Research for Defence. This newly formed committee was originally intended to have an advisory role. It would make recommendations for research, but the work itself would be done under the control of the three services, Army, Navy, and Air Force. A group led by Col W.W. (Wally) Goforth anticipated problems with leaving the research in the direct hands of the services: they foresaw that there would inevitably be inefficiencies caused by rivalry and duplication of effort, and, even more importantly, they felt that civilian scientists would not be adequately integrated into the organization. Goforth [1] felt that "military research was too serious a business to be left entirely to the soldiers."

He proposed that research and development for all three services be organized into a fourth service of National Defence, with its head having status equivalent to a Chief of Staff and to a Deputy Minister. There were objections to this radical idea, particularly by the Air Force, but this new approach to defence research was finally accepted—largely, it is believed, because of the support given by General Foulkes, the Chief of the General Staff, and C.J. Mackenzie, the President of the National Research Council. The enabling legislation was passed in March 1947, and the Defence Research Board (DRB) became an official entity on 1 April, 1947.

The title of "Director-General of Defence Research" was created, and Dr. Omond Solandt was given the post. He, with a planning staff headed by Col Goforth, put meat on the bones of the legislation. Many details had to be decided, but what interests us here are their thoughts on the Arctic.

Very early in the life of DRB a priority hierarchy for projects was created. The highest priority was to go to problems that only Canada could undertake or for which there was a truly Canadian requirement. Initially, the only obvious topics were Arctic-related, and thus Arctic problems were given special preference. And so, right from the beginning, the Arctic was very important to the Defence Research Board.

Sovereignty over the Arctic had become an ever-increasing concern for the Canadian government. During the war, there had been a number of joint Canadian-American projects in the Arctic with the Americans putting up most of the money, material, and people. As well as the Alaska Highway and the Canol Road, the Americans established an airport at Goose Bay (NL) and a number of Arctic weather stations to support the so-called "Goose Bay" route to Europe. The first stations were at Fort Chimo (now known at Kuujjuaq [QC]), Frobisher Bay (now known as Iqaluit [NU]), and Padloping Island (NU), and later there were many more. After the war, the Canadians and Americans signed an agreement to establish Joint

Arctic Weather Stations (JAWS), with the Americans picking up most of the cost. Also, both Canada and the United States worried about Soviet bombers coming over the pole. Planning for the joint Pine Tree Line was well under way as early as 1946.

All of these “joint” projects had the Canadian government concerned that it was giving up *de facto* sovereignty over the “Canadian” Arctic. It was actively looking for ways to show a physical presence and re-establish sovereignty. It was ironic, and perhaps not altogether coincidental, that DRB was brought into existence only a month after the JAWS agreement was signed.

Operation MUSK-OX was an example of an expedition that was carried out partly to test equipment and train troops in the Arctic, but also to show an official Canadian presence. For two months, starting in February 1946, the Canadian Army trekked through northern Canada to show that winter travel by mechanical transport was possible. Supported and supplied by the Royal Canadian Air Force, a group of about 40 soldiers headed north-west from Churchill (MB) to Baker Lake (NU) and then to Cambridge Bay (NU) on Victoria Island (NU). They returned south via Coppermine (now known as Kugluktuk [NU]), Port Radium (NT), Fort Simpson (NT), and Fort Nelson (BC). From Fort Nelson, the route went south along the Alaska Highway to Edmonton (AB). The total distance covered was over 4800 km (3000 miles). This was obviously a learning expedition and a test of military equipment and capabilities, but MUSK-OX was also a gesture to show the flag—to reassert Canadian sovereignty in the north. Fittingly, it was just nicely completed when DRB was established.

Thus, DRB started not only with an official policy of giving high priority to Arctic matters, but also with the press and the government bruiting the importance of the Arctic and the necessity of exercising sovereignty over it. The DRB made a good start. During the first six months of its existence, it started work on a new lab at Fort Churchill (MB) and on eighteen other projects connected with the Arctic.

Several of the Operation MUSK-OX participants were to join DRB and give it an instant connection with the Arctic. LCol Graham Rowley was the head of the advance (path-finding) party out of Churchill. Rowley was an Englishman who had begun his Arctic work in 1936 as an archeologist in the Hudson Bay region. As well as making several important finds related to the “Thule Culture,” he became an experienced dog-team driver, he discovered several islands in the Foxe Basin (NU), and he pioneered a new pass over Baffin Island (NU). When he joined DRB, he became the first head of the Arctic Section, and he was influential in ensuring that DRB gave a high priority to the Arctic. He recruited Geoffrey Hattersley-Smith, who is of particular importance in the history of Arctic exploration, science, and sovereignty. Another participant in Operation MUSK-OX was Patrick Nasmyth, who acted as a navigator on the trek. He was to join the Pacific Naval Laboratory (PNL) in Victoria (BC) soon after it opened in 1948, and he encouraged research in the Arctic. He participated in ship-borne expeditions to the Bering and Chukchi Seas. Finally, Col J.T. (Tuzo) Wilson, who was the Deputy Director of the exercise, should be mentioned since he went on to become famous for his contributions to plate-tectonics.

The rest of this book discusses the contributions of each of the DRB organizations to northern research. Some of the labs were heavily involved, and others much less so. All of the labs have had name changes over the years, some labs have been absorbed by others, and some labs (such as the Defence Research Northern Laboratory in Fort Churchill [MB]) have closed down. However, this book tries to touch on them all.

3 Defence Research Board Headquarters

In more recent decades, the research work has all been done at the various Establishments. However, in the beginning, before the Establishments were built up, DRB Headquarters ran its own scientific program. One of the sub-branches under the Board was the Headquarters Scientific Organization. In this branch, there were six divisions: Electrical Research, Biological Research, Naval Research, Scientific Intelligence, Weapons and Equipment Division, and Special Problems Research. It was in the Special Problems Division that the Arctic Section resided. The Arctic Section organized and ran the initial expeditions to the north coast of Ellesmere Island (NU), to Lake Hazen, and Tanquary Fiord.

The driving force and the principal investigator in the early DRB work on Ellesmere Island was an Englishman named Geoffrey Hattersley-Smith (1923–2012). His main scientific interests were glaciology and geology, and in 1951 he was recruited to come to Canada and join DRB with the expectation of working in the High Arctic. He was one of those people who became a legend. He was tough and indefatigable. He could walk kilometers and kilometers every day with barely a pause. Harold Serson, who, himself, was as tough as an old boot and a legend in his own right, confessed that occasionally he wanted to trip up “The Hat” just to slow him down [2]. Hattersley-Smith was a good scientist, a good organizer, and a good leader. Moreover, he wrote well and was quite prolific in his writings. In fact, the main source of information for the following section is the large report “North of Latitude Eighty” by G. Hattersley-Smith [3].

Hattersley-Smith points out that for many years after World War II the only maps of the Queen Elizabeth Islands (Figure 1) were based on the observations of the explorers of the late 1800s and early 1900s. In particular, the charts of the north coast of Ellesmere Island had not been adjusted since the visits of Lt P. Aldrich RN, of the British Arctic Expedition of 1875/76, and R.E. Peary, at the turn of the century. Although the latitudes measured by early explorers were fairly accurate, the same cannot be said about the longitudes, which require a very accurate timepiece for their determination. Moreover, the northern coast was very indented with deep inlets, many of which had not been explored at all. The coast was often shrouded with fog, which made it hard even to see into these inlets. It was evident that there was still much to be done by a keen explorer and map-maker.

On a separate—but related—topic, the United States Air Force (USAF) had discovered a large tabular iceberg north of Alaska in 1946 [4]. It was called an “ice island,” and was known as T-1. (This stood for “Target-1,” and the island’s existence was initially classified SECRET.) By 1950, two more ice islands (T-2 and T-3) had been discovered north of Alaska and eastern Siberia. They were enormous! T-1 was 28 x 33 km, T-2 was 31 x 33 km, and T-3, the smallest, was 9 x 17 km. An organized search was made for similar ice islands, but none was found. A weather station was set up on T-3 by Col J.O. Fletcher (USAF) in March 1952, and the island, which was often called Fletcher’s Ice Island, was occupied off and on until the final evacuation in May 1965. In 1983, it finally drifted through Fram Strait (between Greenland [DK]) and Svalbard [NO]) and disappeared into the relatively warm Atlantic Ocean.

The relevance to our story is that the surface of these ice islands was marked with long alternating troughs and ridges, the distance from crest to crest being some 200 to 300 metres. Air photographs, made by the Royal Canadian Air Force (RCAF) in 1946, of the ice mass attached to the north coast of Ellesmere Island showed the same undulations (Figure 2). It was almost certain, therefore, that the ice islands had calved off one or more of the ice shelves attached to Ellesmere’s north coast. To a glaciologist, such as Geoffrey Hattersley-Smith, the Ellesmere ice shelves cried out for investigation. Not surprisingly, Dr. O.M. Solandt, the Defence Research Board’s chairman, and G.W. Rowley, Head of the Arctic Section, encouraged him in this quest.

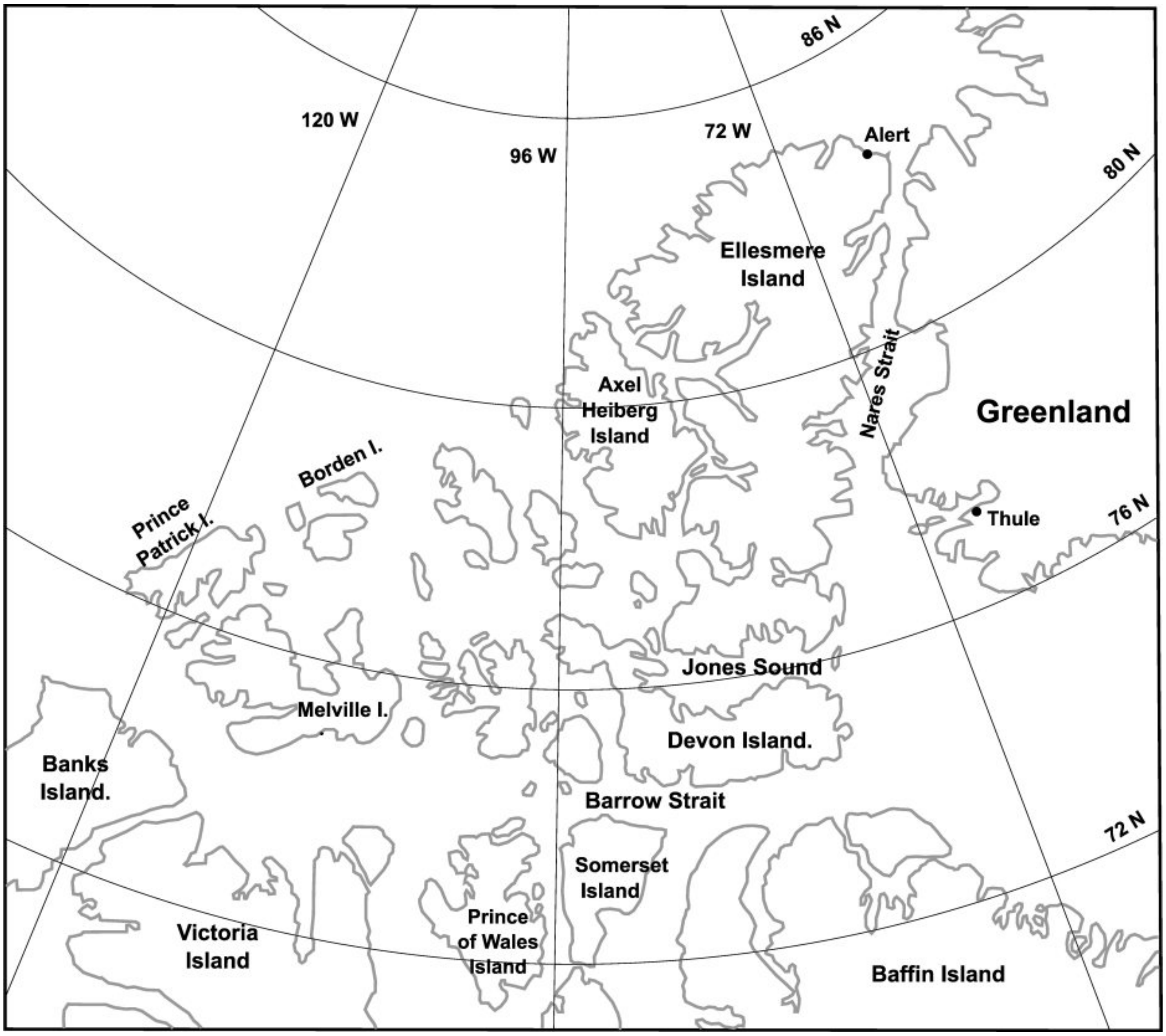

Figure 1: *The Queen Elizabeth Islands of the Arctic Archipelago include Devon Island, Prince Patrick Island and all islands in between and north.*

3.1 1953 Expedition

The 1953 expedition consisted of two scientists, Geoffrey Hattersley-Smith from the Defence Research Board, and R.G. Blackadar from the Geological Survey of Canada, plus two Greenlanders, Rasmus Majak and Sigssuk, together with their dog teams.

On 20 April, Hattersley-Smith and Blackadar were flown by the USAF from Ottawa (ON) to Thule Air Base in Greenland, where they picked up Majak and his dogs. From Thule, the three men and 13 dogs were flown to Alert (NU) in a ski-wheel C-47 (Dakota or DC3). They soon realized that Majak was not willing to go for more than one day out of Alert without another Greenlander, so they made arrangements with the Danish authorities to hire a second Greenlander. A week later, Sigssuk and his dogs were flown from Thule to Alert.

On 29 April, the four men and two dog teams left Alert for the north coast of Ellesmere Island (Figure 3). They cut across the Cape Joseph Henry promontory and the Parry Peninsula, following the same route

***Figure 2:** Looking east up the Ward Hunt Ice Shelf to Ward Hunt Island. The trough-like lakes are very evident. Photo credit: This picture was taken on 16 July, 1950, and is copied from* North of Latitude Eighty, *by G. Hattersley-Smith.*

that Lt Aldrich and Robert Peary had taken many years before. East of Point Moss they were hindered by soft deep snow, just as Aldrich had been in 1876, but they made much better time since Aldrich's crew had been man-hauling brutally heavy sleds without benefit of snowshoes or skis. Hattersley-Smith says that they travelled for the first nine hours of each day and then did their scientific measurements after making camp.

On 11 May, they arrived at Cape Aldrich, the most northerly point in North America and the place where Peary (and others) had left land on their way to the pole. Cape Columbia, which is about 5 km west of Cape Aldrich, used to be given the distinction of being the most northerly point, but Cape Aldrich now appears to be the winner by a couple of hundred metres.

On 13 May, they climbed Mt. Cooper Key, which is just inland of Cape Columbia, to examine the cairn that Peary had built and to copy the message that they found there. This peak rises to an altitude of 660 m and does so only 1500 m from the coast. Not surprisingly, given the steepness of the direct approach, Hattersley-Smith says that they climbed it along the "shoulder." He also mentioned that it was "a three-hour climb." That is about 200 m of vertical rise per hour.

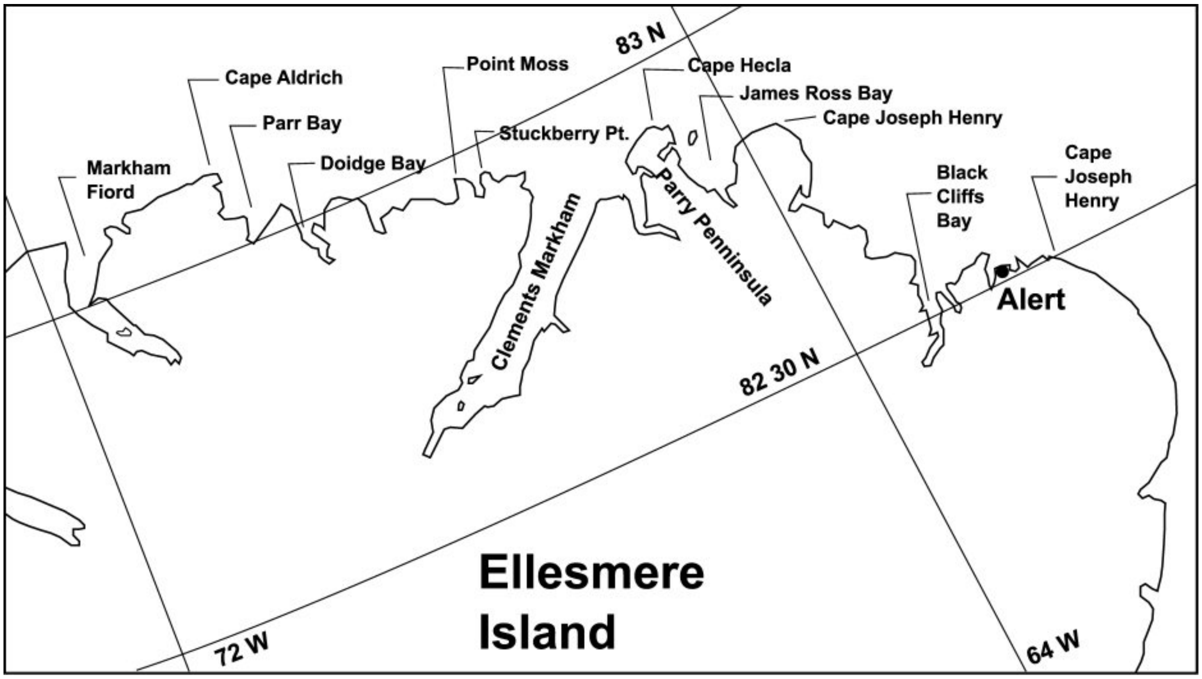

Figure 3: *The northern coast of Ellesmere Island from Alert to Markham Fiord.*

During their trip from Alert to Cape Aldrich, Blackadar did a survey of the geology of the region and Hattersley-Smith studied the snow and ice features. They were able to spend a couple of days as far west as Markham Fiord, which held the most easterly tongue of the Ward Hunt Ice Shelf. Hattersley-Smith set ablation stakes into the ice so that he could measure both ice ablation and ice movement the following year. Markham Fiord was their “farthest west” for the 1953 expedition.

On 16 May, after waiting out the only blizzard of the trip, they started back for Alert, which they reached in only four days.

Hattersley-Smith does not say why they returned to Alert. Perhaps it was for food and fuel, but on 28 May they headed back west. This time they went around Cape Hecla, rather than cutting across the Parry Peninsula. They travelled as far west as “the small bay just west of Point Moss.” After a three-day survey they returned via a long detour down Clements Markham Inlet. Before the Greenlanders and their dogs returned home at the beginning of July, they made a three-day survey of the Cape Sheridan region, where they found cairns and monuments from the Nares expedition of 1875 and from Peary’s expeditions at the turn of the century.

On 3 July, Hattersley-Smith and Blackadar headed off on a hiking trip up the Wood River, which empties into Black Cliffs Bay from the west. This route took them up into the mountains and glaciers of the United States Range, where they continued their study of geology and glaciology. This was followed by a trip into the hills south of James Ross Bay, where geology was the prime interest. By this time the snow had gone, which was a great boon to the geologist.

On 16 August, they left Alert for the south.

3.2 1954 Expedition

The main goal for the 1954 expedition was to study the ice shelves, which had not been done the previous year. Also, they wished to finish the geological survey of the north coast of Ellesmere Island. The previous year they had made it only as far west as Markham Fiord, which is less than half-way across the north coast.

This year there were four scientists: G. Hattersley-Smith (DRB), R.L. Christie (Geological Survey of Canada [GSC]), A.P. Crary (Air Force Cambridge Research Centre [AFCRC]), and E.V. Marshall (Snow, Ice, and Permafrost Research Establishment of the US Army [SIPRE]). There were also two Greenlanders, Imina and Karkutirak, with their 20 dogs.

One of the big differences that year was the improvement in the logistics. Instead of having to start with dog teams at Alert, carry everything they needed, and travel many days just to get to the area of interest, they were set down by ski-wheel C-47s (Dakota or DC3) two kilometres west of Ward Hunt Island (NU) (Figure 4). This placed them about 40 km west of their furthest westing in 1953. They were now right in the centre of their area of interest. Moreover, all the freight they would need for the season's work was brought in by aircraft—a total of about 8000 kg in six loads. They arrived on 24 April, and all the freight was in place by 14 May. The aircraft support was compliments of Thule Air Base, and the project was of sufficient interest that the first two flights were flown by the Base Commander and the Base Deputy Commander.

Their first investigations were to the east—to Cape Albert Edward and to Cape Aldrich, where the previous year's geological survey had ended. Hattersley-Smith checked the ablation stakes that he had installed in 1953.

About this time the Greenlanders decided that they needed to go home, but they left 14 of their dogs behind for Hattersley-Smith, who fortunately had experience driving dogs.

On 14 May, Hattersley-Smith and Christie left camp for a fast trip to Lands Lokk Point, the most westerly point of the Ellesmere north coast. Their plan was to drive there quickly, spend several days doing surveys and then return more slowly making observations along the way. By travelling 30 to 40 km per day, they made it to Lands Lokk in eight days, where they made camp. They spent a day walking to Krueger Island (NU) and back while the dogs rested. On 24 May, they headed back, arriving at the Ward Hunt camp on 6 June. Hattersley-Smith makes the point that, prior to their trip, only Peary had explored the north coast west of Alert Point.

The rest of the summer was spent by the four men doing many types of science: geology, depth measurements off the edge of the shelf, taking ice cores, measuring ice thickness and ice temperatures, taking water samples and temperatures, making seismic measurements, maintaining a tidal record, and collecting plant samples. Also, some of the inland glaciers were investigated, the reconnaissance going as far as 25 km south of the coast.

In July, the travelling became very difficult because of the melt. The troughs on the shelf became long lakes (shown in Figures 2 and 5). At one point they needed to make a scheduled radio contact with Alert, and for some undisclosed reason, they had left their radio at the ice edge—where the shelf meets the pack ice. Meeting the "sched" required them to cross the ice shelf and wade through 40 trough lakes, where the water temperature was, of course, 0°C. Hattersley-Smith also mentions that they could reach the Ellesmere shore from their ice camp on the shelf only by wading through 26 trough lakes.

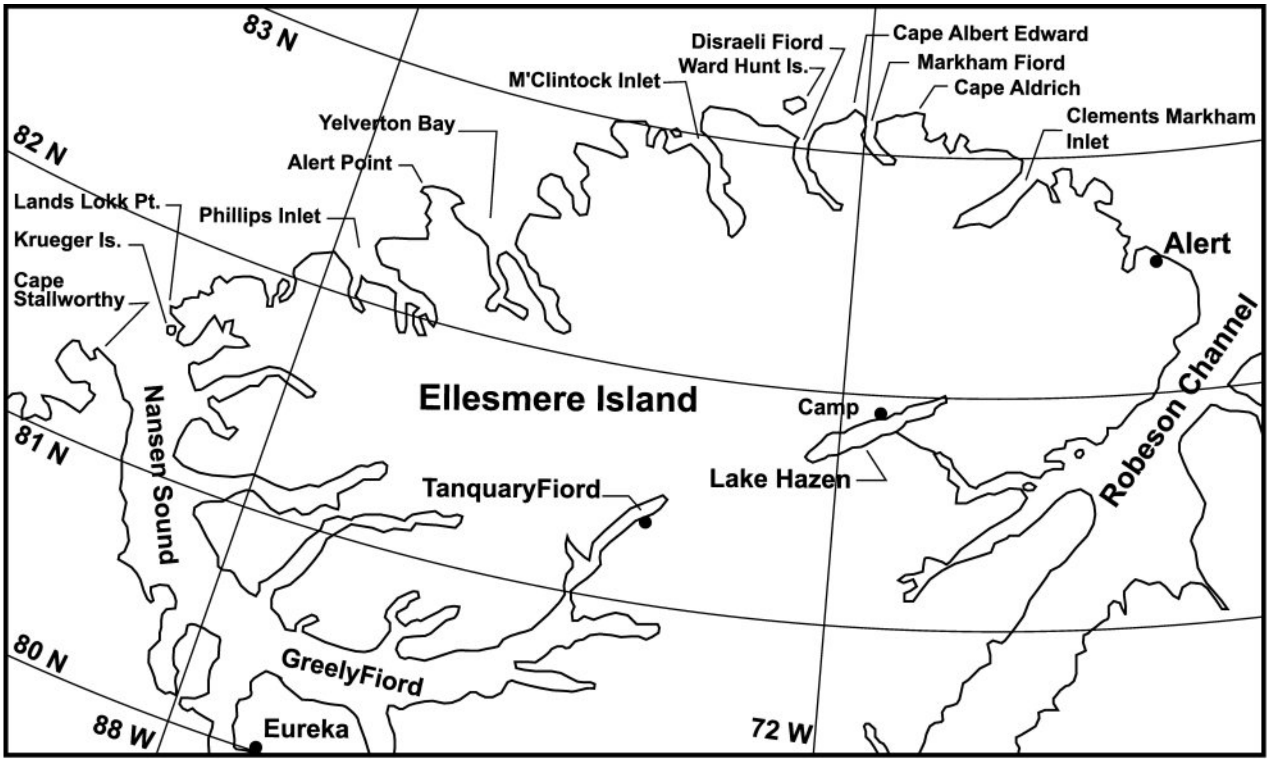

Figure 4: *The north coast of Ellesmere Island from Alert to Lands Lokk Point. The map also shows the DRB camps at Lake Hazen and Tanquary Fiord.*

By 6 September, the day of the first sunset, the freeze-up was well under way. They used the colder, drier conditions to take cores from the ice shelf and the ice rise (where the ice is grounded on the bottom).

Their back-haul by C-47 aircraft lasted from 17 September to 26 September.

Hattersley-Smith points out that this particular trip represented a transition between the old pre-war expeditions and modern field trips. In the old days, before airplanes and good radios, the field party travelled for many days getting to the area of interest, and, once there, spent the duration completely cut off from the rest of the world. In modern trips, air transport is easy and the field party is in daily radio contact with the “outside.” This (1954) trip used aircraft to get men, dogs, and all their equipment quickly and easily to a central location, but for the five succeeding months their only communication with the outside was the occasional radio contact.

3.3 Lake Hazen 1957–58, the Geophysical Year

The International Geophysical Year (IGY) of 1957–58 involved 55 countries in an international program of scientific research. The IGY was a natural evolution of the First and Second International Polar Years of 1881–82 and 1932–33, so it was not surprising that an emphasis was placed on research in the polar regions. Canada was well placed to play an important role.

DRB established a camp on the north shore of Lake Hazen in 1957 (Figure 4). The choice of the location was made primarily by F.T. Davies, Director of Physical Research, and T.A. Harwood, Head of the Geophysics Section. The area had a number of advantages, both logistical and scientific. It had an excellent

Figure 5: *Looking east along the Ward Hunt Ice Shelf. The picture shows the trough-shaped melt ponds that develop during the summer. Photo credit: Denis Sarrazin, CEN/ArcticNet* `www.studentsonice.com`.

source of fresh water, and the frozen lake became a natural landing field for eight months of the year. Moreover, it had a reputation for having fine windless weather. Scientifically, there were ice caps and glaciers readily available, and the area was almost unexplored geologically and botanically.

DRB, in the person of G. Hattersley-Smith (Figure 6), was entrusted with the task of organizing Operation HAZEN. Various other government organizations were invited to send field scientists. The organizations that participated were: Defence Research Board, University of Toronto, McGill University, Geological Survey of Canada, Dept. of Mines and Technical Surveys, National Museum, Fisheries Research Board, and the Canadian Wildlife Service.

The Lake Hazen camp was established and supplied by spring airlifts operated by the Royal Canadian Air Force and by sealifts courtesy of United States icebreakers. LCdr J.P. Croal of the RCN coordinated these activities.

Four men wintered-over at the camp, and up to 23 men operated out of the camp during the following summer.

The scientific work included a mapping survey (for both positions and altitudes), geology, glaciology (snow accumulation, ablation and movement), meteorology (including a continuous record of the conditions for the entire winter), gravity, seismic measurements of ice thickness, botany and plant ecology, biology of the lake, wildlife, and archaeology.

3.4 Operation HAZEN 1959–61

Although the geophysical year was over, the Lake Hazen camp and work site were still attractive to scientists who wished to continue their research.

Figure 6: *Geoffrey Hattersley-Smith at Hazen Lake when fishing for char was allowed. Photo credit: Library and Archives Canada, James Croal collection.*

A limited amount of work was carried out in the Lake Hazen area from May to August 1959. Beginning 17 May, R.B. Sagar and J.M. Powell, of McGill University, investigated the micrometeorology of an area near the snout of the Gilman Glacier.

On 8 August, G. Hattersley-Smith of DRB, together with eight tons of fuel and equipment, arrived on the United States Coast Guard Cutter (USCGC) WESTWIND, which anchored not far from the mouth of the Ruggles River (which drains Lake Hazen to the south-east). After the freight was lifted to the camp by helicopter, Hattersley-Smith joined Sagar and Powell at the Gilman Glacier. When they finished their ablation measurements, the three men cleaned up the Gilman camp and battened down the Lake Hazen camp for the winter (Figure 7 shows the Gilman Glacier camp).

Getting out was not easy. Unlike the previous year's August, the lake was almost all covered by ice, which prevented a float plane from picking them up at the camp site. The only place where a plane could land was at the source of the Ruggles River on the south shore of the lake, and so they had to make their way to the other side of the lake. However, since the ice was too thin to hold them and too thick for a boat, they had to walk 100 km around the lake in order to be picked up.

In 1960, Hattersley-Smith and an assistant, Lotz, revisited and measured some 50 glacier ablation stakes on the Gilman Glacier. They reset the ones where there had been substantial ice ablation. They arrived on 20 May and left on 12 June.

Figure 7: *Gilman Glacier Camp northwest of Lake Hazen. Photo credit: Library and Archives Canada, James Croal collection.*

In 1961, a scientific party of seven arrived on 15 May, and an eighth member arrived on 7 July. The group continued with studies on meteorology, glaciology, geology, and soils. In addition, two new topics were explored: geomagnetism and entomology.

At the end of the summer the party was flown out to Thule Air Base on four flights of an RCAF Albatross amphibian. Landing on the lake was possible, although the 7/10 ice cover made it difficult. The last flight left on 21 August.

3.5 Tanquary Fiord 1962–1970

By the early 1960s, the threat of submarines in the Arctic channels was an impetus to leave their inland work on Lake Hazen for renewed work in oceanography. The DRB Arctic Section hunted for a coastal location that was as far north as possible but was still reachable by an ice-breaking ship. Their reasoning was that a camp that can be serviced by ship can be made large enough to support many research parties.

Flights and photographs in 1961 by the RCAF showed that Tanquary Fiord (Figure 4) was nearly ice-free in the summer, and that approaches through Greely Fiord were easily navigable.

In 1962 G. Hattersley-Smith and S.J. Windisch explored the head of Tanquary Fiord looking for a site for a DRB field camp the following year. They found a very good site on the flats of the Macdonald River delta, which runs into the fiord from the south. There was level ground for an air strip and a good supply of fresh water from glacier run-off (Figures 8 and 9).

Figure 8: *Tanquary Fiord camp and airstrip, 1971. Photo credit: Harold Serson.*

In August of the same year the Canadian Coast Guard Ship (CCGS) SIR JOHN A. MACDONALD made its way through Greely Fiord and Tanquary Fiord to the chosen site. It unloaded fuel, housing materials, and other equipment for the new field camp (Figure 10 on page 15). LCdr J.P. Croal was present to supervise the handling of the freight. It is worth noting that the SIR JOHN A. MACDONALD, which had been commissioned in 1960, was transferred to the Canadian Coast Guard, which had been created

Figure 9: *Looking west to Tanquary Fiord from Per Adua Glacier, 1964. The Macdonald River delta is at mid-picture, left. Photo credit: Harold Serson.*

just that year (1962). In travelling to Tanquary Fiord, the SIR JOHN A. MACDONALD had set a "farthest 'north' record" for Canadian ships.

Figure 10: *The CCGS SIR JOHN A. MACDONALD delivering supplies to Tanquary Fiord camp, 1966. Photo credit: Harold Serson.*

Figures 11, 12 and 13 show a few of the activities that went on at Tanquary Fiord.

Tanquary Camp was an important staging point for many years. The main fields of study were meteorology, oceanography, glaciology, geology, biology, archaeology, and sea-ice investigations. Every year an average of 20 scientists and assistants worked out of the camp. The season lasted from early April to late August or early September.

In his book "North of Latitude Eighty" [3] Hattersley-Smith praised Harold Serson. He says, "The mainstay of these oceanographic parties in all seasons was H. Serson, who with his extraordinary all-round aptitude for field work, designed and modified many items of trail and scientific equipment." All who knew him in the Arctic would agree with those words. They would also talk about the selflessness and friendliness with which he gave his help and advice.

Harold (Figures 14 and 15, pages 18 and 19) was another of the early DRB employees who became a bit of a legend in his own time. He was tough as nails, and he could fix just about anything. He helped with the aurora investigations that were done along the Hudson Bay Railroad. He spent 15 months in Resolute Bay (NU) on ionospheric work, and he was in Prince Albert, Saskatchewan, when the enormous radar dish was being erected.

He spent a lot of time travelling via snowmobile along the north coast of Ellesmere Island. When it was very cold he would take the snowmobile's carburetor to bed with him at night to keep it warm (people will do amazing things to get an engine to start). According to one story, he was kilometres from anywhere

Figure 11: *Research group at Tanquary Fiord, 1967. Left to right: Dave Farmer, Dunc Finlayson, Guy Brassard, John Keys, John Van Der Lieden, Redge Anderson, Garry Schram, Bill Blake, and Mark Curtis. Photo credit: Harold Serson.*

Figure 12: *Geoffrey Hattersley-Smith and Ian Jackson of the London School of Economics near the entrance to Tuborg Lake, which is at the head of Greely Fiord. Photo credit: Harold Serson.*

Figure 13: *Measuring solar radiation below the ice with a spectrophotometer. Tanquary Fiord, June 1971. Photo credit: Harold Serson.*

when his snowmobile's engine blew a hole in the piston. He made camp, took the engine apart, plugged the hole with a bolt, a nut, and two washers, and put the snowmobile back together. It got him home.

Back in the south, he continued his adventurous life. Larry Maynard relates the story of Harold, John Keys, and himself building home-made scuba gear and going diving. As Maynard [5] says, "At times, I look back and wonder how we survived some of our exploits."

Harold Serson was impressive enough that the Inuit had a special name for him: "Toomalik." It was given to him by the Inuit at Arctic Bay (NU) in 1946–47 when he wintered there, and he was known by that name throughout the North [6]. In English it means "bent arm." Harold had been born with a weak arm, and he generally held it at an unusual angle. It certainly did not slow him down, and he never gave the impression of any weakness at all.

When Harold died in 1992 there was a push, spearheaded by Martin Jeffries of the University of Alaska Fairbanks, to honour him by having an Arctic geographic feature named after him. When Martin had been a graduate student, Serson had mentored him in the lore of the Arctic, and this was Martin's way of showing his appreciation and respect. After much effort—and even more time—the iceshelf in the bay on the northwest side of the Wootton Peninsula was officially named the Serson Ice Shelf. (Figure 4 on page 9 shows this large bay between Phillips Inlet and Alert Point.)

DRB concluded its Tanquary operation in 1972, but others continue to visit. Tanquary Fiord is a beautiful area, and it is now part of the Quttinirpaaq National Park (Figure 16 on page 19). A warden station

Figure 14: *Harold Serson at Perry's signpost, Cape Columbia. Photo credit: Harold Serson.*

is staffed by Parks Canada during the summer months, and it is possible to reach the park by charter aircraft or by icebreaking cruise ships. Serson loved the region enough that he called his sailboat "THE TANQUARY FIORD."

Figure 15: *Harold Serson driving ablation stakes and generally enjoying life. Photo credit: Harold Serson.*

Figure 16: *A more recent picture of the Tanquary Bay site. It is now part of a park and constitutes a tourist destination. Photo from: Reference [7] Photo credit: Ansgar Walk.*

3.6 Advances in Arctic Air Navigation

This section is almost entirely about one person, Flying Officer (later Brigadier-General) Keith Greenaway. He became world-renowned for his contributions to Arctic navigation, and some of his best work was done under the auspices of the Defence Research Board.

During the war, he served in Canada as an instructor, and he was so good at it that, to his disgust, his supervisors never allowed him to go overseas to fight. After the war, he decided to stay with the RCAF and make it a permanent career. One of his first postings was in April 1946 with a United States Army Air Force (USAAF)/RCAF joint project on low-frequency LORAN (long range navigation). Although they were stationed in Edmonton (AB), he was the only Canadian for some time, but his charm and diplomacy soon made him accepted.

During his thousands of hours of flying in the Arctic, he saw many problems that faced the navigators. Since the magnetic compass was not useable in much of the Arctic, the gyro-compass was relied upon more and more to provide heading information. A gyro-compass, in those days, had a fairly high precession rate, and its accuracy needed to be checked regularly with an astronomical body—either the sun or a star. This was fine as long as the navigator could see the sun or a star, but at twilight neither was visible. In high latitudes, where the sun sets very slowly, twilight can last a long time. And if the aircraft is heading west, twilight can last a *very* long time. Greenaway mentions once flying for four hours in the Arctic without being able to get a heading check. The accepted solution to this dangerous situation was to schedule the flight so that twilight was avoided. However, the computations to do this were not particularly quick and easy.

Greenaway and J.W. Cox of the Defence Research Board made an important contribution by developing the Twilight Computer [8], a mechanical device, somewhat like a circular slide rule, that gave quick predictions as to when twilight could be expected—and for how long. The device was a success and became a mainstay of air forces worldwide (Figure 17).

In 1948 Greenaway was persuaded by Graham Rowley to work with the Arctic Section of DRB Headquarters. His friends in the RCAF discouraged him from this, saying that by removing himself from the RCAF milieu he would be ruining his hopes for promotion. However, he could not resist the academic challenges. He was seconded to DRB, and he stayed there until 1954.

In 1950 he was awarded the President's Prize by the Canadian branch of the Royal Meteorological Society for the best paper presented in 1950. Entitled "Experiences with Arctic Flying Weather" [9], it was based on his many years of experience with long-range Arctic flights.

In 1951 he published *Arctic Air Navigation* [10], which became the standard text for the RCAF and all others who flew in high latitudes. In the same year he was given the Thurlow Award by the US Institute of Navigation [11] for having "become an authority on Arctic air navigation second to none in Canada, and probably equally well-known and recognized in the U.S.A. and Great Britain." He was also awarded the Trans-Canada Trophy for 1952. This award recognized "the person rendering the most meritorious service during the year in the advancement of aviation in Canada."

In the early 1950s the US and the UK were expressing a lot of interest in Doppler navigation. The idea was to measure the aircraft's velocity—in both the forward direction and laterally—by using the Doppler shift of radar waves bounced off the ground. There was no support for this from the RCAF, but Greenway and J.J. Green of DRB found funds to get Doppler work going at the Defence Research and Telecommunications Establishment (DRTE) Electronics Laboratory in Ottawa (ON).

Figure 17: *Keith Greenaway with his Twilight Computer. Photo credit: DND via Kathy Bergquist.*

One of the big problems was the size, weight, and power consumption of the experimental units. These all had to be reduced to something reasonable if the radar set was to be used in an aircraft. The Canadian approach was to use continuous wave (CW) signals rather than the pulsed signal favoured by the Americans and the British. The CW radar used less peak power than the pulsed unit, and so the equipment did not need to be as big. A Canadian prototype was ready to test in 1953. Marconi Canada was given a contract, and by late 1953 Marconi was at the forefront of frequency modulated / continuous wave (FM/CW) technology. In 1956 the security restrictions were lifted, and both military and civilian versions were sold world-wide.

Much of this information has been taken from *Great Circles: The Keith Greenaway Story*, by Kathy Bergquist [11]. It is a good read!

3.7 Arctic Canada from the Air

Like many of the other scientists at DRB Headquarters in those days, Moira Dunbar was a bit of a legend. She started work with the Defence Research Board in 1952, and one of her first jobs was to edit a research paper on the Arctic. She became fascinated with the subject and ended up devoting her career to Arctic work.

She first had to break down a number of barriers. She was the first woman to fly to the Arctic on a military aircraft and the first to sail north on an icebreaker. Both of these feats showed her to be an articulate, persuasive, and stubborn woman. She was also one of the first women to fly over the north pole, but that is not nearly as impressive as overcoming the male prejudices.

She became a recognized expert on sea ice, and she and Keith Greenaway wrote a very important book on Arctic geography. They were both fascinated by the look of the Arctic from the air. One important feature, for example, is the difficulty of telling where the land ends and the water begins when it is all covered with snow.

In 1956, after six years of work, they published *Arctic Canada From the Air* [12]. It contains over 500 photographs of many parts of the Arctic in all seasons. Their intention was to improve navigation by providing pilots with a good image of the geography of the Arctic from the air. It was a seminal work and became a great success. The official opinion was written by Air Marshal W.A. Curtis (Chief of the Air Staff) in a letter to Greenaway in October 1957:

> Your book is most welcome at this time. There are always people in other parts of the world who question Canada's interest in the North and ownership of the territory, and a publication such as yours will be of great assistance in convincing these people that we are vitally interested in this territory and consider it part of Canada [11].

4 Defence Research Telecommunications Laboratory (DRTE) and Associate Labs, Ottawa, Ontario

4.1 Organizational History

The organization of Defence Research Telecommunications Laboratory (DRTE) and all its associate labs, with their amalgamations, splittings, name changes, and changes of department affiliations seems to have been designed to challenge historians. An attempt at untangling the organizational history yielded the information in this section.

During the Battle of the Atlantic, German submarines were required to report to Admiral Doentz at his headquarters at Lorient on the west coast of France. The "Wolf Pack" tactics that they were using required a lot of organization and direction, and this resulted in much radio traffic. The messages were extremely difficult to decode since the Germans were using a four-rotor Enigma machine, but the radio emissions themselves could be used to help locate the submarines. The Allies developed high-frequency direction-finding equipment (HFDF—pronounced "Huff-Duff") that could give the bearing of the talkative submarine. Such equipment was, of course, given to the Navy escort vessels to help them find the submarines, but it was also installed at numerous stations around the Atlantic Ocean. Through triangulation, these stations could keep track of the Wolf Packs and help the convoys keep their distance.

The Canadian branch of this organization was run by Frank Davies with a military assistant, Lt Jack Meek. Their small group was the modest beginnings of the post-war telecommunications establishment.

It was evident that much needed to be learned about how radio waves propagated, and in 1944, the Canadian Radio Wave Propagation Committee (CRWPC) was established with Frank Davies, Lt Jack Meek, and Squadron Leader Jim Scott as its members. In 1947, this group was taken over by the Defence Research Board (DRB), and they became the Radio Propagation Laboratory (RPL) in Ottawa (ON). When they outgrew their work space, they moved to a large new laboratory at Shirleys Bay (ON), about 22 km up the river (west) from Parliament Hill, where there was room for large antennas and where there was less radio interference from the city. Their interest expanded from "propagation" to other radio problems and their name changed (slightly) to the Radio Physics Laboratory (RPL).

Meanwhile, another electronics defence laboratory, the Defence Research Electronics Laboratory (DREL), which was housed with NRC at their Montreal Road location, was working on communications equipment problems. In 1951 they amalgamated with RPL to form the Defence Research Telecommunications Establishment (DRTE) with both RPL and DREL being sections of the new establishment. Frank Davies (Figure 18) was the Chief Superintendent, Mr. J. Scott was the Superintendent of RPL, and Mr. J.W. Cox was the Superintendent of the Electronics Laboratory, the two labs still being at different locations. In 1961 the Electronics Laboratory section also moved to the Shirleys Bay site.

In the late 1960s, the Chapman Report [13] recommended that Canada should have its own communications satellite network. This resulted in the government's decision to establish the Department of Communications (DOC) and Telesat Canada. In 1969, the DRTE staff, buildings, resources, and programs were transferred to the new Department to become its research branch under the name Communications Research Centre (CRC). However, the divorce from DRB was not complete. DRB did not want to lose the research that DRTE was doing, so they paid the salaries of 16 to 18 people in a cooperative arrangement called the DRB Recovery Program. The Defence Research Establishment Ottawa (DREO) was assigned responsibility for liaising with CRC. Thus, the DRB people of DRTE were officially part of CRC, but some of them were now doing projects for (and being paid by) DREO [14]. These same

Figure 18: *Frank Davies, who played such an important part in the early growth of DRB. Photo credit: University of Saskatchewan, A-7082.*

people resurface in the history of the microwave link between Canadian Forces Station (CFS) Alert (NU) and Eureka (NU), and then again in the story of SARSAT (Search and Rescue Satellite).

Since 1994, CRC has been operating as part of Industry Canada, but as of 2013 it still has the same name. Forty-four years without a name change! That must be a record for a government lab.

4.2 Ionospheric Research—Sounders

When the Radio Propagation Laboratory (RPL) was established, one of its main interests was the ionosphere and how it affected propagation. Bill McLeish was loaned to them from the National Research Council. As well as helping to set up the organization, he led a team that designed a new ionospheric sounder for the group.

The ionosphere is that part of the atmosphere that extends roughly from 50 km to 600 km above the earth. At those heights the sun's various radiations (e.g., ultraviolet, X-rays, protons, etc.) knock electrons off air molecules causing them to become ionized, hence the name "ionosphere." Moreover, the pressure at that height is so low that the ions and the free electrons are widely spaced and do not recombine very quickly. The resulting gas of charged particles (sometimes called a "plasma") acts as a mirror to radio waves, refracting and reflecting the radio signal back down to earth, thus greatly increasing the distance over which a radio transmission can be heard. It is this effect that is of such great interest to people trying to communicate over long distances by radio. For many years, high-frequency radio (HF) was the most important way of communicating in the Arctic.

The principal tool for investigating the ionosphere is the ionosonde—or ionospheric sounder. It is a combination of a special transmitter, a receiver, and an antenna that shoots bursts of high-frequency energy upwards and then listens for reflections off the various layers of the ionosphere. From the travel time it calculates the height of the reflector. Moreover, since the ionosphere responds differently to different frequencies, the transmitter is made to sweep through a range of frequencies (e.g., from 0.1 megahertz [MHz] to 30 MHz). The receiver has to be capable of following the changing transmit frequency, and the antenna has to be both directional and efficient over this very wide frequency range.

The importance of Arctic installations was articulated by Frank Davies when he said [15], "It had become necessary to continue an ionospheric service as part of the rapidly growing international effort which in a relatively short time included more than one hundred ionosondes around the globe. In this effort, the Canadian ionosondes were much more important than their number would suggest because they spanned the northern auroral zone in which ionospheric disturbance was a maximum."

Technicians were hired to assemble and run the sounder that McLeish had designed. The first to be employed was Claire McKerrow, followed by Del Hansen, and then Armour Warwick, who had been officer in charge at Clyde River (NU). Harold Serson joined the Lab and was soon followed by Jim Wiskin, Cam Baker, Keith Bedal, Jerry Moss, and Jim Bennett [16].

One of their interesting projects was stimulated by some HFDF anomalies during the war. It had been noted that transmissions passing through the auroral zone sometimes were deflected by as much as 20 degrees. Obviously, this was not good for triangulation. To investigate this effect, Jack Meek proposed what became known as the "Mobile" experiment. The auroral zone in Canada is roughly at the latitude of Churchill (MB). In fact, the Hudson's Bay Railway, which runs from The Pas to Churchill, passes beneath some of the most intense and active auroral displays. So, in the autumn of 1947 the DRTE crew set up a laboratory in a railway car, and they travelled from The Pas to Churchill, stopping at four different sidings (Wabowden, Pikwitonei, Gillam, and Herchmer) to erect their antennas and make ionospheric measurements (Figure 19). Once the trip was completed, they stayed a week at the terminal and then turned around and did it all again. The experiment was repeated over and over until the following autumn [17].

Figure 20 shows the railway carriage parked in a siding at one of their stops, and Figure 21 gives an idea of the electronics set-up inside the carriage.

One of their many adventures (related by John Keys [16]) had to do with a fire on the train. As the train approached Gillam Station, Claire McKerrow smelled smoke, and a quick look showed him that the galley was in flames. He alerted the conductor who had the train pull into a siding in such a way that the burning car was directly under the water tower. Del Hansen chopped a hole in the roof of the car, and they dumped several hundred gallons of water onto the offending blaze. As John Keys puts it, "The fire was thoroughly extinguished as was most of the equipment." The laboratory car was returned to Winnipeg (MB) for a rebuild, and the experiment was temporarily placed on hold. They all thanked their lucky stars that the fire had occurred in the daytime and close to a siding. Otherwise, they could all have died. Del Hansen offers many more details and amusing anecdotes, although they perhaps were not quite so amusing at the time [17].

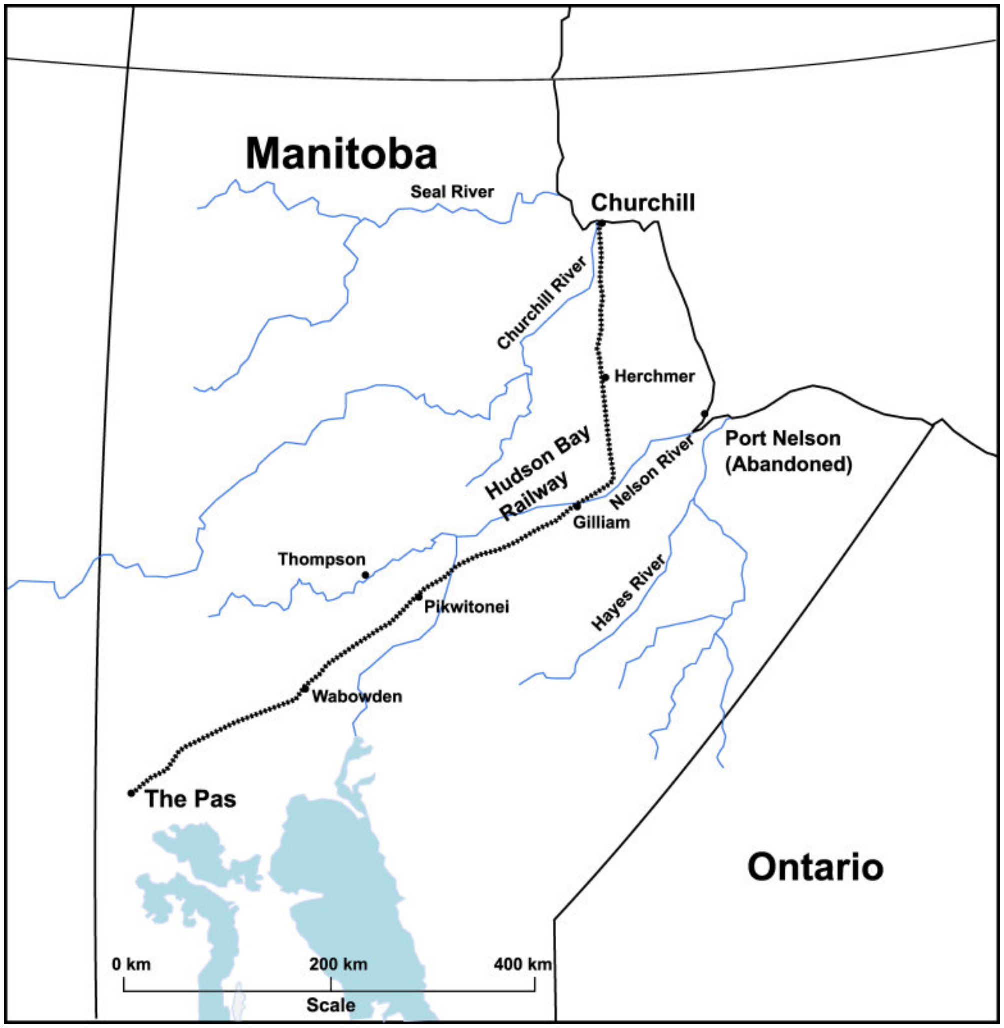

Figure 19: *Map of Northern Manitoba showing the location of The Pas, Churchill, and the Hudson Bay Railway joining them. The major waterways are shown, but many small northern lakes have been omitted for clarity.*

Later, their experiments moved farther north—into the Arctic proper. In July 1951 Harold Serson and Bill Campbell went to Resolute Bay (on Cornwallis Island [NU]) where they made auroral measurements and listened to signals coming over the Pole from the Soviet Union (Figures 22 and 23). Resolute Bay was still very new and isolated at that time. It had been started in 1947 as a Joint Arctic Weather Station (JAWS), and it had expanded slightly in 1949 with the addition of the RCAF Station Resolute Bay. As yet, there were not even any Inuit (the first group were brought in by the Canadian government in 1953). Harold and Bill were in Resolute without a break (except for a quick X-ray in Churchill after a tuberculosis [TB] scare) until September 1952.

They were tough guys. When Harold developed a bad toothache, he and Bill read the "how-to" book that came with the dental equipment, and Bill drilled out the tooth and filled it. There was no mention of a diamond drill or any anaesthetic. At another time the cook became quite ill. Harold and Bill again read "the book" and decided that the cook had a kidney infection. To treat it they had penicillin, sulpha drugs, and aureomycin, but the book did not say which to use. So, to be "safe" they combined all three.

Figure 20: *A mobile ionosphere experiment. The railway carriage that contained the laboratory was left on a Hudson Bay Railway siding for several days at a time. Note the antennas on top of the carriage. What looks to be an antenna off to the left of the car is probably just a clothesline. Photo credit: Harold Serson Collection, DRDC – Ottawa Research Centre.*

Every day they jabbed the poor cook in the buttock and injected a cocktail of the three antibiotics. As John Keys says, “Despite their efforts, he survived and recovered.”

Without a doubt their sense of humour helped them survive their fourteen continuous months in the Arctic. Their cook and the Department of Transport (DOT) cook were very keen to shoot a polar bear, so Harold and Bill decided to help. They built a realistic snow-bear a hundred yards or so from the camp and inserted several bottles of ketchup in it. Then they alerted the cooks who, as Keys says, “blazed away at it for some time, amazed to see it bleeding copiously but refusing to fall.”

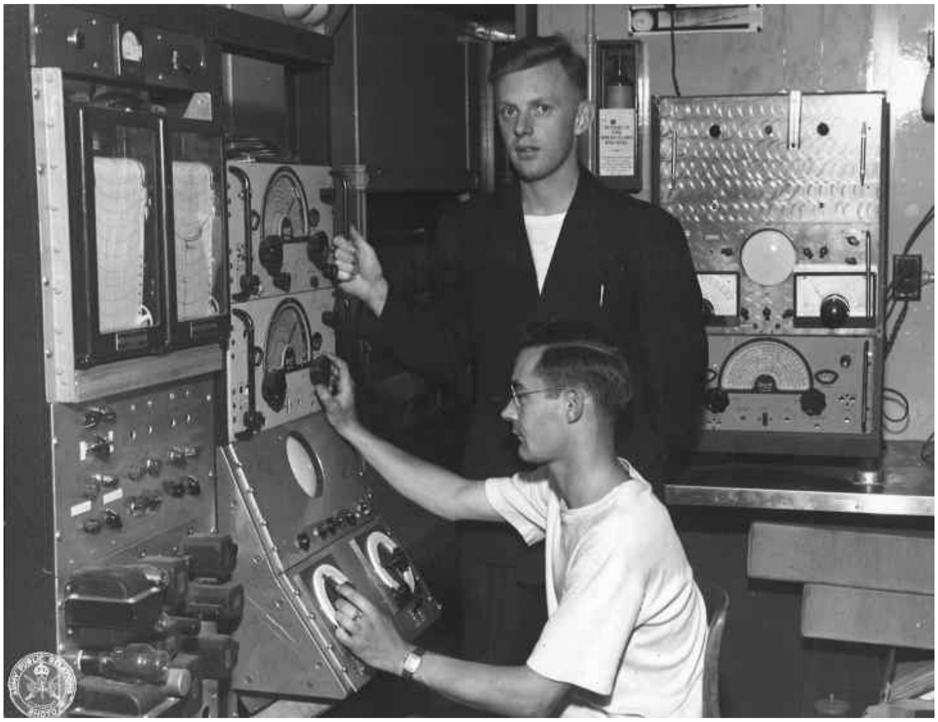

Figure 21: *Inside the mobile laboratory. Cam Baker and Bill Pen (standing). Photo credit: Harold Serson Collection, DRDC – Ottawa Research Centre.*

Figure 22: *A tower for an auroral spectrograph. The picture was taken in Resolute Bay, looking eastward to the hills on the other side of the runway. The present-day view from this point would be cluttered with buildings. Photo credit: Harold Serson Collection, DRDC – Ottawa Research Centre.*

Figure 23: *At Resolute Bay. Back row, left to right: Jesse Robinson, Jeff Willis, Kit Loomer, Vic DeCloux, Bill Campbell, and Harold Serson. Front row: Joe (last name unknown) and Joe Merrifield. Photo credit: Harold Serson Collection, DRDC – Ottawa Research Centre.*

4.3 Ionospheric Research—Rockets at Churchill

The great advantage of ionospheric sounders is that they provide a lot of data at a relatively low cost. Their disadvantage is that the measurements are all made remotely and that the ionospheric properties have to be inferred from reflected radio waves. Also, the lower ionosphere can interfere with a study of the upper ionosphere since it is, after all, in the way. A more direct—albeit more expensive—approach is to put sensors right up in the region of interest.

Rocket technology has proved to be very useful in this regard. It can quite handily put sensors up at heights between about 35 km and 300 km, which bracket the lower "D" layer of the ionosphere and the upper "F" layers. This range tends to be too high for balloons to reach and too low for satellites.

The impetus for a rocket program came from American scientists who wanted to probe the auroral zone during the International Geophysical Year (IGY) in 1957 to 1958. They had been using rockets to investigate the upper atmosphere at White Sands, New Mexico, and they wanted to make comparisons at higher latitudes. After an investigation into sites in Alaska, Canada, and Greenland, they settled on Churchill (MB)—partly because of its location in the middle of the auroral zone, and partly because it was accessible by rail, air, and sea. In 1954, during a planning and reconnaissance trip, they visited DRTE in Ottawa and discussed the project with Frank Davies, the Chief Superintendent.

Davies was enthusiastic, and the facilities at Churchill were found to be quite adequate. However, there is a bit of a "weather shock" in going from New Mexico to Churchill. For starters, the Americans had never before heard the term "windchill."

Rocket-launch facilities were installed by the American Army in 1956 and 1957. During the IGY ('57–'58), about 95 Aerobee (Figure 24) and Nike-Cajun class rockets were launched. They measured the electron density of the ionosphere for comparison with the numbers inferred from ionosonde measurements. When the IGY ended in December 1958, the Churchill range was closed.

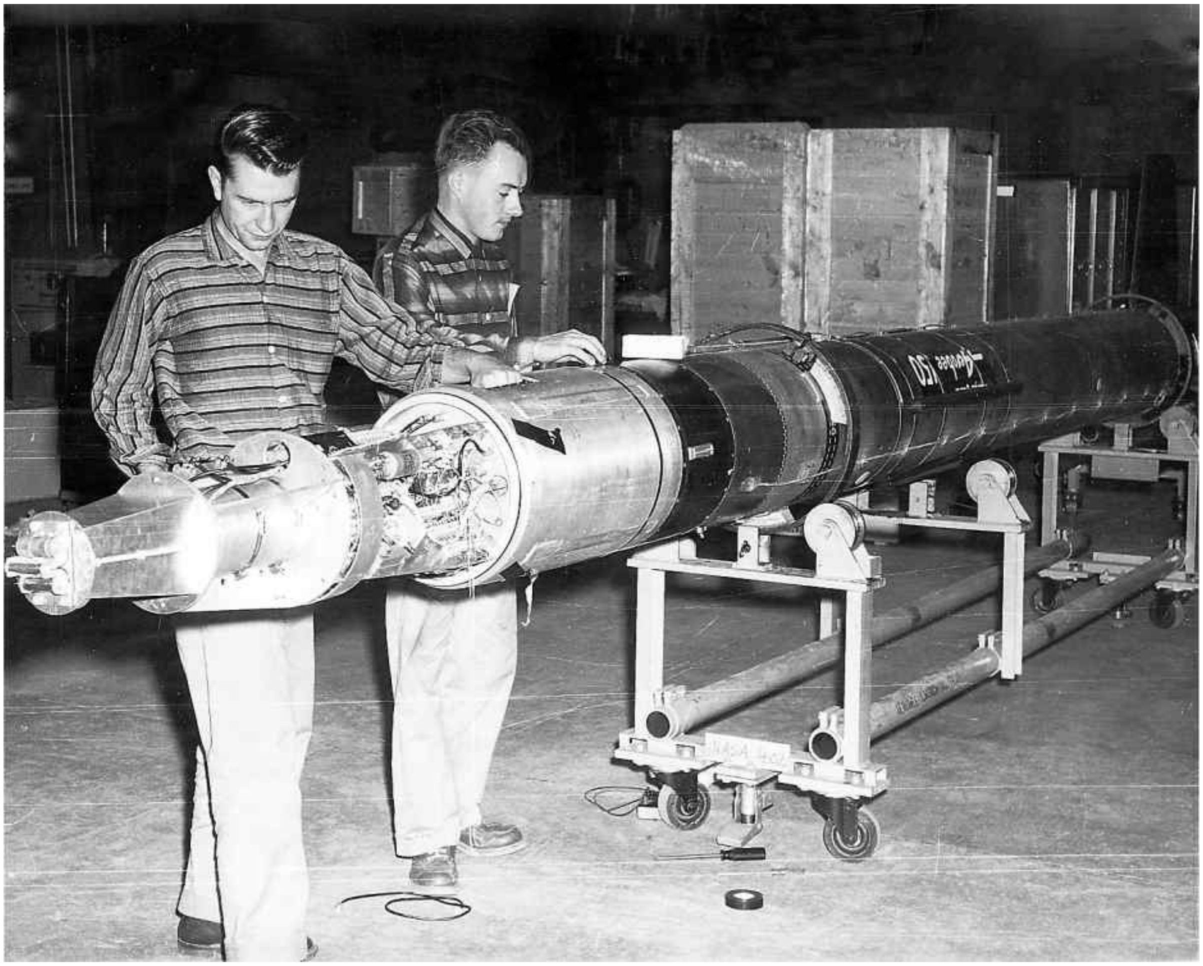

Figure 24: *The first DRTE rocket payload was launched at Churchill in 1959 by an Aerobee 150 rocket provided by NASA. Steve Cebuliak and Gordon Bird inspect the instruments. Photo credit: NRC. The print was provided by Stu McCormick who manages the following website:* `http://www.friendsofcrc.ca/Projects/Sounding%20Rockets/rocket.html`.

However, it did not stay closed for long. The Soviet Union had launched its first SPUTNIK in 1957, and this suggested that it would soon have the ability to launch intercontinental ballistic missiles (ICBMs) over the pole toward the heavily populated sections of the United States. Work on anti-ballistic-missile systems quickly became high priority. Since ICBMs flew very high, peaking out at about 1200 km, it was evident that radar could probably detect them at a great distance, and radar became the detector of choice.

The radar experts were quite concerned, however, that the heavily ionized upper atmosphere of the northern aurora zone might adversely affect the radar's operation. It was known, for example, that wavelengths of 10 metres and longer were reflected and refracted by the ionosphere. What would the ionosphere do to the shorter wavelengths of their radar? In order to find out, the US Army reopened the Fort Churchill facility in August 1959, and it ran the range with the participation of both American and Canadian groups. A similar research facility was opened at about the same time near Prince Albert, Saskatchewan. The Churchill laboratory is described in this book in Chapter 5, and the Prince Albert Radar Laboratory is the subject of Chapter 6.

The first two payloads built at DRTE were launched at Fort Churchill in September 1959 aboard Aerobee rockets provided by the Americans. In the following years more than 50 rockets carried a variety of DRTE/CRC experiments. Most of these launches were made from Churchill, but a few were made from Resolute Bay (NU) in 1967 and 1968. Walter Heikkila managed the DRTE contribution.

When the range was due to be closed down again in 1970, the National Research Council (NRC) picked up the ball and operated the facility in support of the Canadian Upper Atmosphere Research Program. The program was finally terminated in 1984 [18].

The rockets that carried these experiments up into "near space" were a very important part of the program. The first rockets to carry ionospheric probes were Aerobee rockets provided by the Americans. Very early on, however, another DRB establishment became interested in the problem. The Canadian Armament Research and Development Establishment (CARDE, the forerunner of the DRDC – Valcartier Research Centre) near Québec City (QC), had been investigating solid propellants for military rockets, and when they became aware of the scientific need they started a program to develop rockets as instrument carriers. They called their rockets "Black Brants" (Figures 25 and 26) after a goose that nests in the Arctic, and the first Black Brant at Churchill was launched in September 1959.

The family of Black Brant rockets became a great success. The technology was commercialized by a Winnipeg (MB) firm that became Bristol Aerospace, Ltd., and the rockets were sold internationally (refer to Section 10.2 for more information on the Black Brants).

4.3.1 ALOUETTE 1 Satellite

The previous sections describe the use of upward-looking sounders and rocket-carried instrument packages for investigating the ionosphere. The sounder is relatively inexpensive, and it can keep up a round-the-clock series of measurements. However, the upper layers of the ionosphere are hard to measure because they are shielded to some extent by the lower layers. The rockets, on the other hand, can place a measuring package right up in the region of interest and measure the density of electrons and other charge carriers. The disadvantage to the rocket system is that it makes a very quick (spot) measurement, and then comes back down to earth. It is not capable of making measurements lasting more than a few minutes, and, unless one has a very large budget, it is not capable of examining the fluctuations between day and night.

This is where the satellite enters. It can fly over the ionosphere looking down with its radio sounder in the same way that a ground-based sounder looks up. This so-called "topside sounder" can get much more detail on the upper ionosphere than can a bottom-side sounder. Also, it can get many "looks" per day; it can examine vast regions of the ionosphere over inaccessible parts of Canada, thus measuring spatial variations, and it can make comparisons between night and day, and between winter and summer. In addition, a satellite can measure the number of charged high-energy particles coming (primarily) from the sun. A knowledge of this flux of particles is important to an understanding of the ionosphere.

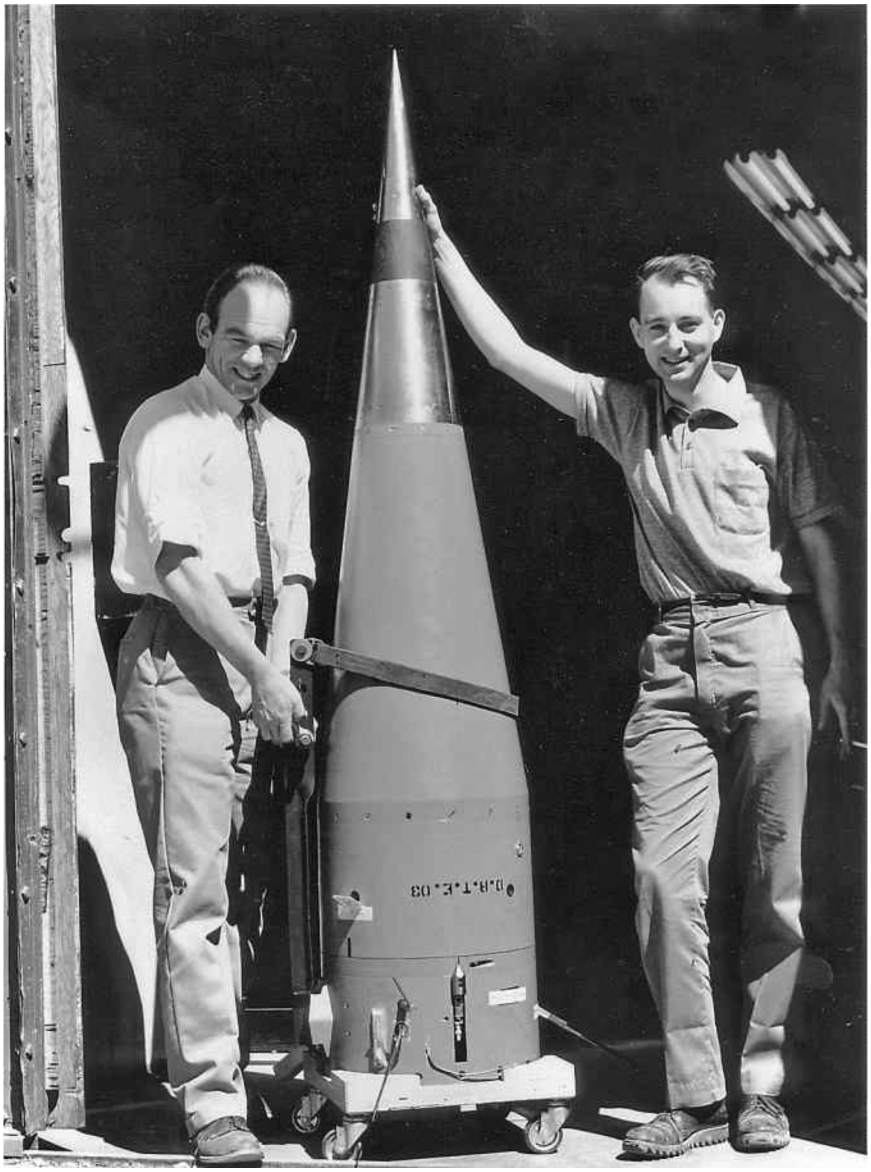

Figure 25: *Walter Heikkila (who initiated the DRTE rocket program) and Sid Penstone with the Black Brant DRTE 03 nose cone. Photo credit: NRC. The print was provided by Stu McCormick who manages the following website:* `http://www.friendsofcrc.ca/Projects/Sounding%20Rockets/rocket.html`.

Figure 26: *Black Brant Rocket taking off at Fort Churchill. Photo credit: DRDC – Ottawa Research Centre.*

In July 1958, soon after SPUTNIK's launch, and with some urgency, the Space Science Board of the US National Academy of Sciences solicited proposals for scientific experiments to be conducted with satellites. On 31 December, 1958, DRTE submitted a proposal, and on 20 April, 1959, the newly formed National Aeronautics and Space Administration (NASA) accepted it. The project, known as ALOUETTE 1, was to be joint between Canada and the United States [19, 20].

References [20] and [21] give very interesting descriptions of the project. The general feeling was that the DRTE was exceedingly bold—almost foolhardy—to attempt to build something as advanced as ALOUETTE 1 using scientists and technicians who had virtually no experience in space technology.

However, the ALOUETTE project was a great success. The ALOUETTE 1 satellite (Figure 27) was launched from the Vandenberg Air Force Base, California, on 29 September, 1962, and it transmitted data flawlessly for seven years, after which it was turned off. On its tenth anniversary it was turned on briefly for the celebrations, and it was found to be still working.

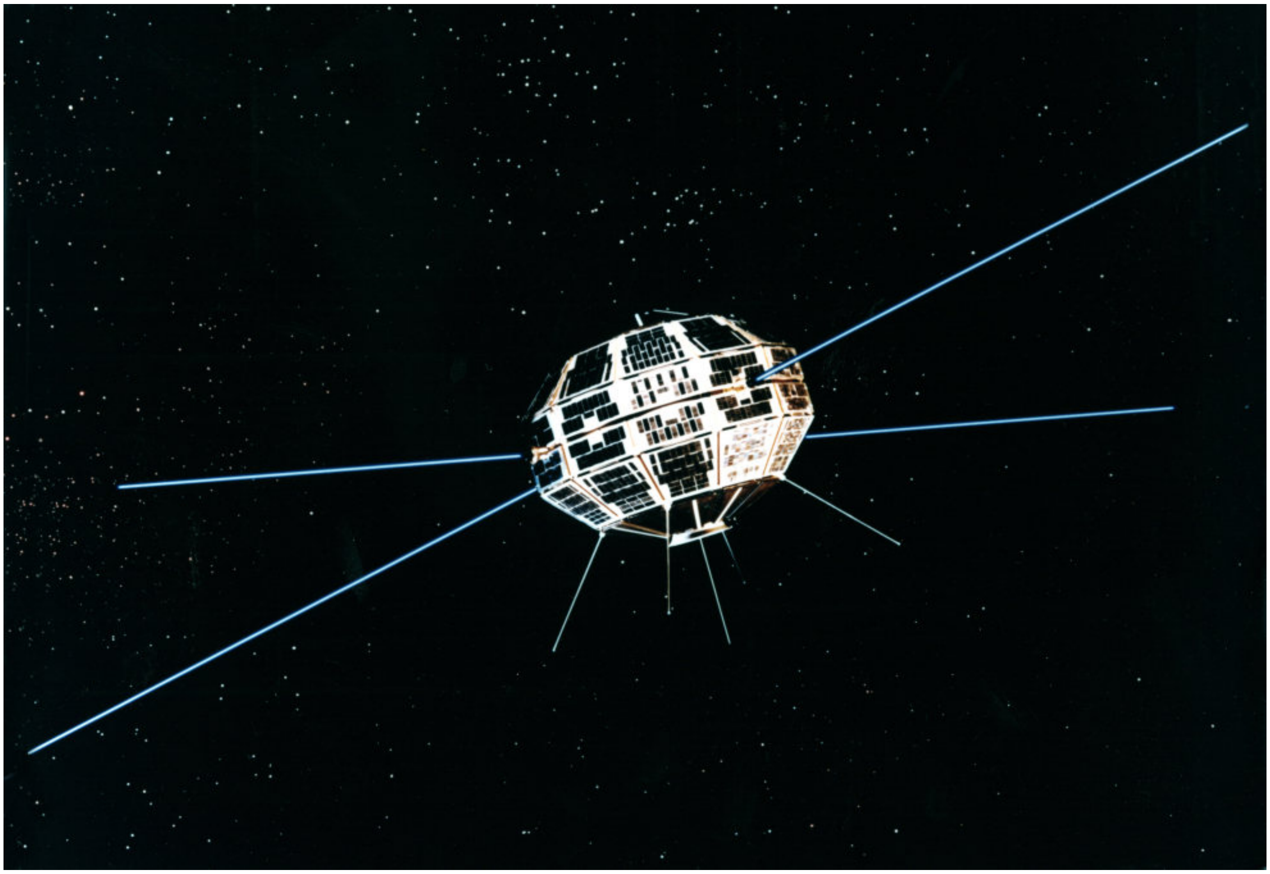

Figure 27: *An artist's rendering of the ALOUETTE 1. For its topside sounder work it had two rigid dipole antennas, 46 m and 23 m tip-to-tip. Each of the four 1-inch tubes comprising the antennas were stored at launch as a wound-up four-inch-wide flat piece of spring steel, much like the tape in a very wide tape measure. Once the satellite was in orbit the metal was extruded, and, because it was prestressed, the flat ribbon rolled itself up to make a round tube, and this tube was stiff enough to hold its shape as an antenna arm. This technique was called Storable Tubular Extendible Member (STEM). STEMs were invented by George Klein of the National Research Council and were one of the first products of Spar Aerospace Ltd. Photo credit: Communications Research Centre of Canada.*

ALOUETTE 1 vastly expanded human knowledge of the ionosphere above 300 kilometers [19]. Among other things, it provided information on the distribution of electrons and the variation of this distribution in both time and space. It measured the influence of incoming charged particles, and it studied the solar wind.

In 1993, the Institute of Electrical and Electronic Engineers (IEEE) designated the ALOUETTE as an International Milestone of Electrical Engineering. In accepting the award, Admiral J.R. Anderson, Chief of the Defence Staff commented [20], "I can't help but marvel at the brash confidence—the boldness—of the group at DRTE who decided to take on the world and build one of the most complex satellites of its day, and to do the job so well that it set world records for scientific discoveries, for length of deployed antennas, for battery life and for longevity in space."

In May 2010, the historical significance of ALOUETTE 1 was recognized with a ceremony and plaque erected at Shirleys Bay (ON) by the Historic Sites and Monuments Board of Canada [22]. Figure 28 shows a picture of the plaque surrounded by many of the original ALOUETTE pioneers.

Figure 28: *The ALOUETTE plaque surrounded by thirty-four of the original ALOUETTE Pioneers. Photo: Janice Lang, DRDC – Ottawa Research Centre.*

ALOUETTE 1 was just the first of a series of satellites that studied the ionosphere. In May 1963, negotiations with the Americans led to the creation of a program called the International Satellites for Ionospheric Studies (ISIS). Under this program ALOUETTE 2 was launched on 29 November, 1965, ISIS 1 was launched on 30 January, 1969, and ISIS 2 was launched on 31 March, 1971.

As an outcome of the knowledge and experience gained through these satellites, Canada launched the first national domestic communications satellite, the ANIK A1. It and some of its successors are described in the next section.

4.4 Microwave Link Between CFS Alert and Eureka

Canadian Forces Station (CFS) Alert (NU), on the north coast of Ellesmere Island, was established as a Joint Arctic Weather Station (JAWS) in 1950 by the Canadian Department of Transport and the United States Weather Bureau. It started off with twelve people, an airfield, three Jamesway huts, and some weather monitoring equipment (Alert's location is shown in the map in Figure 1, page 5).

In 1956 the RCAF put up a building to house their "High Arctic Long Range Communications Research"—or signals intelligence. In 1957 this was expanded by several buildings, and it was jointly staffed by the RCAF and the RCN.

CFS Alert grew steadily during the Cold War, but its only contact with the outside world was HF radio and a weekly flight. It needed better communications.

A satellite relay was the method of choice for most remote locations in the world. A satellite in a geostationary orbit, in which the satellite revolves around the earth once every 24 hours, appears to remain motionless over a point on the equator. It will do this if its orbit has the right radius—about 36000 km above the surface of the earth. Such a satellite is particularly useful for communications since ground-based antennas need never change the point at which they are aiming. Moreover, the satellite never "sets." The first geostationary satellite was SYNCOM 3, launched by the Americans in 1964. The first Canadian geostationary satellite, ANIK A1, was launched in November 1972 by Telesat Canada, becoming the world's first national domestic communications satellite. It could carry many thousands of telephone circuits, and it brought television to the Canadian Arctic for the first time.

But it did not serve the whole Canadian Arctic. A geostationary satellite cannot be seen from the very far north. If, for example, you imagine yourself standing at the north pole, you would not be able to see anything that was directly over the equator unless it was extremely far away from the earth—like the sun at equinox. A geostationary satellite is not particularly far away: the 36000 km is only about three and a half earth diameters, and so the satellite would be well below your horizon. In fact, you cannot see it unless you are farther south than latitude 80°N, roughly, and if you cannot see it you cannot communicate with it.

Alert (NU) is at 82.5°N, and that extra couple of degrees north makes communication with a geostationary satellite impossible. On the other hand, Eureka (NU) is right at latitude 80°N, and the ANIK A1 satellite was just visible, even though the geometry was worsened by the fact that the satellite was not due south of Eureka. Because the satellite was visible it was felt that Eureka should be able to get high-speed communications, and it did not take long before people were imagining the further step of connecting Alert to Eureka by a land-based microwave telemetry link.

However, just because the satellite was above the horizon at Eureka (by about half a degree), it did not mean that communicating with it would be easy. First of all, there was the obvious problem of the local hills getting in the way; one needs to have a clear shot at the horizon. A more subtle problem, however, was that of fading. When a satellite is that close to the horizon, its signals can be reflected off mountains and other such irregularities on the ground, and the multiple paths from satellite to receiver can interfere with each other. Also, the signal passes through a lot of the earth's atmosphere, and the resulting refraction can cause the signal path to bend. Thus, the multi-path interference is not stable, and the inevitable fading will come and go, with the received signal sometimes dying away to nothing (this effect is known as "scintillation" in optics).

The cure for this is usually antenna diversity (or space diversity) where two or more antennas are set up a suitable distance apart so that when one antenna is experiencing a deep fade, the other antenna will still have a reasonably large signal.

This is where DRB became involved. A study of the feasibility of satellite communications into Eureka was carried out by CRC (the Communications Research Centre). This was not nominally DRB, but the study was done under the DRB Recoverable Program—i.e., with DRB money. Larry Maynard, the then director of the Program, says [5] that his people who were involved included Harvey Werstiuk and Gerry Poaps. Another group specializing in Propagation Physics contributed Rod Olson and John Strickland to the project. Strickland has written extensively on the project (see, for example, Reference [23]).

Their first test, with the support of Telesat Canada, involved a link between CRC in Ottawa (ON) and a temporary terminal placed on a hill to the east of Black Top Creek near Eureka. For three weeks, in 1974, they monitored the signal strength and got a preliminary measure of the fading problem. In 1976, with the aid of Telesat, they placed two antennas near the Eureka runway, one being 500 m west of the other. Their expectation was that a horizontal separation of this magnitude would give sufficient "spatial diversity." In other words, they anticipated that both antennas would never go into a deep fade at the same time. This turned out to be wishful thinking. Strickland, who was at Eureka plotting the signal strengths, says that the fading at the two sites was quite well correlated. Later, they found that a 20-m vertical separation of antennas gave about the same diversity as the 500-m horizontal separation [24]. Obviously, vertical separation was the strategy to use.

The final location for the antennas was at Skull Point, which is north and west of Eureka and commands an unobstructed view SSW down Eureka Sound toward the satellite (Figures 29 and 30). One antenna is about 30 m above sea level, and the other (to provide vertical separation) is uphill from Skull Point at a site known as Upper Paradise. The system works well.

The next step was to get a high-speed link from Eureka (NU) to Alert (NU). Although this project did not involve any participation by DRB, the link is so important to the military's Arctic work that the high points of the story are mentioned here.

In the summer of 1976 Honeywell built and installed a demonstration radio repeater that would be suitable for an Arctic environment. It successfully sent data over four paths in the Alert area.

Upon the success of this demonstration, planning for the High Arctic Data Communications System (HADCS) began. The system was to include the two satellite stations already mentioned, and six repeater sites were to be installed between Eureka and Alert (Figure 30). The Black Top site shown in Figure 31 is the first link in the chain of repeater sites that connect the satellite with Alert. The data speed was to be 1.544 megabits per second (Mbps) (known as "T1 speed"). Construction began in 1981.

The T1 speed was soon found to be too slow; much of the output of signals intelligence (SIGINT) still had to be shipped south on the weekly Hercules run. As a consequence, HADCS was upgraded to HADCS II in the summer of 1998. The data rate was quadrupled from T1 to T2 (6.312 Mbps). As well as helping to cure the SIGINT bottleneck, the larger bandwidth brought television and Internet access to Alert.

Figure 29: *The Skull Point location as seen in April 1982. Upper Paradise is approximately 1000 m behind Skull Point and about 150 m higher. The smaller dish is a 12' (3.6 m) reflector that was installed and used for the original propagation measurements from Skull Point in 1978. Photo credit: Griff Toole. This photo was taken from* `http://jproc.ca/rrp/alert.html`*.*

The design of the power supplies for the remote repeaters was a particularly interesting problem. The specifications were very severe. The power packs had to survive and work through the bitterly cold Arctic winter. Moreover, the sites were not accessible during the dark period, so repairs had to be considered impossible except for a brief window during the summer. In short, reliability had to be very high. Several ideas were considered, and the one that seemed the most suitable was the simplest—carbon-zinc primary cells. Cipel (later SAFT) made a 2000 ampere-hour cell that was rugged and quite resistant to cold. Each repeater site (Figure 31) required 140 of these cells to power it for a year, and every summer they all had to be replaced. The cost—in man-hours, helicopter and Hercules time, fuel, disposal of the old batteries, etc.—was estimated to be several million dollars, of which only a minor amount was the cost of the batteries.

In about 2002, a new type of power supply, designed by John Strickland, was installed at all sites. It used rechargeable lead-acid batteries, which were recharged by solar cells during the summer and kept adequately warm all winter by a container that had high-tech insulating walls (Figure 32). The very interesting story of the evolution of the repeater power supplies can be found in Reference [23].

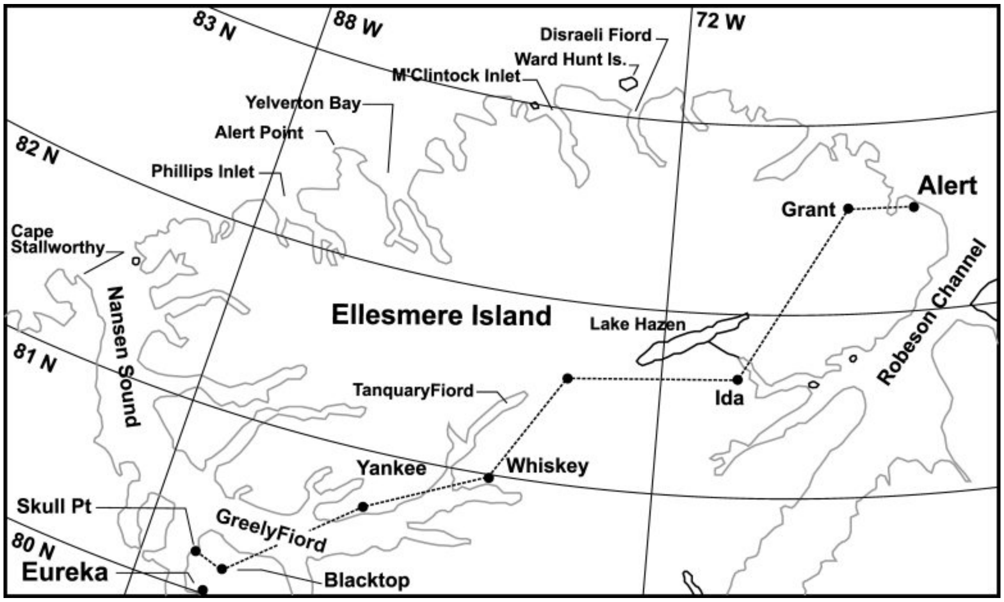

Figure 30: *The microwave link from Eureka to Alert showing the six repeaters from Blacktop (bottom left, close to Skull Point) to Grant (top right, next to Alert). The signal comes from the satellite to the antennas at Skull Point, and from there it is sent to Eureka and to Blacktop (and from Blacktop to Alert).*

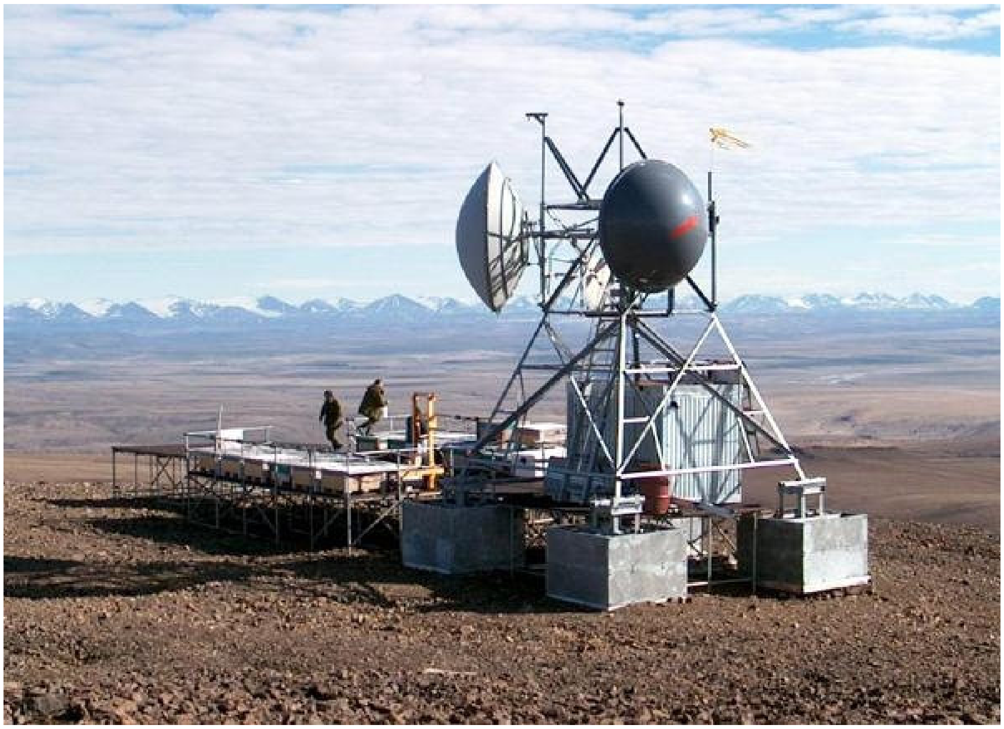

Figure 31: *Black Top Mountain repeater station. Racks of SAFT Inc. carbon-zinc batteries can be seen to the left of the tower structure. Photo credit: DND photo library. This photo was taken from* `http://jproc.ca/rrp/alert_photos3.html`.

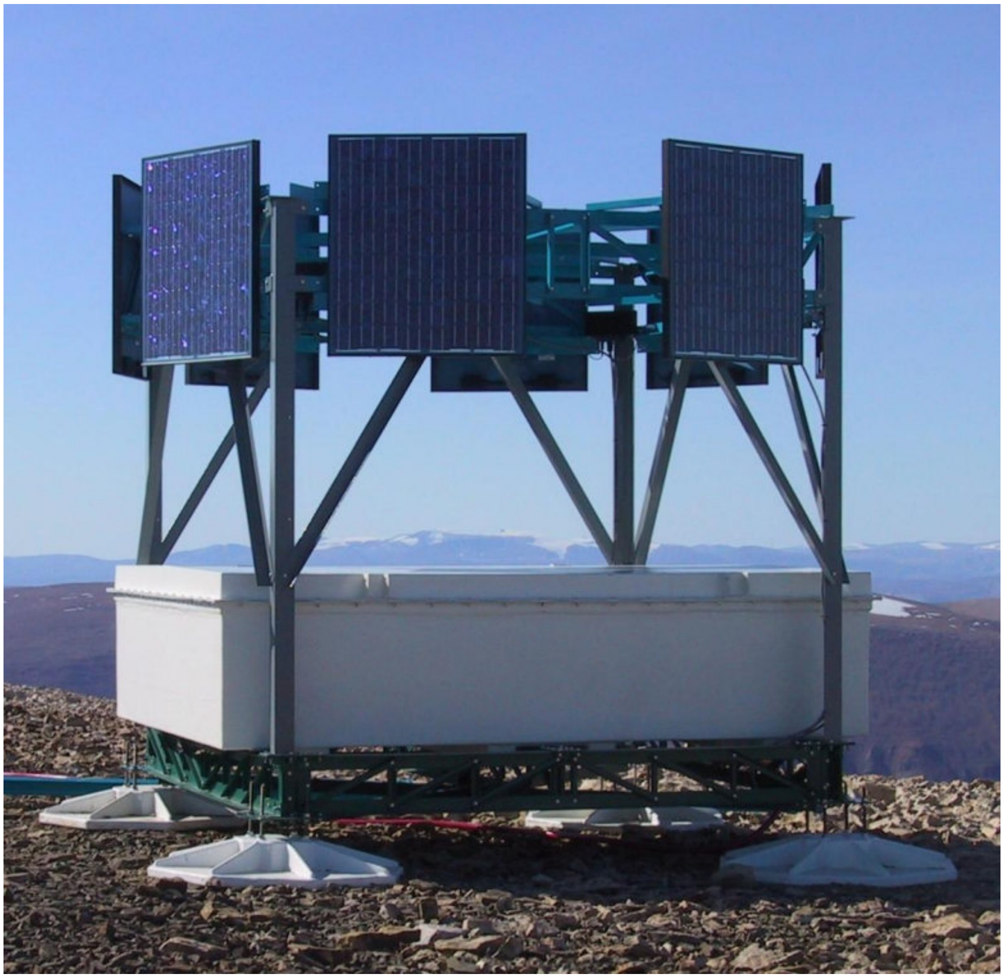

Figure 32: *Modern power supply for a relay station of the HADCS II data link between Eureka and Alert. Note the vertical solar panels that take advantage of light reflected from the snow. Photo credit: Alan Strickland, Diversitel Communications.*

4.5 SARSAT—Search and Rescue Satellite Tracking

SARSAT is a system that uses satellites to help find disaster scenes such as crashed aircraft, boats in trouble, or lost or injured hikers. Specifically, the satellite helps find an emergency locator transmitter (ELT) that has been activated. The principle behind this is the Doppler shift of the emitted ELT radio signal as the satellite passes over. When a car passes you by or when an airplane flies overhead, the sound that you hear drops in frequency. This is known as the Doppler shift. The ELT radio signal picked up by the satellite does the same thing: the frequency is higher as the ELT is being approached, and it is lower as the ELT is being left behind. The Doppler shift is zero when the satellite is at its closest point of approach to the ELT. Moreover, the rate at which the frequency changes from high to low gives an indication of how far the ELT is off to the side of the satellite's path. The result of the appropriate calculations is a prediction of the ELT's location. Actually, the calculations give two possible locations—one to the left of the satellite's track and the other to the right, but one location can usually be ruled out by a second pass or by other considerations. A low-altitude orbit is preferred since the Doppler shift will be rapid as the satellite flies over the ELT, and this means better accuracy. A low-altitude orbit also means that the ELT can have a lower power output. Finally, if the orbit is polar, the satellite will cover the whole earth.

DRB is very proud of the fact that it was instrumental in both the genesis and the development of SARSAT. The project was not particularly oriented toward the Arctic, but, on the other hand, SARSAT makes search and rescue in the Arctic very much easier and quicker, and speed in that cold climate usually means the difference between life and death. Consequently, it is appropriate that the story of SARSAT belongs in this history of DRB and the Arctic.

ELTs were made mandatory in California in 1969 after the crashes of three aircraft searching for a crashed DC-3 in the Sierra Nevada Mountains. Over the next five years or so, the US federal laws mandating their use became more and more strict [25].

When an aircraft crashes the sudden shock turns on the ELT, and it broadcasts a radio signal that serves as a beacon to guide search aircraft to its location. Originally, satellites were not involved.

The SARSAT system was originally conceived during a coffee discussion in the Space System Group at the Communications Research Centre (CRC) in the early 1970s [5]. The question was whether space technology could be used to pinpoint an ELT's location. This would save significantly on the cost of searching, and the shortened time might well save lives, especially in Arctic regions.

The discussions involved Larry Maynard, LeRoy Pearce, Doug Lambert, and Menno Stoffels. They puzzled over just how they could use an orbiting satellite to locate an ELT. Someone eventually pointed out that the received signal would experience a Doppler shift as the satellite went by, and, if the satellite's location were known accurately, this shift might be sufficient to help locate the ELT.

The idea seemed to be a good one, and it was pursued by CRC with costs recoverable from the Chief of Research and Development (CRAD), which was the organization that had replaced the Defence Research Board.

Initially, however, the level of support was not very high. In order for the project to take off, they had to arrange a demonstration, and, of course, the demonstration had to be successful. The first problem was to find a satellite that might be used for this demonstration. At the time, an organization of radio amateurs had an orbiting satellite, named OSCAR (Orbiting Satellite Carrying Amateur Radio), which was used as a repeater in their two-metre Ham band. The uplink frequency was 145 MHz, which is close enough for demonstration purposes to the ELT frequency of 121.5 MHz. Larry Kaiser of the AMSAT (Amateur Satellite) organization was contacted, and he generously gave his support for the use of OSCAR.

The demonstration was organized largely by LeRoy Pearce, Doug Lambert, Menno Stoffels, and Allen Winter under Larry Maynard's supervision. An ELT was modified to emit a signal at 145 MHz so that it could use the OSCAR satellite. The modified ELT was flown to a remote location in northern Quebec and turned on. This location was known only to the helicopter pilot and to an Associate Assistant Deputy Minister (Materiel), or AssocADM(Mat) for short. After the next OSCAR pass, the ELT location was calculated from the Doppler shift information, and this position was presented for verification to the AssocADM(Mat). The accuracy of the location convinced him of the feasibility and value of the project, and he gave it his full support.

Sometime later Maynard received a very encouraging telephone call from Bernie Trudell of NASA. Bernie had heard of the successful demonstration and indicated that they had been looking into a similar concept. As a result of the subsequent discussions, the two countries eventually agreed to a joint project.

In 1978 CRAD sponsored Canada's SARSAT project and assigned it to DREO [26]. The project team consisted of Rod Hafer, the Project Manager, Harvey Werstiuk, the Technical Manager, and Roy McPherson, the Deputy Project Manager. The other SARSAT countries were France and the United States. Also, a memorandum of understanding (MOU) was signed with the Soviet Union, whose equivalent program was called COSPAS.

The first satellite for the COSPAS/SARSAT system was the COSPAS-I, launched by the Soviet Union in June 1982. COSPAS-II and SARSAT-I were launched in March 1983 (Figure 33 shows their logo).

Figure 33: *COSPAS/SARSAT Logo. Image provided courtesy of the International COSPAS-SARSAT Programme.*

On 9 September, 1982, even as the COSPAS-I was being checked and verified, a small aircraft crashed in a mountain valley in northern BC. COSPAS-I detected the ELT and relayed the data to DREO. The crash location was calculated and sent to the local Rescue Coordination Centre, and within hours the survivors were being airlifted out. The plane was 90 km off its planned route, and without the satellite information the rescuers would have spent days of fruitless searching. By the time the evaluation was completed in 1985, the system had located some 194 distress incidents worldwide. Of the 529 people involved in the incidents, nearly 500 were rescued.

Once the evaluation was completed, DREO's role was over. An interim system was put in place, and in 1991 the Canadian SARSAT system was declared fully operational.

5 Defence Research Northern Laboratory (DRNL), Churchill, Manitoba

5.1 US Army and the Crimson Route

The Hudson Bay Railway, joining Churchill to southern Manitoba, was built to connect the grain fields of the prairies to the markets of Europe. When it was completed in 1931 there was no thought of Churchill (MB) as being militarily important, but this was to change during the Second World War.

The United States' entry into the war was planned secretly during 1941. One of their concerns was the enormous number of aircraft that they expected to ship to Great Britain. The standard air route went via New England (USA) and Labrador (NL), and the authorities were concerned that this route would not be able to handle the traffic. Also, a more direct path (i.e., a more northerly route through central and northern Canada) was needed for aircraft built in California and other western states, and Churchill was an obvious waypoint. This route was known to the American military as the "Crimson Route," "Crimson" being their code word for Canada [27].

In 1942 the American Army received permission to establish a hospital and an airport in Churchill. These were finished in 1943, but the Crimson Route was deemed unsafe because of the bad weather and the high accident rate over the North Atlantic during the winter of 1942. All aircraft destined for Britain were diverted to the safer (but much longer) route through the Azores. The airfield at Churchill was abandoned by the US Army Air Force in the spring of 1944 and turned over to the Canadian Department of Transport (DOT).

5.2 Fort Churchill

In 1946, the Canadian Army, with a new-found interest in Arctic warfare, took over the camp from the DOT and renamed it "Fort Churchill" to emphasize its military nature and to distinguish it from the Churchill town site. The general location of Churchill is shown in Figure 19 (page 26), and a map of the area is shown in Figure 34. The Army's intent was to investigate the military problems associated with surviving and fighting in the harsh conditions of the Arctic and Subarctic (in both winter and summer). Churchill was well situated for training purposes, being within easy reach of both barrens and bushland.

5.3 Early Defence Research Work

Interest in Arctic research predates the establishment of the Defence Research Board in April 1947. In the fall of 1946 the Arctic Warfare Committee recommended to the Director General of Defence Research that it initiate a research program in the Arctic [28, p. 12].

To direct this program LCol P.D. Baird and LCol G.W. Rowley were transferred from the Army, and Maj C.P. Macnamara, Maj A.C. Jones, and Dr. Alan Woodcock from the National Research Council (NRC) were chosen to initiate several lines of research.

Jones and Woodcock arrived at Churchill on 1 January, 1947, and began a series of clothing tests using a group of paratroopers as "subjects" for the experiments. They also used the Churchill winter for cold-weather tests on tents, fuels, and lubricating oils.

A larger group returned to Churchill in June 1947, with A.C. Jones the only member associated with DRB. They began a study of biting flies (including mosquitoes). Jones comments that they found more

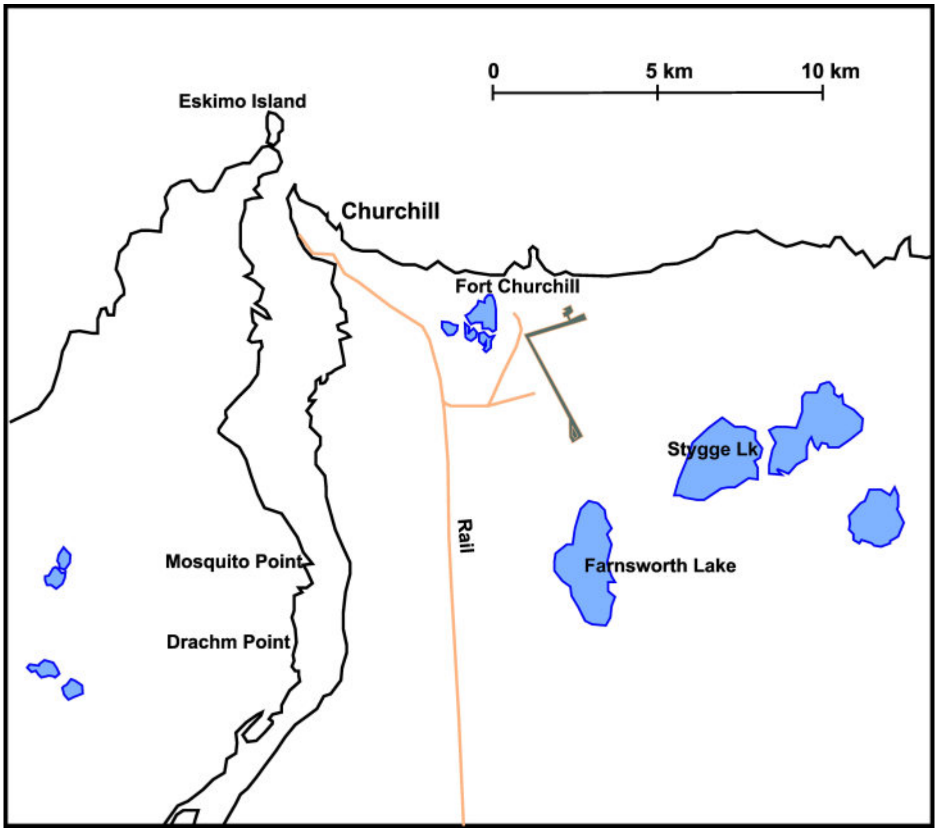

Figure 34: *The Churchill and Fort Churchill area. The map is adapted from an older Department of Natural Resources Canada image. Only the larger lakes are shown. Most of the land is low-lying and is almost entirely muskeg.*

species of biting flies than they had expected. He also says that the intensity of their attack was higher than they had encountered anywhere else in the world—not a big surprise to any Manitoba resident. He says that the standard way of measuring the intensity of attack was by exposing a forearm and counting the number of bites per minute (Figure 35). However, none of the investigators was willing to endure a full minute of this. They backed off to ten or fifteen seconds and extrapolated. Counts of 250 bites per minute were recorded [28, p. 16].

Their program was two-fold. The first objective was to find ways of reducing the mosquito and fly population in a given area, and the second was to provide protection to personnel against the pests. They found that they could kill 95% of the larva in a given area, but foreign flies and mosquitoes coming in from beyond the sprayed area soon made life unbearable again. They switched to aerosol spraying the adult flies. With regard to protecting the individual, they found that the insect repellents then in use were far from adequate for the northern muskeg country. And, although much was learned on this topic, they never came up with the ultimate “fly dope” that would truly discourage those persistent Arctic pests.

Many of the personal accounts of people who have lived in Churchill have comments about the mosquitoes, and none of them is particularly charitable. For example, C.J. Eagan (in Reference [28], page 77) says, “The overwhelming density of the tundra mosquitoes has often been described but must be experienced to be fully appreciated as the single most important feature governing activity in the North (at least in the summer).”

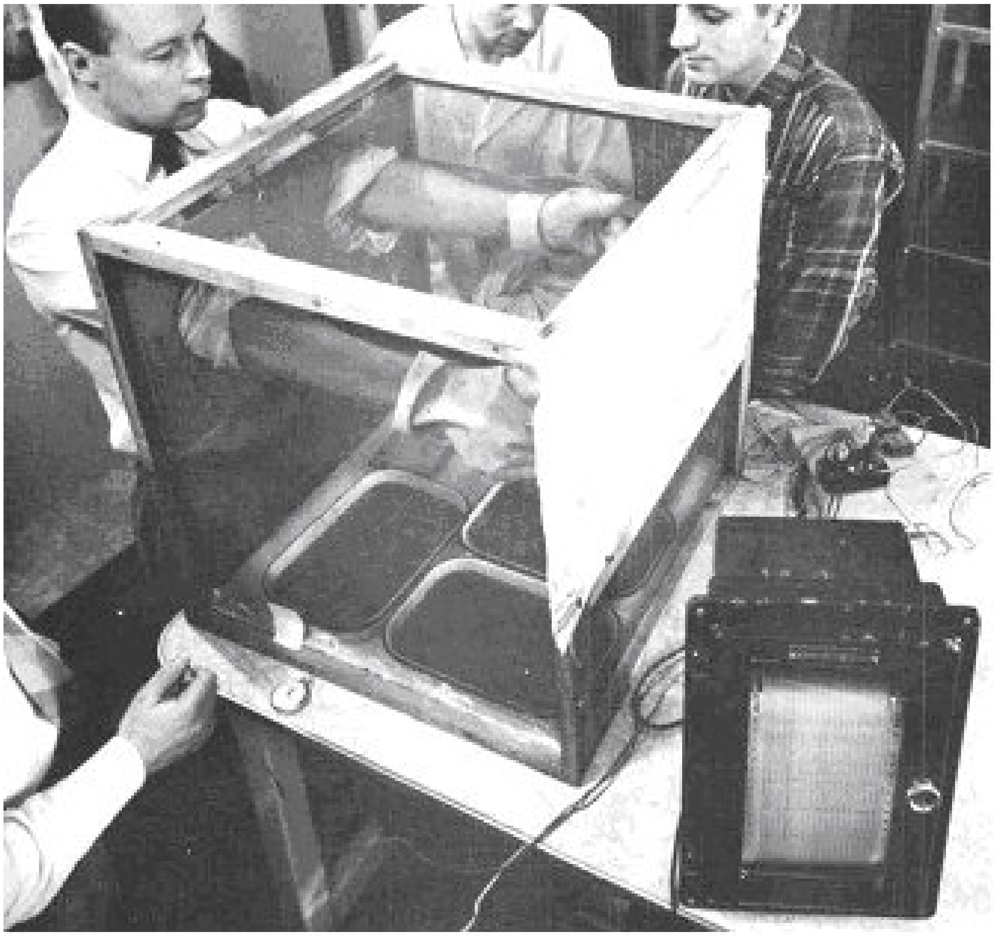

Figure 35: *An insect-biting trial. Ed Lytle was the victim—1954. Photo taken from Reference [28, p. 53]. Photo credit: DRB*

He goes on to say, "Bob Cunningham claimed that no mother in Churchill should ever worry about her daughter walking in the woods with a young man in summertime!"

Who would have thought of the mosquito as a chaperone?

Partly in support of the "biting insects" program, botanists at the laboratory carried out extensive studies of Subarctic vegetation.

5.4 DRB and the Establishment of DRNL

DRB was officially created 1 April, 1947, and by mid-summer the decision had been made to establish an official DRB laboratory at Churchill. The lab had not yet been created when Mr. J.P. (Jim) Croal arrived in late August 1947 ready to conduct permafrost investigations. In several references (e.g., Reference [1]), Mr. Croal is credited with the honour of being the first employee of DRB to be stationed at Churchill. One wonders why Mr. A.C. Jones is not given this honour. He arrived in June 1947, after DRB had become an official entity and almost three months before Mr. Croal. Perhaps Mr. Jones was not an employee of

DRB at that time, although he certainly was when he became the first Superintendent of the laboratory at Churchill, to be called Defence Research Northern Laboratory (DRNL).

In any case, Jim Croal seems to be one of those early DRB employees who is just a little larger than life. He regularly showed up precisely where and when he was needed. In February 1947 Lt Croal (of the RCN) took part in Operation MUSK-OX where, to add luster to his fame, he won the official beard-growing contest. In August of the same year, after resigning from the Navy, he arrived at Churchill as a one-man DRB contingent. In 1948 he helped with the start-up of Resolute Bay (NU). Later, he rejoined the Navy, and in 1957–58 during the International Geophysical Year, as LCdr Croal, he supervised the airlifts and sealifts of freight to the Lake Hazen Camp on Ellesmere Island. In 1959 he helped with the logistics and accompanied Allen Milne, of the Pacific Naval Lab (PNL) (Section 8.1), on his first Arctic trip to Barrow Strait. In August 1962 he supervised the freight delivery by the SIR JOHN A. MACDONALD to the new camp at Tanquary Fiord on the western coast of Ellesmere Island.

Moreover, he seems to have left a trail of good will behind him. In Reference [28], in one of several similar comments, he says, “I have discovered in 20 years of Arctic operations that Servicemen and scientists can work and live together in perfect harmony.” He was very complimentary toward the two Army Commandants he had known in his time at Churchill, LCol D.C. Cameron and LCol A.J. Tedlie. He says they were patient, effective, and very helpful to the scientists, who were not particularly high on the Army’s official list of priorities.

Late in 1947 Mr. A.V. Hannam arrived in Churchill to take command of the DRB establishment. Croal proudly led him to DRB Headquarters, Fort Churchill—a 6’ x 8’ x 8’ drill shack. Hannam’s reaction, apparently, is not printable, and he hot-footed it to the Camp Commandant in an effort to get more space. Before long they were working out of three buildings (Figure 36).

Accommodation of any kind was exceedingly hard to get through the “system,” and so Croal built himself a small house (which he calls a “shack”) in order to bring his wife and children to Churchill. It was made primarily out of scrap lumber scavenged from an old dump, and everyone from the local trappers to US Army officers provided him with no end of cheerful help. He completed his house in one month—working weekends and at night—for a total cost of about seven hundred dollars [1]. He makes the quite delightful (and moving) statement, “At one time or another nearly all the townspeople of Churchill hammered a few nails into the house and so it was built, and I became one of them, and this is the secret of the North—the people.” Croal and his family moved into their new house on Christmas Eve 1947.

5.4.1 Early Scientific Work

By the end of 1947 there were four scientists and one clerk working for DRB at Churchill. They continued the earlier work on Arctic clothing and equipment, fuels, and lubricants. They also began a study of nutrition, medical problems, and permafrost.

Croal’s diamond drilling in the permafrost soon showed temperatures of about 25°F (-4°C). Mr. A.C. Jones [28, page 17] expresses disappointment at such “warm” temperatures, saying that they would not be able to use caverns cut into the permafrost as frozen-food containers. Perhaps, he was not aware that the average yearly temperature in Churchill is -7°C, not nearly cold enough for a deep-freeze.

A regular summertime project was the study of biting bugs. Croal says, “Somehow we got through the first winter and it was good to see the entomologists arriving in force, for we then knew we had survived the winter.” He describes them as [28, p. 31 and following], “. . . a lively group covered with evil smelling bug

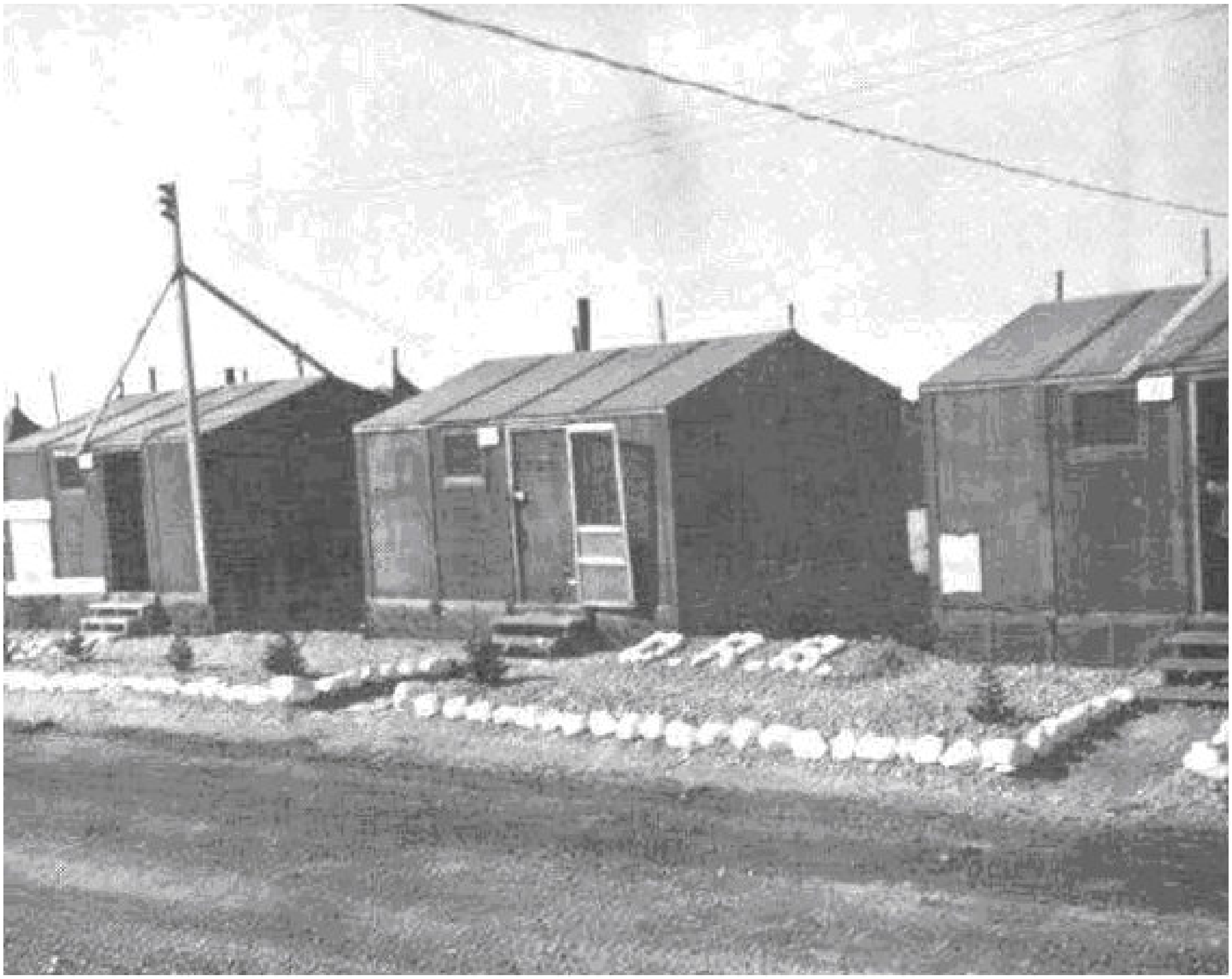

Figure 36: *In 1947, the DRB laboratory grew from one shack to three. Photo from Reference [28, p. 18]. Photo credit: DRB.*

lotion, pith helmets, mosquito netting and with jars, bottles and specimen nets hung on their persons." He continues with tongue in cheek, "Daily in the summer months there were requests to the Army for vehicles to go out into the muskeg and gas cars to go down the railway to Goose Creek which seemed to be the favorite breeding place of all insects. It is a strange coincidence that it was also a good place to fish."

5.4.2 Living Conditions and Social Life

Life was very primitive and rough at first. Water had to be brought in by hand, and melted ice was all that was available in the winter. And, of course, without running water the toilet facilities were rather unrefined. Married quarters were very scarce, which made a posting to Churchill particularly unattractive.

Buildings—or even huts—for offices and storage were almost unobtainable. The struggle for offices and storage space was one of the principal themes in all the stories of early Fort Churchill. Not surprisingly, they took pride in their ability to beg, borrow, and scrounge the necessary equipment to build primitive offices and laboratories. For example, one story in Reference [28, p. 15], tells about obtaining a disused hut from the Commandant. It goes on to say, “Sharp and Jones, using Army trestle tables and ‘acquired’ lumber, built a reasonable facsimile of a laboratory in about a week.” The fact that the word “acquired” was in quotes suggests that not everything was completely above board, and, moreover, it indicates that they were particularly pleased with themselves for creating something out of virtually nothing. Who can blame them?

The ultimate “scrounge” was carried out by Alex Fordyce [28, p. 24]. He noticed that there was an unused Army H-hut in Ottawa (ON) at the closed-down Rideau Military Hospital. It was not a small building. The two wings of the “H” were each 150’ x 25’, and the cross of the “H” was about 40’ x 25’. He organized a crew of 13 carpenters, a plumber, and an electrician who dismantled the building in three days. They loaded it onto five flatcars and sent it to Churchill, where it arrived three weeks later. The same crew met the train and put the building back together on a well-drained, high gravel bank where there was no danger of frost heave. Five days after their arrival, the crew hung the last door and turned the building over to DRNL. The timing was impeccable, for the next day it started to snow. The shortage of accommodation had led DRNL to consider cancelling much of the 1948–49 winter program; outside scientists were to be told that there was no room for them. Only the impressive conjuring of the new H-hut saved DRNL from embarrassment.

A more permanent DRNL building had been started in 1947, and it was completed and occupied in the spring of 1949 (Figures 37 and 38).

By 1951, conditions had become more civilized. Offices and labs had been built, and living quarters for both the married and the single had increased in number and quality. Most histories and reminiscences of DRNL talk about the good social life, which is not at all unusual in a remote northern town where people must make their own fun.

F.P. Donovan [28, p. 91], after praising the friendliness of the people, comments on the wild beauty of country. “The limitless horizontal format of the landscape in its greens, blues, purples, browns and yellows of summer and fall made it the ideal subject for water colors. The detail of the colorful foreground was the subject of a few oily brushmen I have known: Bob Bateman would dash off a scene of the southwesterly oriented spruce on the rocks while the less intrepid would top off a couple of ales in the Stag Room.”

This Bob Bateman was, indeed, Robert Bateman, who went on to become a very well known artist, who is famous for his wildlife paintings in a realistic style. When he was in Churchill, however, his style was strongly influenced by the Group of Seven. An example is the painting in Figure 39 (page 51) called, appropriately enough, “Churchill.” Permission [29] has been given for us to reproduce it here.

As in most frontier towns, women were a scarce commodity, and those who were present were very much appreciated. Mr. Croal had some very nice things to say about the Army nurses: “The small group of Army nursing sisters will never be forgotten in those early days. Their charm in the mess and hospitality in their small lounge will be remembered by a good many of the early scientists.”

Later, he points out some of the particular problems they had [28, p. 35], “Sometimes the Army nursing sisters would be invited out to one of the winter camps of the Signal Corps trials unit. The poor girls were completely clothed in the men’s cold weather gear including string vests worn next to the skin. Needless to say, a woman’s anatomy is not designed to carry a string mesh vest and there was much squirming and agitated female comment.”

It would appear that the scientists who were working hard on developing cold-weather clothes for the men could have done a little more for their female comrades.

Figure 37: *The DRNL Laboratory in Churchill (MB). By the look of the cars, this picture was taken sometime during the 1950s. Photo credit: DRDC – Ottawa Research Centre.*

5.4.3 Research in Aid of Northern Military Exercises

As living conditions improved, the research work expanded to include operational research into northern military exercises. The researchers took part in Army exercises and training programs since they were interested in the psycho-physiological effects of cold and insects on the soldiers' effectiveness. They studied the difficulty of moving military units across various types of terrain, and they investigated ways of making maps that would show these relative difficulties.

Travel through the country was particularly difficult in the summer. The ground was [28, p. 23], "muskeg with 6 to 20 inches of soft organic material and mud, with hard hummocks scattered seemingly at random, and was nearly impassable to man and vehicle." Canoes were useful if the water courses went in the direction you wanted to go. Otherwise, you were out of luck. They tried using the Penguin snowmobiles in the summer (Figure 40, page 52), but the brush accumulated in the tracks, and the vehicles jolted and side-slipped over the hard hummocks. The Penguins, which were not designed for this type of abuse, broke their bogies, axles, and sprockets, and, for good measure, threw their tracks. The break-down rate was horrible. Besides, as A.C. Jones says [28, p. 26] "The Penguin . . . had all the comfort of a battle tank."

Figure 38: *Installing the sign for the new DRNL laboratory. Photo credit: DRDC – Ottawa Research Centre.*

A very successful British Commonwealth Conference on Clothing and General Stores was held at DRNL in 1956. After this, interest switched from human and environmental research to communications research.

5.5 Communications Research, the Importance of the Aurora, and Rockets

Churchill's location was ideal for studying the aurora and its effects on radio communication. Beginning in the mid 1950s, rockets were used to probe the ionosphere. A rocketry complex was built in 1954 by the Canadian Army, but it was shut down in 1955. Then the site was reopened and expanded in 1956 in preparation for the International Geophysical Year (IGY) in 1957–58. The rocket program closed again in December 1958 once the IGY was over. However, there was immediate pressure to reopen it. First of all, the scientific results had been very good, and the scientists could see that there was much more to learn. Secondly, and probably more importantly, the Russians had launched SPUTNIK 1 in October 1957 and SPUTNIKs 2 and 3 in short order after that. To the defence departments in the United States and Canada, this indicated that the Soviet Union would soon be able to launch ballistic missiles over the polar regions toward the heavily populated areas in North America. Any sort of detection system would involve

Figure 39: *“Churchill” by Robert Bateman. Done in oil. Painted in 1955 when he was in Churchill. Photo credit: ©Robert Bateman.*

radar, and that meant that an understanding of the ionosphere and the aurora was very important. The Churchill facility was reopened by the US Army in August 1959 as part of its network of sounding rockets (refer to Sections 4.3.1 and 6.5).

During the early 60s, the rocketry program at Fort Churchill moved into high gear, and DRNL served as a base for visiting scientists. The Canadian Armament Research and Development Establishment (CARDE), with its Black Brant rockets, and the Defence Research Telecommunications Establishment (DRTE), with its upper-atmosphere instrumentation, were important participants in this program (Chapter 4 gives more information on the contributions of DRTE, Chapter 10 discusses the development of the Black Brant rockets, and Chapter 6 describes the supporting work that was carried out at the Prince Albert Radar Laboratory).

5.6 Closure of Fort Churchill and DRNL

By the mid 1960s, the American military was losing interest in Churchill. President Johnson was escalating the war in Vietnam, and the State of Alaska was pressuring the US military to move their cold-weather testing to the United States. Also, the Canadian government was trying to cut the expenses of its military. As a result, Fort Churchill was closed in 1964 and the rocket range was turned over to the NRC. On 29 June, 1965 DRB gave up control of DRNL, and all the laboratory resources were turned over to the NRC. Some interest by the US Army lasted until June 1970, after which the site was run solely by the NRC in support of the Upper Atmosphere research Program. Only a small amount of work was done during the 1970s and 1980s, and by 1990 it was all over.

Figure 40: *A Penguin snowmobile during the cold season, when travel was easier. Operation MUSK-OX. Photo credit: Canadian Army.*

Upon the closing of DRNL, Mr. A.M. Pennie compiled a very interesting document describing work and life at DRNL, Churchill. In addition to Pennie's foreword, there are sixteen informative and very entertaining memoirs written by scientists who had worked there [28].

An annotated bibliography of DRNL's unclassified reports was compiled by G.K. Davies [30]. Much of its interest lies in the "annotations." Mr. Davies gives a very nice overview of the history of DRNL, and he talks about the various aspects of their research work.

6 Prince Albert Radar Laboratory (PARL), Prince Albert, Saskatchewan

6.1 Introduction

The first Russian SPUTNIK was launched in October 1957. To those responsible for North American security this surely indicated that the Soviets were able—or would soon be able—to launch a missile over the Arctic regions toward the heavily populated eastern seaboard of the United States. Although SPUTNIK was not the direct reason for a ballistic missile defence (BMD) system, it certainly accelerated the system's development [31].

Canada's finances were strained with the expenses of an antibomber defence system, and it could not handle an independent BMD system. On the other hand, Canada was fully prepared to contribute to the American anti-ballistic-missile program.

The American Ballistic Missile Early Warning System (BMEWS) was based on long-range radar detection, and, since the missiles were expected to come over the polar regions, there was a real concern that little was known about the effect of the aurora borealis. It was known that the aurora scattered and deflected radio waves having a wavelength of several tens of metres or longer. Would one metre and shorter radar waves be similarly scattered? What about centimetric radars? Would the heavy ionization in the aurora screen the missile until it was too late? Canada, being situated where the aurora was strongest, was obviously well-positioned to help with the appropriate studies.

6.2 Location of the Radar Lab

The United States Army Air Force (USAAF), which was responsible for the creation of a BMEWS, called on Dr. Peter Forsyth for advice. Forsyth, who at that time was working for DRTE in Ottawa (ON), had done research on the aurora and its effect on radar while working for his PhD at the University of Saskatchewan.

The outcome of a meeting between Forsyth and the Americans was that two radar units were to be established in Canada in order to examine the effect of a highly charged ionosphere on radar's detection ability. One unit was to go to Fort Churchill, where the aurora was particularly strong, and the other was to be placed some distance from Churchill, where the radar's grazing angle to the aurora would be appreciably different. For this second location they preferred a site near Saskatoon (SK) since its university had experience studying the aurora with radar.

All sites near Saskatoon that were both available and scientifically acceptable were investigated. Forsyth favoured the army base at Dundurn (SK), which is about 40 km south of Saskatoon. Another possibility was near La Cole rapids, 30 km east of Prince Albert and 135 km north of Saskatoon.

Forsyth says [32], "These recommendations went up the ladder. We all know what came down. The Prime Minister wanted to know why the radar (whatever it is) could not be placed on some Crown land at Prince Albert. There followed a breathless ten microseconds while DRB made up its mind that there was no reason at all." (Note that Prince Albert happened to be Prime Minister Diefenbaker's riding)

A laboratory at La Cole rapids was soon established (1959) and was called the Prince Albert Radar Laboratory (PARL).

In some accounts of PARL's beginnings, the statement is made that they had wanted a site that was within radar range of Churchill. Now, since Prince Albert and Churchill are almost 1000 km apart, and since radar is limited (roughly) to line-of-sight, this statement gives one a moment's pause. How can one possibly see "over the horizon" for a distance of 1000 km? All is made clear, however, when we realize that the radar was to look at the ionosphere, which is very high. A quick calculation reveals that anything higher than about 55 km above Churchill will be visible to a radar located at Prince Albert. Since the ionosphere extends from about 85 km to about 600 km in height, the radar at Prince Albert was well positioned to study it at angles close to the horizontal. Parenthetically, when one realizes that the ICBMs of the day could reach heights of 1200 km, it is evident that line-of-site radar could be very effective at long-range detection.

6.3 Radar Electronics and Antenna

PARL was run jointly by the Defence Research Board (with the Defence Research Telecommunications Establishment [DRTE] as the operational unit) and by the USAAF, which assigned the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) as its agent. PARL's primary purpose was to investigate long-range radio and radar propagation in the presence of the aurora borealis. Del Hansen, from DRTE, was the lab's first director. It is from his articles that most of the following is drawn [32].

The centre-piece of the lab was the enormous radar tower and dish that they brought in from the United States. The antenna was a steerable 26-m-diameter parabolic dish suspended on an alt-azimuth mount (Figure 41). Its orientation (in altitude and azimuth) was controlled by two sixty-horsepower motors.

The radio frequency (RF) energy was generated by two klystron tubes, each weighing 1500 pounds (682 kg) and standing 12 feet (3.7 m) high. A travelling beam crane was built into the new lab building so that the tubes could be changed when necessary. However, the original klystrons (X626s) developed by Eitel-McCullough were not satisfactory, and in 1960 they were replaced by klystrons developed by Varian (Figure 42).

The Varian klystrons operated at 150 kV and produced 1.25 MW peak power at 75 kW average power. These klystrons, used for the BMEWS sites, were called "superpower" klystrons, and were the most powerful ever made [33]. The power transformer for the site weighed five tons.

Since cables were too lossy, waveguides were used to conduct the RF power from the transmitter to the antenna, and, because the frequency for this radar was relatively low—440 MHz—the rectangular waveguides had to be very big—over 60 cm wide [34].

There were many problems that had to be overcome in getting the radar system from the eastern United States to Prince Albert and then assembled on site. For starters, the hub for the parabolic reflector (not the whole reflector—just the hub) was too big to be shipped by train. It had to come by truck. Each state that it passed through had a different set of regulations for the passage of such wide loads. The owner of the trucking company travelled the whole route by car discussing the problems and collecting permits in each state.

6.4 Antenna Assembly

Once all the pieces were on site, the parabolic dish had to be assembled on the ground (Figure 43, page 57) and "surveyed" with a theodolite to make sure its surface was the correct shape. The occasional shim was added to bring the shape to a true paraboloid. The records do not say what accuracy was required,

Figure 41: *The main antenna at the Prince Albert Radar Laboratory. Photo credit: Communications Research Centre Canada.*

but on the assumption that they needed to be within a tenth of a wavelength, the whole 530-m^2 surface could not be out more than 7 cm from a true paraboloid. Harold Serson, a senior DRB technologist, did the measuring and the truing.

Once the reflector was deemed to be sufficiently accurate, it was taken apart, and the individual pieces were hoisted by crane—like petals on a flower—and attached to the telescope's hub. Each petal was attached to the hub and to the preceding petal.

Everything went well until the wind picked up a little. One of the sections had just been attached to the hub when the wind caused its outer end to lift and remove itself from the supporting cable hook (which had not been fitted with a safety snap). At this point, no doubt, there was a collective intake of breath since the section was not stable until it was attached to its neighbour. A bigger gust of wind could cause the section to deform, thus making it necessary to start all over again—perhaps with a whole new antenna. The hook needed to be reattached to the unsecured petal as quickly as possible.

Figure 42: *A VA-842 klystron. Klystrons were more powerful and more stable in frequency than magnetrons. Photo taken from Reference [33]. Photo credit: Courtesy of the Silicon Valley Historical Association.*

Figure 43: *The parabolic dish laid out flat on the ground. The workmen inside the dish give an indication of the scale. Photo credit: Communications Research Centre Canada.*

The crew's foreman—it is unfortunate that the names of some heroes are never recorded—had the situation in hand. He climbed up the 90-ft (30-m) boom and out the 30-ft (10-m) jib. He then slid down the steel cable—using his gloved hands to control his descent—until he could sit on the big steel ball that was just above the hook. By reaching under the ball he was able to attach the hook to the antenna section. The hook took the weight, and all was safe again. On the ground everyone remembered to breathe.

While the tower and the antenna were being assembled, the transmitter and all the electronics were being installed in the laboratory, and soon after the antenna was finished the system was operating tentatively on low power.

6.5 Official Opening

A grand opening was planned for 6 June, 1959. The fact that Prince Albert was the Prime Minister's riding added tension and drama to the event. Something special was called for. They decided that the appropriate "high-tech" demonstration was for the American President Eisenhower to send a congratulatory message to Prince Albert via the moon. The radar transmitter at Millstone Hill (near Boston, MA) would bounce a signal off the moon, and the new radar establishment at Prince Albert would receive it and play it over loudspeakers for the Canadian Prime Minister and other assembled dignitaries. As is told humorously in Reference [32], there were numerous problems in bringing this to fruition. There was a real fear that things would not work properly on the appointed day, so Eisenhower delivered his message several days early, and it was recorded at Prince Albert. This was a deception, but it was small, and the message really did go via the moon.

On 6 June, the big day, Mr. Zimmerman, the chairman of DRB, introduced Mr. Diefenbaker, the Canadian Prime Minister (Figure 44), who then made his welcoming remarks. He then pressed a button on the podium, and, as Del Hansen [32] says:

> At the press of the button, the 84 foot parabolic antenna swung into action and pointed to what the guests doubtless thought was the location of the moon. Then the voice of the President of the United States, General Dwight D. Eisenhower, was heard congratulating Prime Minister John Diefenbaker on the establishment of this cooperative effort. The fact that the movement of the dish was being controlled by PARL staff, that the antenna was pointed nowhere in particular, and that the voice that was heard had been recorded some days before, didn't matter. The effect was the same. It was a very convincing demonstration.

The president's greeting can be found in Reference [35]. It starts, "I am delighted to greet you, Mr. Prime Minister, and the Canadian people on the occasion of the opening of the Prince Albert Radar Laboratory. The completion of this laboratory . . . "

Research into the aurora began in January 1960 in cooperation with the Institute of Upper Atmospheric Physics, University of Saskatchewan. Peter Forsyth and Gordon Lyon were the principal researchers. Collaborative experiments were also carried out with the University of Illinois and the State University of Iowa.

The radar was also used to track rockets to help plot their paths. PARL tracked ARCAS rockets (All-Purpose Rocket for Collecting Atmospheric Soundings) fired from Cold Lake (AB) as part of the DRTE auroral experiments. The radar was also used to track many Black Brant rockets fired from Churchill.

On 31 January, 1961, the lab suffered a serious setback. In the process of adding an extension to the laboratory building, the workers cutting into the steelwork started a fire. It rapidly got out of control and caused major damage (Figure 45). One of the reasons that the fire spread so rapidly was that the building did not have the fire protection that was in the specifications. A Steelox building had been requested since that is what the Americans had recommended, but the Inter-Equivalents Board of the Canadian Government had stated that the Canadian Butler buildings had equivalent fire stoppage. A true "trial by fire" proved this to be in error.

The building (Figure 46, page 61) was rebuilt with a great number of improvements, and the facility was soon back in operation. Al Seaman took over as lab director from Del Hansen in early 1963, and Larry Maynard arrived at about the same time to head-up their research program. Maynard says that they had

Figure 44: *Canadian Prime Minister Diefenbaker at the official opening of the Prince Albert Radar Laboratory. Photo credit: Communications Research Centre Canada.*

three principal tasks. The first was to investigate any possible impediments to the detection of ballistic missiles. The second was to continue with the investigation of the nature of the ionosphere. And the third was to track satellites. Maynard comments that the three years or so that he spent at PARL was a great period in his life, partially because of the very interesting physics they were doing and partly because of the fascinating people that surrounded him [5]. PARL, as a defence laboratory, was moth-balled in 1967, and the installation was later transferred to Natural Resources Canada.

From the beginning of the space program, the radar was used to track satellites. It tracked the first ALOUETTE satellite as it crossed Alaska on its first pass. As of 2012 tracking satellites has become the radar's primary purpose. Now known as the Prince Albert Satellite Station, it is operated by the Canada Centre for Remote Sensing, which is part of Natural Resources Canada. It is used as a ground station for the following satellites: the European Remote Sensing Satellite (ERS), Environmental Satellite (ENVISAT), National Oceanic and Atmospheric Administration (NOAA), LANDSAT, RADARSAT-1, and RADARSAT-2 [36].

Before we leave this large and impressive radar installation, we should perhaps put it into perspective by comparing it with an actual Ballistic Missile Early Warning System (BMEWS). There were three BMEWS

Figure 45: *Fire at the Prince Albert Radar Laboratory, 31 January, 1961. Photo credit: Communications Research Centre Canada.*

in the world, and Thule, Greenland, hosted one of them (Figure 47). Whereas PARL had one pair of large klystrons, Thule had six pairs [34]. And, as well as having the large steerable antenna, Thule also had four fixed dishes, each having an area of about 5000 square metres (compared to the 500 square metres of the PARL reflector).

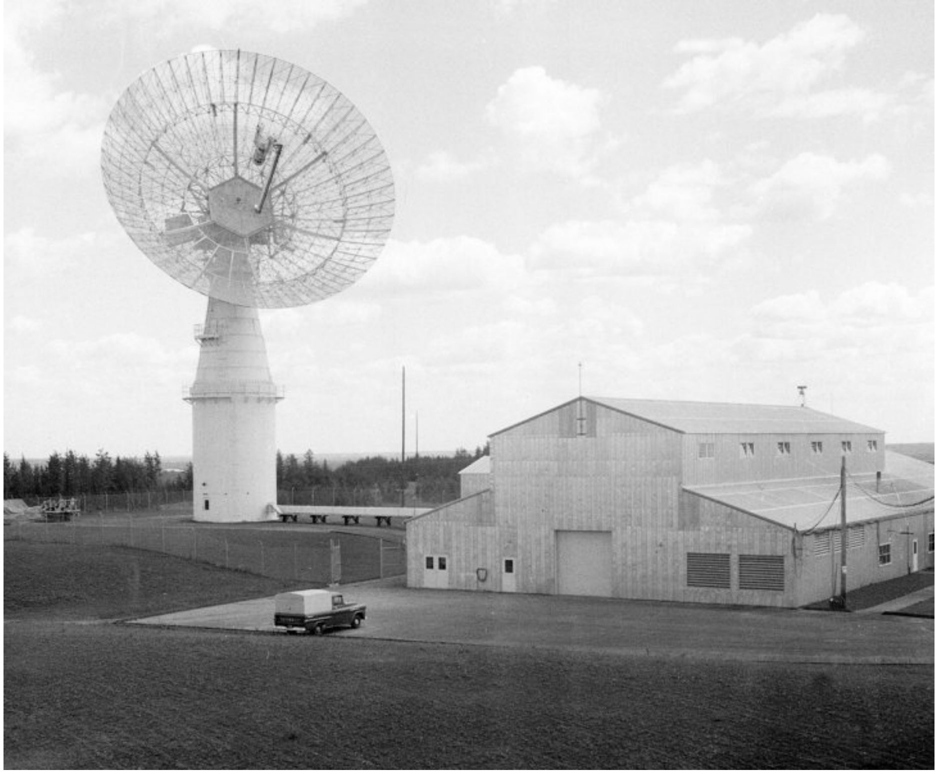

Figure 46: *PARL radar tower and new laboratory building. Photo credit: Communications Research Centre Canada.*

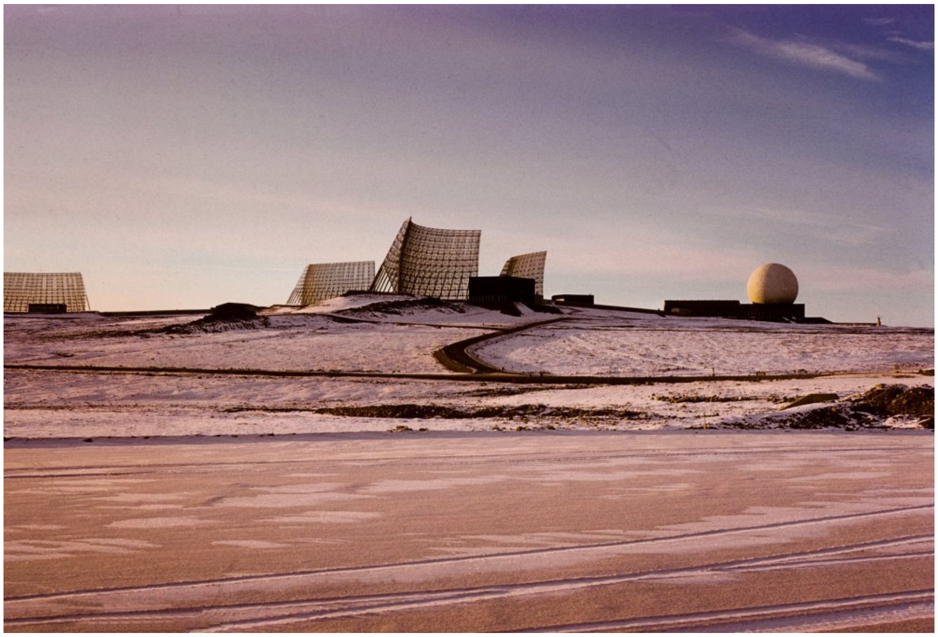

Figure 47: *Ballistic Missile Early Warning System at Thule, Greenland. Circa 1961. Photo credit: Jon Paul Chandler, see Reference [37].*

7 Defence Research Establishment Ottawa (DREO), Ottawa, Ontario

7.1 Introduction

As the Second World War approached, many Canadian officials recognized the need for preparation. One of the tasks that Canada took on was the manufacture of gas masks (or respirators) for its own population. In 1936 a small assembly plant was set up at Valcartier, Quebec, but it was soon realized that technical specialists and lab facilities were necessary to test and monitor the production. As a result, the assembly plant was moved to Ottawa where it would be closer to the expertise of the National Research Council. Consequently, when the war started in 1939, a fledgling war-oriented chemical research establishment was in place in Ottawa. It quickly took on other chemical-related tasks.

In 1941 the facilities were absorbed into the military and became known as the Chemical Warfare Laboratories (CWL). The head, Dr. E.A. Flood, was put into uniform, becoming LCol Flood for the duration. The chemical lab is considered to be the genesis of DREO [38].

In the 27 years between 1941 and 1968 there were two main groupings of laboratories, with each grouping having a series of different names. There was the chemistry/biology grouping, which started as the Chemical Warfare Laboratories (CWL) and morphed into the Defence Research Chemical Laboratories / Kingston Laboratories (DRCL/KL), the Defence Research Chemical Laboratories (DRCL), the Defence Chemical, Biological, Radiation Laboratories (DCBRL), and the Defence Chemical Biological and Radiation Establishment (DCBRE). At the end of the war the chemistry work was still being done downtown Ottawa (ON) in buildings on John St. and Sussex Dr. These laboratories were overcrowded and much too close to residential areas considering the hazardous materials they were dealing with. In 1952 they moved to a new site near Shirleys Bay, about 22 km up the river (west) from Parliament Hill.

The other main grouping dealt with radio propagation and other problems of telecommunication. The Radio Propagation Laboratory (RPL) was established shortly after the war. When DRB was formed in 1947, RPL became one of its responsibilities. In 1950 a second small defence research group, known as the Defence Research Electronics Laboratory (DREL) was established to evaluate the potential of promising electronic equipment. They were located first at Rockcliffe Park but were moved in 1952 to NRC's Montreal Road site. The two electronics-related groups, RPL and DREL, were combined in 1951 under the new name Defence Research Telecommunications Establishment (DRTE). The two groups retained much of their old identity, with RPL (now called Radio Physics Laboratory) moving to the Shirleys Bay site and DREL (now called the Electronics Laboratory) remaining on Montreal Road. In 1961 the infrastructure at Shirleys Bay had become large enough that both labs could take up residence there.

In 1968 all labs at Shirleys Bay were amalgamated under the one organization, Defence Research Establishment Ottawa (DREO). What follows recounts the Arctic-related work done by DREO after this date. The earlier Arctic work done by DRTE is outlined in Chapter 4.

7.2 The Environmental Protection Section

In the 1960s, as has been discussed previously, there was an awakening of the Canadian government to the existence of the Arctic, their responsibility to it, and the danger inherent in its being on the flight path between two superpowers. Moreover, from DREO's point of view, most of the chemical program was being consolidated at Suffield (AB), and since they did not want to lose their expertise in the design of protective equipment, they decided to refocus their efforts on protection against cold weather rather than against chemicals.

The laboratory formed the Environmental Protection Section in 1969. They worked on such problems as measuring heat transmission through clothes, electrical hand warmers, the frosting of eyewear, static electricity in clothing, moisture accumulation in sleeping bags, and the improvement of heating and lighting equipment for the Arctic. Figure 48 shows a volunteer testing a coat made of a nylon pile fabric, developed by members of the section to simulate the characteristics of wolverine fur. DREO was an early fan of biomimetics, the use of nature's ideas to help with engineering design. Velcro, which was modelled on the hooks of burrs, is the best-known example of this design strategy.

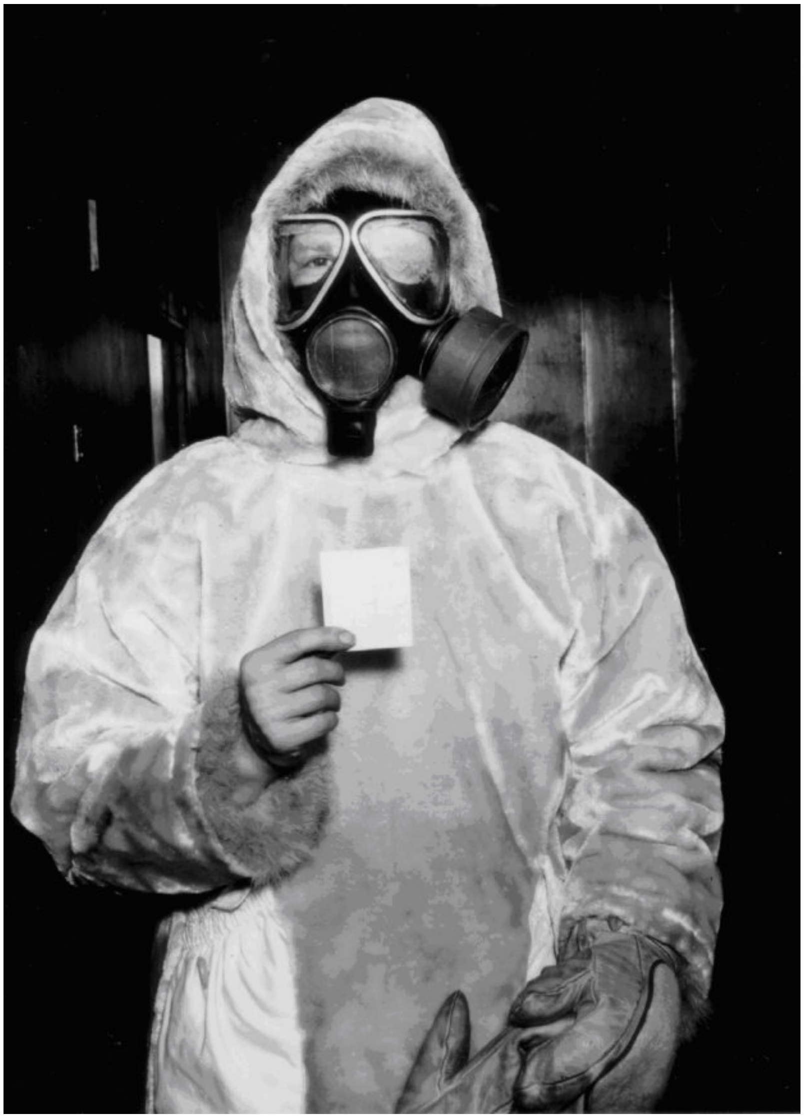

Figure 48: *Testing a new nylon pile fabric in the DREO cold chamber, which could be cooled to -40°C. They are also giving a cold weather test to a gas mask (or respirator). Photo credit: DRDC – Ottawa Research Centre.*

An example of a field test carried out in 1988 is described in *Trial Run II: A Cold Weather Clothing and Equipment Trial Conducted on the West Coast of James Bay*, by R.J. Osczevski [39]. This was a nine-day journey travelling by snowmobile along the west coast of James Bay from Moosonee to Ekwan Point and back, a distance of about 280 km each way. It was not the Arctic, but it was sufficiently cold that it was, indeed, a test of cold-weather gear, which they hoped would be useful for troops in the Arctic. There were four people on the trip: Randall Osczevski, Brian Farnworth, Brad Cain, and Andy Main. They used three Bombardier Ski-Doos for four people, testing whether there would be problems having two people using one Ski-Doo. They used Elans, which are probably the smallest of the Bombardier Ski-Doos. Their lightness gives the Elans definite advantages. In particular, they can be easily manhandled out of trouble when they get bogged down in deep snow. However, they give a rough ride when they are pushed, and the rider gets very tired on a long trip. At one point, the author makes the rather wistful comment, "Machines with slide rail suspensions seem to be able to travel faster on such roads than we could on the Elan with its bogie wheel suspension." They also had another problem that is endemic with the Elan: the engine bolts (the ones holding the engine to the frame) tended to shear off.

The Osczevski report makes mention of three other trials that had been conducted earlier: the west coast of James Bay, February 1986; Churchill area, February 1988; and Pangnirtung, August 1988. Each trip was a learning experience leading to the next trial.

On this (1988) trial they tested clothing, tents, stoves, snowmobiles, sleds, and radio communications. Although the narrative is very interesting, they do not express great enthusiasm about any of the items tested. However, their continuing innovations and tests over many years resulted in improvements to tents, sleeping bags, and cold-weather clothing.

7.3 Remote Sensing of Ice Drift in Robeson Channel

In 1969 the Geophysics Section in DRB Headquarters, which had been heavily involved in Arctic work, closed down. Its activities were transferred to an Earth Sciences Division at DREO. This division stayed in existence from 1970 to 1974.

They were interested in remote-sensing techniques, and in the summer of 1971 they tried to monitor the motion of ice in Robeson Channel southeast of Alert (NU) [40]. A small group (Figure 49) set up a radar camp on a cliff just south of Lincoln Bay (location shown in Figure 107, page 130). The radar camp was 400 m above sea level and was back 600 m from the cliff edge. Unfortunately, this geometry caused interference. The radar return from the target could bounce off the cliff edge, and this interfered with the signal that did not bounce. Moreover, the many unwanted radar returns from the ice (known as "clutter") made it difficult to follow a floe of interest. Even with radar corner reflectors set on the ice, they were not able to follow the target ice floe for long enough to plot a reasonable track.

In 1972 they fixed the interference problem by putting the radar only 4 m from the cliff edge (Figures 50 and 51). The problem with clutter was cured by putting transponders on the ice. These were active devices that sent out a 400-Watt pulse when they received a radar signal. With this kind of response, there was no doubt about which floe they were following. There were usually two transponders out at any one time, and the average tracking time was about 40 hours. Once a transponder was out of radar range, a helicopter picked it up and set it on a new floe farther north (the general ice drift was north to south).

Along with the radar transponders, each ice station was equipped with a wind recorder. Also, at the occasional place where they could find a convenient melt hole, they lowered current meters to 5 m and

Figure 49: *Group at Lincoln Bay in 1971. From left to right: Scotty Yool, Harold Serson, Fern Dickaire, George Pudsy, Barry Hughes, Dunc Finlayson, Moira Dunbar, John Keys, Charlie Pope. Photo credit: DRDC – Ottawa Research Centre.*

15 m below the water surface. Melt holes, however, were few and far between (Figure 52). Of the 27 stations that they monitored, only four had current meters. Records were taken from 10 July to 30 August.

Later, they replaced the radar system with an optical technique. The ice was watched by a suitable camera that displayed a real-time image on a television screen. The images were stored and could be compared later to follow the drift of individual floes.

One advantage of this optical technique was that smaller floes could be watched; there was now no need to land a helicopter on the ice. The disadvantage was the shorter range of the optical system.

The data they collected over a time span of about five years gave them valuable insight as to the relative effects of wind and current on the motion of ice.

Moira Dunbar also monitored the wintertime ice between Ellesmere Island and Greenland with airborne radar and, during her third season, with side-looking airborne radar (SLAR) (Figure 53, page 68). For each of three seasons (from 1970 to 1973), she made several ARGUS flights to see where and how the ice moved and consolidated. The report of her third season is available on the web [41].

The Earth Sciences Division at DREO was phased out in 1975, and the Ice Research Section was moved to DREP (Chapter 8) where under-water surveillance work was quite active.

Figure 50: *Looking down on the radar shack (with antenna on top). It is about four metres away from the cliff edge. Photo credit: DRDC – Ottawa Research Centre.*

Figure 51: *Looking north along Robeson Channel. The small shack with the radar is on the left, and Lincoln Bay is behind it. Photo credit: Victor Jones.*

Figure 52: *Setting out an ice station complete with radar transponder, anemometer, and current meters. Note the open water in the melt hole. Unfortunately these holes were rare. Moreover, the hole had to be adjacent to ice thick enough to take the weight of the helicopter. Photo credit: DRDC – Ottawa Research Centre.*

Figure 53: *Moira Dunbar in airplane cockpit doing ice reconnaissance. Photo credit: DRDC – Ottawa Research Centre.*

7.4 Geobuoy Orientation with GPS

A sonobuoy is a device that is used for listening for submarines. It consists of a hydrophone that is suspended in the water from a floating buoy which radios the acoustic signal to an overflying surveillance aircraft. In the Arctic, where open water is almost non-existent for much of the year, the sonobuoy cannot be used. It has to be replaced by an icepick-sonobuoy, formally known as a "geobuoy," which has a prong that sticks into the ice when it is dropped from an airplane (Figure 54). The prong couples the on-board geophone (also known as a "seismometer") to the vibrations in the ice so that if a submarine is in the vicinity the icepick will "hear" it.

Figure 54: *Geobuoy being held by Mike Vinnins. The "prong" is made of bronze-steel. Ordinary steel that size bends upon impact. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

Standard geobuoys are omnidirectional receivers. They listen equally well in all directions, with the result that they cannot determine the direction to a submarine. Knowing the direction to the sub is very desirable, and a program was initiated by Mike Vinnins and Lloyd Gallop of the DRDC – Ottawa Research Centre to develop directional geobuoys.

The first step was to use a three-axis geophone, rather than the single-axis geophone that is used in the standard geobuoy. A three-axis geophone can measure the horizontal (as well as the vertical) motion of the vibrating ice, and from this an operator can infer the direction (relative to the geobuoy's internal coordinate system) to the underwater source. Stan Dosso from the University of Victoria, together with Garry Heard's group from the DRDC – Atlantic Research Centre (see Chapter 12), provided a lot of help determining how the three geophone outputs should be combined in order to give accurate and reliable results. As well as the basic physics of acoustic vibrations in a solid, they had to worry about the effect of such arcane things as variable ice thickness, ice roughness, ice cracks, rubble fields, etc. Real sea ice is not the nice uniform slab depicted in most diagrams.

The other basic requirement was to be able to determine the orientation of the geobuoy after it has stabbed itself into the ice. Given this information the overflying aircraft can take the source's relative bearing from the geobuoy and turn it into an absolute bearing.

The sonobuoy, which is the sensor used in open oceans, simply uses a magnetic compass to determine its orientation. However, the geobuoy cannot use a similar system since the magnetic compass will not work reliably at high latitudes. Some other technique was needed.

Vinnins and Gallop developed a method based on the global positioning system (GPS) to orient their geobuoy. At the top of the geobuoy they mounted two GPS antennas separated by a small-but-known-distance. The signal from a GPS satellite is detected by the two antennas at slightly different times since one antenna is generally closer to the satellite. The time (or phase) difference from the satellite gives information about the heading of the line between the two antennas, and the information from multiple satellites makes the orientation unambiguous and reasonably accurate. The accuracy is better when the antennas are far apart, but even a separation as small as 10 cm will give a bearing accuracy better than 5°.

In the summer of 1996 Vinnins and Gallop did some preliminary trials at DREO (in the south) to test equipment and to show that the technique had promise [42]. The subsequent trials, which took place at Canadian Forces Station Alert, were all done in collaboration with Garry Heard's group at the DRDC – Atlantic Research Centre (previously known as DREA, see Chapter 12).

One of the criteria for the system was that the bearing accuracy had to be better than 5° even at latitudes greater than 80°N. CFS Alert, having a latitude of 82.5°, was thus well suited as a test site. Also, the logistics of getting to the Arctic and working there were looked after by the larger and more experienced DREA group, which was going to Alert (NU) anyway on another project. The following is a brief account of their tests at Alert.

In late October to early November 1996, Mike Vinnins and Lloyd Gallop made some simple measurements in the immediate vicinity of Alert to ensure their equipment would work at high latitude.

In April 1999, during ICESHELF 1999 at Jolliffe Bay just north of Alert, Vinnins, Gallop, and Capt Richard Van der Pryt investigated very short antenna separations—as short as 4 cm.

In March/April 2000, during ICESHELF 2000, the participants were Vinnins, Gallop, Janice Lang, a photographer at DREO, Garry Heard and Ron Verrall from DREA, and Stan Dosso from the University of Victoria (UVic). Dosso was an expert in the response of ice to noise sources in the water. They investigated the (acoustic) coupling mechanisms between the water and the ice, and between the ice and the icepick. They also tested several GPS antennas and receivers.

In April 2002, during ICESHELF 2002, the group tested modified icepicks (renamed "Directional Icebuoys"). That year the participants were Mike Vinnins, Lloyd Gallop, Slobodan Jovic, René Apps, Pierre Richer, Mike Boyle, Janice Lang (all from DREO), and Stan Dosso from UVic. There was also a large group of personnel from DREA and Ron Verrall (then a contractor) who provided support to the Icebuoy work as it was a part of the first field trial under the Rapidly Deployable Systems (RDS) Technology Demonstration Project (TDP). Refer to Section 12.5 for additional details.

At Heard's suggestion, they used DREA's helium-filled kytoon to drop the Directional Icebuoys from a decent height. The kytoon is a cross between a kite and a balloon; the helium provides lift, but so does the wind—if it is blowing. The kytoon lifted the Icebuoy to a height of about 210 m and, on radio command, dropped it. From this height, the Icebuoy and its standard parachute drogue would reach terminal velocity (Figures 55 and 56). Vinnins and company wished to verify that even with this brutal (but more realistic) treatment, the GPS bearing accuracy was better than 3° with a baseline separation of only 10 cm. They also wanted to ensure that the measured bearing to an acoustic source in the water was within 10° of the correct bearing. Also, they were interested in the response of the shattered ice surrounding the impact point. How noisy was this ice before it sintered back into something more solid? How long did this "repair" take? How well did the pick couple (acoustically) to the ice after the impact? Finally, they evaluated the GPS receiver's resistance to an attempted electronic "jamming." This was a preliminary test in preparation for a larger trial the following year.

Figure 55: *Icecamp southeast of King William Island (NU) with the kytoon floating overhead. The kytoon would lift the icepicks to a height of approximately 210 m and, upon radio command, drop them. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

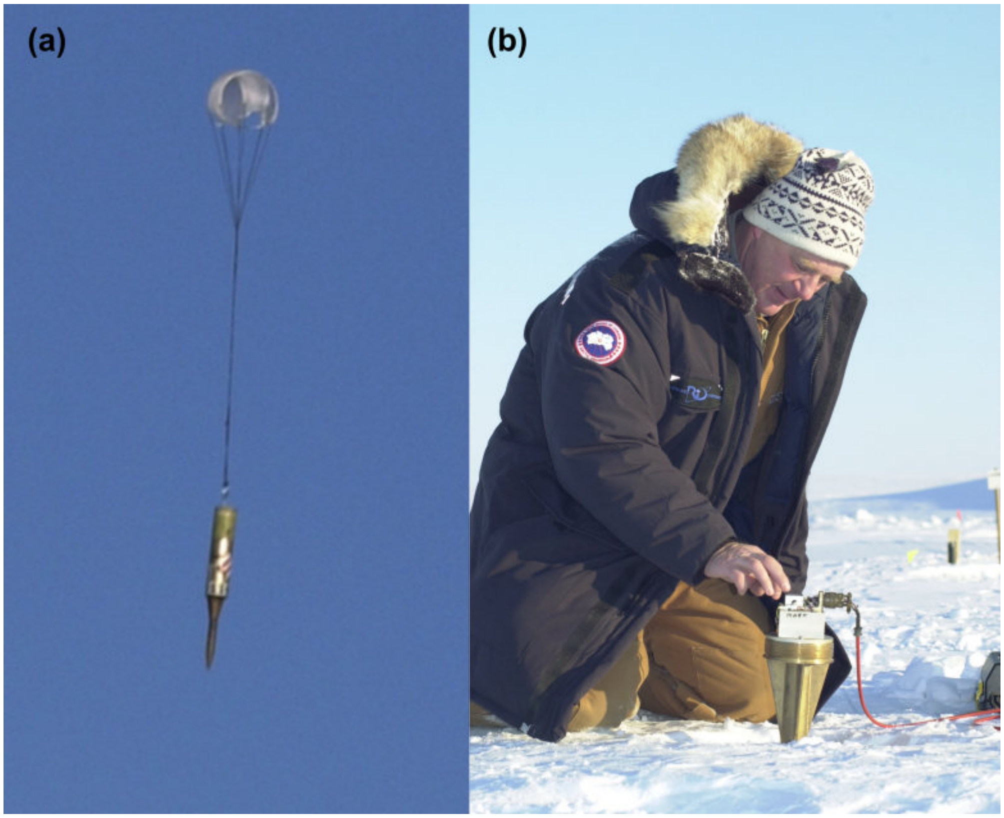

Figure 56: *(a) Icebuoy and its drogue parachute. (b) Lloyd Gallop connecting a dropped icepick to external electronics. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

In March/April 2003, the main objective was the support of the Army's GPS Equipment Replacement Program. Ordinary GPS receivers are easily jammed, and, of course, this is not satisfactory to the Canadian Armed Forces. Canada was part of a North Atlantic Treaty Organization (NATO) testing program to procure a "Defence Advanced GPS Receiver" (DAGR) that could endure low temperatures and that was resistant to jamming. It was logical that Canada should take on the responsibility for cold-weather testing.

The test site was again on the sea ice just a few kilometres from Alert (NU) where the temperature was low and the latitude was high. Several receivers were tested. The personnel for this trial were Mike Vinnins, Lloyd Gallop, Slobodan Jovic, René (Red) Apps, Pierre Richer, Mike Boyle, Bob Gervais, Janice Lang (all from DREO), and Capt Clay Koschnik (USAF). Figure 57 shows Mike Boyle and Capt Koschnik testing the receivers at very cold temperatures, and Figure 58 shows the three receivers that were tested.

As well as these jamming tests, some measurements were made on the Directional Icebuoy (now known as "DIcebuoy"). In the absence of a kytoon, the sensors had to be hand-planted. Then, in order to measure the bearing accuracy of the DIcebuoy, they needed an underwater acoustic signal at a known bearing, and since there was no friendly submarine handy, they had to create their own acoustic sources. They froze wooden posts into the ice. When hit gently with a sledge hammer, a post produced suitable vibrations in the ice (Figure 59). They also used light bulbs for making noises right in the water column. The technique was to lower a weighted bulb on a wire to the desired depth, and then drop a short length of pipe down the wire to break the bulb. The resulting implosion produced a loud, sharp sound in the water.

Figure 57: *Mike Boyle (DRDC – Ottawa Research Centre) and Capt Clay Koschnik (USAF) cold-testing the DAGR and PLGR (Precision Lightweight GPS Receiver) receivers at CFS Alert. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

Figure 58: *The three GPS receivers tested at CFS Alert. From left to right: the PLGR that had been the previous unit of choice; the PLGR-3, an interim design of the DAGR; and the model that was eventually chosen as the CF's handheld receiver. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

Figure 59: *Ron Verrall, Stan Dosso, and Don Richard create seismic waves in the ice with the Hammer Source. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

7.5 Shoreline Delineation

DREO has long had an interest in remote sensing. The measurement of ice motion in Robeson Channel from a point high on a cliff is an example of this. Their more recent work (2002) used the RADARSAT-1 satellite to locate Arctic shorelines accurately [43]. This tool is of particular use for monitoring coastlines that might change rapidly—due to heavy silting at a river mouth, for example, or due to storm erosion. The effects of climate change make the Arctic particularly vulnerable to such changes.

In Section 3.7 the point was made that from the air it is very difficult to determine where the land stops and the sea begins, especially in the winter and spring when snow obscures all the usual clues. Interestingly, the coastline is quite visible in radar images, which makes RADARSAT useful for coastline monitoring year-round.

RADARSAT-1, which was launched in November 1995, was not originally intended to measure small deformations, either in the horizontal or the vertical dimension, but clever use of interferometric techniques has made it possible to measure elevations and to monitor ground movements caused by such things as earthquakes, volcanoes, and landslides.

RADARSAT-1 uses a synthetic aperture radar (SAR) sensor to generate its images. A short explanation of “synthetic aperture” is in order. The word “aperture” has to do with the size of the object taking the picture, and the bigger the aperture the better the picture’s resolution. For example, a big telescope can distinguish more detail than a small telescope. Analogously, a “reasonably sized” radar antenna will not provide the resolution that one would dearly like to have. To improve on this, the radar antenna is artificially made to behave as if it were much longer. Multiple (digital) images are taken as the satellite moves along its path, and the images are combined in a coherent way so as to get higher resolution. The result is the same as what would have been received from a one-dimensional array of great length.

It should also be noted that the analysis of the radar returns requires an enormous amount of computation, and only the existence of very powerful computers makes the whole data-processing scheme practical.

RADARSAT-1 passes over the same ground every 24 days, and successive pictures (24 days apart) can be combined to measure heights—i.e., topography. This is somewhat analogous to taking “stereo pairs,” pictures taken of the same scene but from slightly different locations. Something that this “interferometric” SAR seems to do well is detect shorelines. The stated aim of the DREO study [44] in the Alert (NU) area was to “develop tools and techniques to improve shoreline detection accuracy.” A further aim was to “improve the automation and reliability of map finishing and feature extraction.” The word “feature” here refers to such objects as fuel tanks, large buildings, and roads. An example of a RADARSAT-1 picture is shown in Figure 60.

A program was launched to determine the accuracy with which RADARSAT can determine the locations of items such as shorelines, roads, fuel tanks, etc. In order to measure the accuracy, one must be able to compare RADARSAT’s estimates with the actual positions. A major contribution to the study was the “ground-truthing” of many such locations. People on the ground used GPS to map shorelines and other features, such as buildings and large oil tanks. These bright objects, once their location was known, provided good reference points within the SAR image.

The tide height was monitored and compared to the modelled tide. Finally, radar corner reflectors (Figure 61, page 77) were set out at four different locations along the shoreline. The exact location of these reflectors gives a check on the accuracy of the mapping algorithms. Also, the knowledge of the errors helps the image analysts improve their techniques.

One such “ground truthing” experiment took place between 11 April and 8 May, 2002. The team was composed of Lloyd Gallop, Janice Lang, and Jim Milne. Later in the year, between 23 July and 7 August, a team composed of Lloyd Gallop, Janice Lang, and Al Tremblay carried out a similar operation.

This study, in conjunction with a similar study at the US National Imagery and Mapping Agency, looked at the feasibility of using RADARSAT imagery to improve the accuracy of the existing coastline maps of the Arctic, some of which had been created decades earlier.

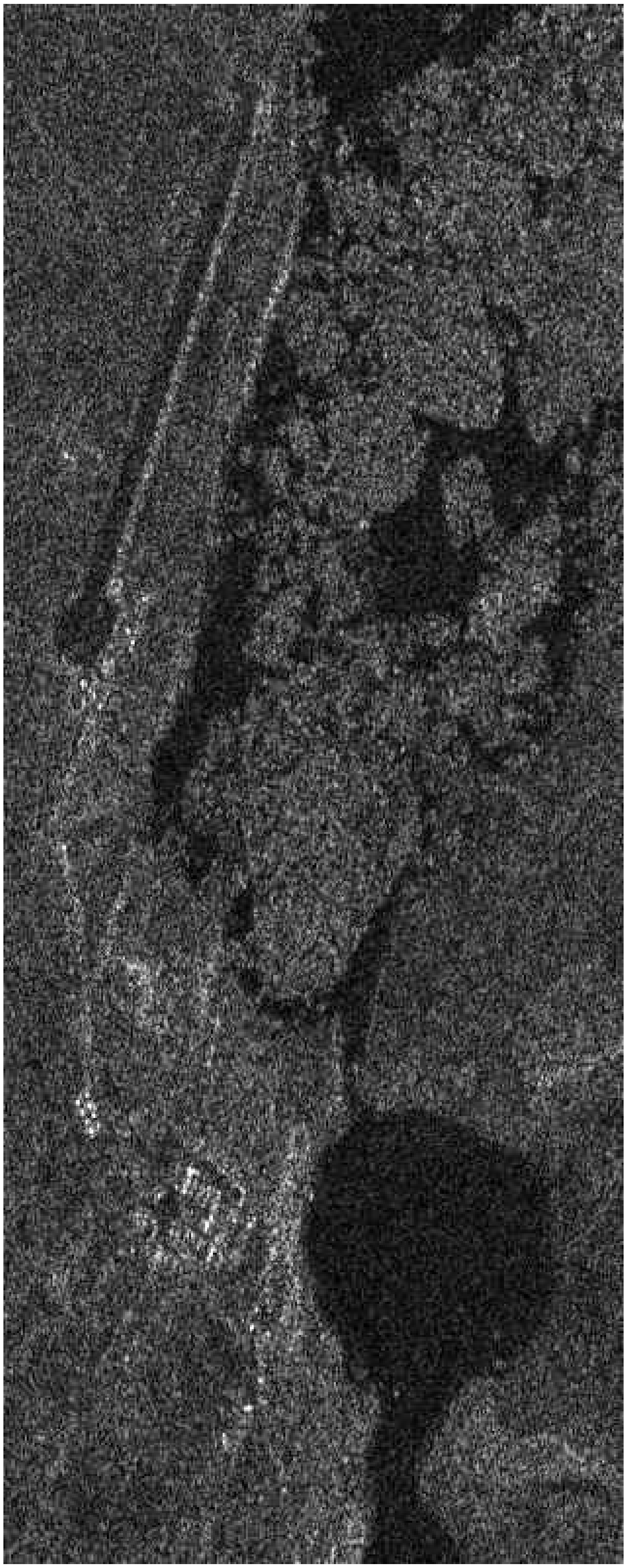

Figure 60: *RADARSAT image of CFS Alert. Note the runway, the shoreline with floating ice to the right of the runway, the Alert buildings, and the tanks. The "picture" was taken from a distance of roughly 800 km. Photo credit: RADARSAT, ©Canadian Space Agency, 2002.*

Figure 61: *Lloyd Gallop (left) and Al Tremblay setting up a metal radar corner reflector at the shoreline. Since it reflects the radar signal very strongly, it will show up as a bright spot on the radar picture and provide a good reference point. Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

8 Defence Research Establishment Pacific (DREP), Victoria, British Columbia

8.1 Introduction

Soon after the Defence Research Board was created in April 1947, it established a laboratory on the West Coast with Dr. Fred Sanders as its first Superintendent. The lab's purpose was to investigate scientific matters that might be useful to Canada's naval forces. In 1948 it opened shop in Esquimalt (near Victoria [BC]) with a staff of four [45].

The lab's original name was Pacific Naval Laboratory (PNL). During its existence there were two name changes, and all three names are used here. In 1967 the name was changed to the Defence Research Establishment Pacific (DREP). There was no organizational change; the name-change was simply to give uniformity to the names of all the Defence labs. The final change occurred in 1995 when the lab closed as a separate entity and became the Esquimalt Defence Research Detachment (EDRD), a division of the east-coast lab, Defence Research Establishment Atlantic (DREA).

Figure 62 is a fairly recent picture of the DREP building taken from the west.

Figure 62: *The DREP building is located in the Esquimalt (BC) dockyard area. Photo credit: DRDC.*

In 1949, soon after the establishment of the lab, research into Arctic matters began with a cruise into the Bering and Chukchi Seas by the HMCS CEDARWOOD. Further scientific expeditions into the Beaufort Sea and Amundsen Gulf were carried out in the summers of 1951 and 1952 on the CANCOLIM II. The interest was in oceanography, acoustics, and biology.

For the next seven years topics other than the Arctic occupied the PNL staff, but in 1959 there was a resurgence of interest in the north. What began as a purely scientific investigation developed over the next decade into a practical study of how best to establish underwater systems for detecting submarines passing through the Canadian Arctic Archipelago. Arctic work eventually became the lab's largest activity in terms of people and funds.

The driving force behind this new and burgeoning interest was Allen (Al) Milne (Figure 63). He saw the opportunity, and through his ability to inspire others, his organizational ability, his inventiveness, and his perseverance (what some might call just plain stubbornness), he gathered support—people and money—and he developed equipment and techniques for surviving (comfortably) in the Arctic and for doing underwater research there. It might be claimed that because of the development of nuclear submarines the Arctic's time had come. However, it was because of Al Milne that the work was done by PNL/DREP and not by some other establishment.

Figure 63: *Allen Milne dressed for the Arctic. Photo credit: DRDC.*

The scenario that frightened the defence community was that of a missile-carrying submarine travelling from the Union of Soviet Socialist Republics (USSR) to the Atlantic Ocean and positioning itself off the eastern seaboard.

A serious attempt was made by NATO to monitor all Soviet subs leaving the Arctic and entering the Atlantic Ocean. The largest and main channel for the submarine traffic was down through the Greenland-Iceland-UK gap (Figure 64). However, these waters were well patrolled and were monitored by SOSUS, the Sound Surveillance System [46].

Consequently, the concern was that the submarines might try to avoid detection by taking the "back door" into the Atlantic Ocean—through the channels of the Canadian Arctic Archipelago. The long excursion under Arctic "pack ice" by the American nuclear submarine, USS NAUTILUS, in 1958, showed that such a traverse was possible (pack ice is a large extent of floating ice moving as a nearly continuous mass). The Soviets, for their part, launched Sputnik in 1957, showing that they had (or would soon have) ballistic missile capability. Moreover, the USSR launched their first nuclear submarine in 1958, and this showed that they would soon be able to carry ballistic missiles under the ice of the Arctic Ocean and into the Atlantic Ocean where they could lurk off the eastern seaboard. It was quite evident that Canada's Arctic was now the front-line between two superpowers, and Canada should really know more about it.

From 1959 until the lab closed in 1998, saving only 1960, at least one trial was held in the Arctic every year, initially in the channels through the archipelago and latterly in the Arctic Ocean north of the islands.

In 1971 the acoustic effort in the Arctic was joined by that of the Magnetics Group, whose interest was in the detection of submarines by sensing the changes they make in the local magnetic or electrical fields in the sea water. The following account splits the story into two parts, first the acoustic and then the magnetic/electric.

8.2 Acoustics Work in the Arctic

8.2.1 The Early Years 1958–1971

As mentioned before, the instigator and prime motivator for the early acoustics work in the Arctic was Al Milne who, up until 1958, had been working on more southern underwater acoustics problems for PNL. He saw that there was new and untapped science in the measurement and the understanding of under-ice noise and the propagation of sound in Arctic waters. He also saw that he could garner support from the "establishment" because of the practical nature of his work. Any attempts by the Navy to detect ships or submarines in the Arctic would require a knowledge of underwater ambient noise and sound propagation.

A foray into the relatively unknown High Arctic was a brand new undertaking for PNL, and the thought of "all those things that could go wrong" must have given pause to the management. However, Al—with the bit in his teeth—was hard to resist, and he did have the argument that the Canadian Prime Minister Diefenbaker had just been elected (1957) with "northern development" as one of the planks in his platform. Moreover, the development of rocketry and nuclear submarines made the Arctic waters into strategic channels. By 1959, when the USS SKATE surfaced through the ice at the North Pole, few doubted the importance of Al's acoustic research.

Since neither Milne nor any of the PNL people he was to take north had any Arctic experience, the first order of business was to learn how to work and live in a cold climate. He was initially assisted by Trevor Harwood, an employee of DRB in Ottawa who had spent part of his youth working for the Hudson's Bay Company in the Arctic. In 1958 there was a DRB lab in Churchill (MB)—the Defence Research Northern Lab (DRNL) (Chapter 5), and Trevor arranged for Al to come to Churchill and take a military Arctic survival course. So, equipped with two thin sleeping bags (one to go inside the other) and some not-very-adequate army-issued clothing, Al spent part of March 1958 on route marches with twenty soldiers, sleeping in snow caves and unheated tents.

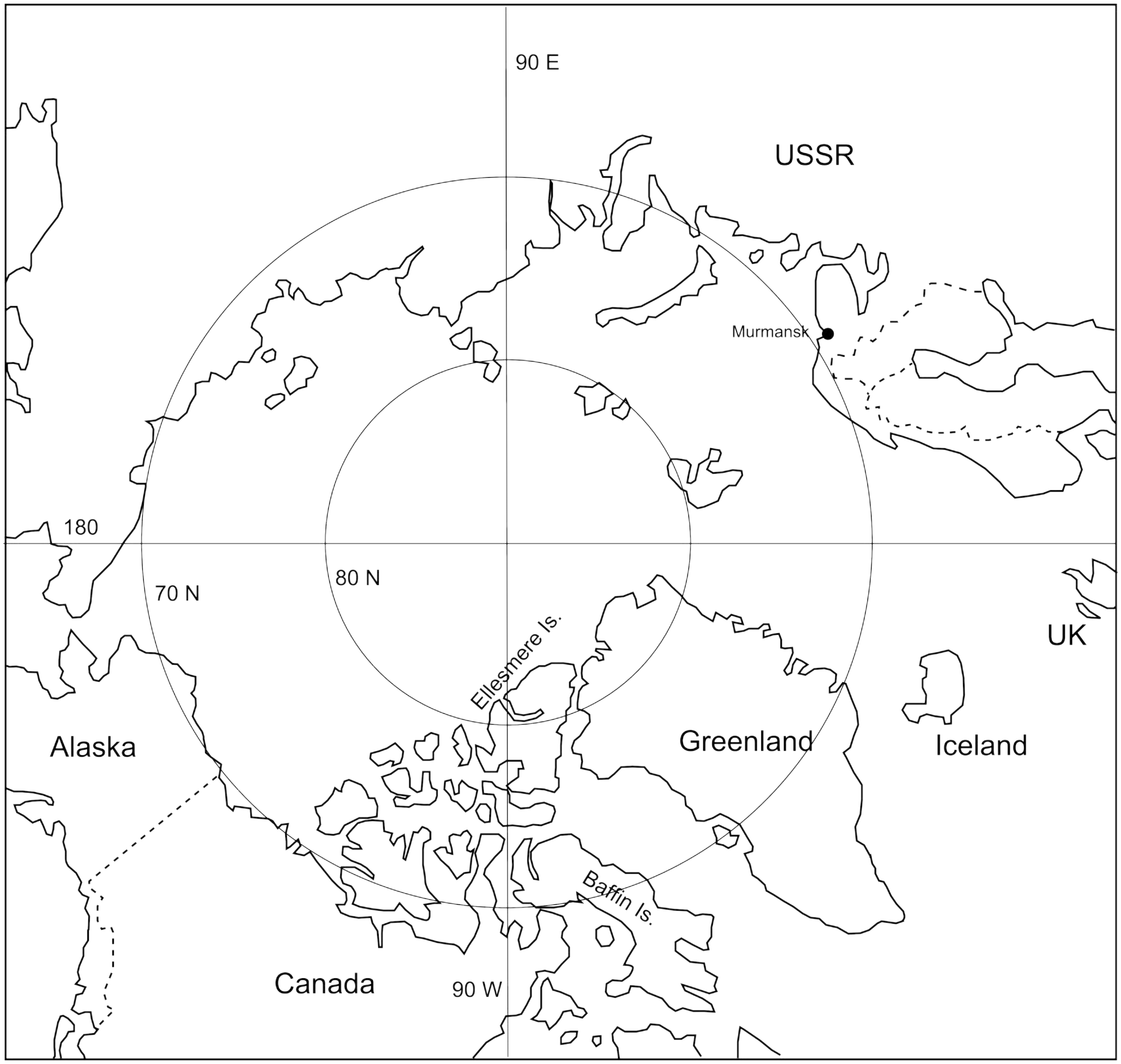

Figure 64: *A polar map of the Arctic Ocean and surrounding countries/regions.*

Later that year, he and three other PNL people, John O'Malia, Carl Kelly, and Tom Hughes, took the explosives course given by the Navy Demolitions Group in Esquimalt (BC). This gave them the skills (and permission) to handle the explosives that they would use in their underwater sound propagation work.

Table 1 lists their various expeditions between 1959 and 1970. The locations of these exercises are shown on the map in Figure 65. These locations have been taken from maps and other descriptions given by Allen Milne in Reference [45].

8.2.1.1 1959—April—PACLABAR

For their first expedition onto the sea ice, Milne chose to work in Barrow Strait, just south of Resolute Bay (NU), which is on Cornwallis Island. From the military point of view, Barrow Strait was part of the

Table 1: *Names and locations of PNL Arctic Research Sites in the 1960s.*

No.	Name	Year	Location
1	PACLABAR	1959 Apr	Barrow Strait—west of Resolute.
2	ICEPACK 1	1961 Apr/May	Just west of Isachsen.
3	ICEPACK 2	1961 Aug/Sep	M'Clure Strait.
4	POLARPACK 1	1962 Apr/May	Camp 1 NW of Mould Bay, Camp 2 NW of Isachsen.
5	ICEPACK 3	1963 Feb	Just West of Isachsen.
6	ICEPACK 4	1963 Aug	Prince Regent Inlet—just east of Somerset Island.
7	ICEPACK 5	1964 Jan/Feb	Prince Gustav Adolph Sea.
8	ICEPACK 6	1964 Sep	Byam Martin Channel—just east of Melville Island.
9	ICEPACK 7	1965 Jan/Apr	Barrow Strait—just out of Resolute.
10	POLARPACK 2	1965 Apr	NW of Mould Bay.
11	POLARPACK 3	1965 Aug	Beaufort Sea—north of Pt. Barrow (not on map).
12	ICEPACK 4/66	1966 Apr	M'Clure Strait.
13	ICEPACK 8/67	1967 Aug	Recording Instrument Packages (RIPs) (see map in Fig. 77).
14	ICEPACK 4/68	1968 Apr	M'Clure Strait.
15	ICEPACK 8/68	1968 Aug	(See map in Fig. 77).
16	ICEPACK 4/69	1969 Apr	M'Clure Strait and nearby cliff camp.
17	ICEPACK 4/70	1970 Apr	Drift Buoys (see map in Fig. 76).

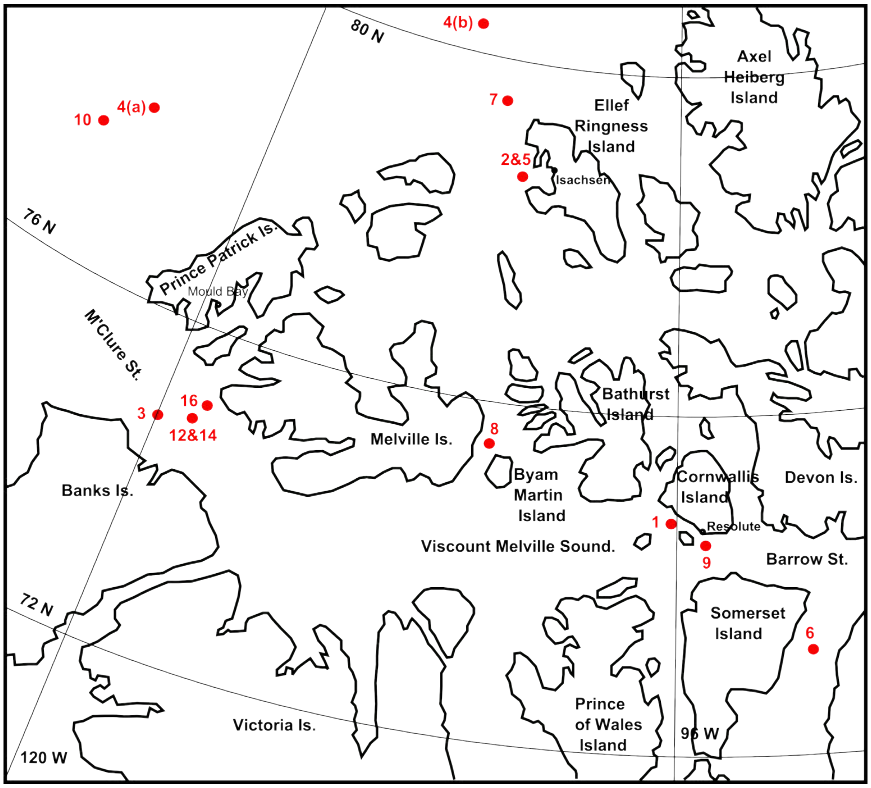

Figure 65: *The approximate location of the various PNL expeditions carried out between 1959 and 1970. Compare the numbers with those in the left-hand column of Table 1.*

east-west route known as the “Northwest Passage,” and it was navigable by submarines. From a logistics, safety, and learning point of view, the ice in Barrow Strait was ideal. It was annual ice, thick enough for safety, but not too thick to drill through. It was fixed in place by the surrounding islands, so their camp was not going to be crushed by moving ice. Also, Resolute had a runway long enough to facilitate the delivery of the PNL freight, and the town was large enough to have an RCAF base and a weather station, so the PNL crew could be assured of temporary accommodation.

Trevor Harwood and Cdr Jim Croal, experienced Arctic people from DRB Ottawa, agreed to help them with preparations and with logistical arrangements. They later agreed to participate in the field trial, itself. Reading between the lines, one suspects that it did not take much to persuade them to go along. Trevor Harwood hired an Inuk, Jackoosie, who, with his dog team, was to guide them to a suitable spot on Barrow Strait.

Elton Pounder and Paddy Stalinski from McGill University’s ice-research group also joined the team in order to study the physical properties of the ice.

There were four in the PNL contingent: Al Milne, Tom Hughes, Carl Kelly, and John O’Malia. This group worked hard during the summer and fall of 1958 preparing, testing, and packing all the field equipment.

Early in the spring of 1959 all the equipment and the people from both Victoria (BC) and Ottawa (ON) were flown first to Churchill (MB), and then, after a few days, to Resolute Bay (NU) in the High Arctic. All transportation was provided by RCAF C119 “Box Cars.”

Once at Resolute they unpacked and, with Jackoosie as their guide, found a route through the rough shore ice and set out a base camp at a suitable location on the ice. The first thing in the experimental program was to make a hole through the ice and lower a hydrophone (an underwater microphone) that would be used to detect the underwater noise.

With this listening device they could measure how well sound traveled in this particular body of water. They used their newly acquired skills with explosive charges to make loud noises (underwater) at ever increasing ranges from the base camp. These acoustic signals were picked up by the hydrophone and were recorded. From these recordings the scientists were able to calculate how the transmission loss increased with range.

The other important use for the hydrophone was the measurement of ambient noise. The fascinating—and completely unanticipated—result of these measurements was the exceedingly low levels of the noise. For all frequencies above 40 Hz the instrument noise was actually higher than the ambient noise. This meant that under-water ambient noise in the Arctic, at least in the ice-covered shallow waters of Barrow Strait, was much lower than that in the open sea. This was an important discovery even though the actual numbers were not—as yet—known.

According to their account, they were visited by only one polar bear during the field work, but that visit was exciting enough. Their story (and we can trust them not to exaggerate) was that the bear was young and quite aggressive. Everyone was nervous, even somewhat frightened, while Jackoosie, who was in charge of bear control, calmly stood there with his hands in his inside pockets. Only when the bear was dangerously close and making threatening motions did Jackoosie pull out his hands, grab his gun, and shoot the bear. Afterward, he explained that he had to warm his hands enough to handle the gun.

This Arctic expedition was the first of its type made by PNL, and it was a learning expedition. Some of their equipment and procedures were quite inadequate and had to be rethought entirely. The food (military ration packs) was not satisfactory, and in the future they took their own. The sleds and small shacks (Wannigans) were too heavy for the small J5 tractor (Figure 66). The very low ambient noise made it mandatory to obtain more sensitive hydrophones and to build quieter electronics. The untanned caribou hides that they used to insulate themselves from the ice were not popular: the hides shed hair, and the hair got everywhere.

One of their successes had to do with isolating the sensitive hydrophone from the vibrations of the main cable, which was held at depth by a heavy weight and which vibrated if there was any current. A major effort was made to isolate the hydrophone from this vibrating cable. The hydrophone was made neutrally buoyant, and it was attached to the main cable by about 10 m of cable that was also made neutrally buoyant. Since there was very little tension in this second cable, it didn't transmit the vibrations of the main cable; it acted as an isolation spring. The problem was that, during deployment, the light cable floated upward and wound itself around the main cable. Tom Hughes came up with a way to avoid this tangle, a technique that is brilliant in its simplicity. He attached a small weight to the hydrophone so that it would lead the way down and keep the two cables separate. The clever part was that he attached this weight with a string and a candy Lifesaver whose hole allowed it to be rigged as a noose. When the Lifesaver dissolved (after about 40 minutes) the weight and the attached string dropped away to the bottom, and the hydrophone found itself decoupled from the strum of the main cable. This technique is still used—utterly unchanged.

Figure 66: *John O'Malia and Carl Kelly with Bombardier J5 tractor and sled. The small building on the sled is known as a "Wannigan." Photo credit: DRDC.*

The basic techniques for measuring transmission loss and ambient noise worked well and continued for decades with only minor modifications. The main changes were improvements in the logistics, the transportation, the sensors, and the electronics.

8.2.1.2 1961—April/May—ICEPACK 1

In 1959 the ice had all been annual ice—ice that had formed that year and had frozen to a thickness of about 2 m. In the second PNL expedition to the High Arctic, Al Milne wanted the ice conditions to be quite different. He decided that he wanted to investigate the acoustic conditions under old polar ice—ice that had been circulating in the Arctic Ocean for years and was typically 5–7 m thick. Polar ice is hard and brittle since almost all the salt has leached out of it. The surface is hummocked and rolling from years of being exposed to the summer sun, and the bottom of the ice is usually very rough since polar ice has generally had a history of ridging and rafting. This structure is very different from annual ice, and it was suspected that the under-ice acoustics would be different also.

A suitable location for working on ice like this was just west of Isachsen (NU), which is on Ellef Ringnes Island (Location No. 2 in the map in Figure 65 on page 82). The channel there is just south of the Arctic Ocean proper, and heavy old ice gets blown south into it. As a result, the ice is a mixture of polar ice, new ice, and ground-up new ice.

The logistics of working in the Arctic had been enormously helped by the formation, in April 1958, of the Polar Continental Shelf Project (PCSP), generally known as “Polar Shelf.” Its purpose was to provide logistics assistance to those doing Arctic research. It was particularly useful to small groups, such as university departments that had neither the resources nor the long-term commitment to purchase and develop everything needed to run an Arctic field camp. The service that PCSP has provided over the years has made it an invaluable part of the Arctic landscape.

Polar Shelf’s first Arctic station was at Isachsen (NU), which explains the choice of Milne’s research site. Fred Roots, who was both PCSP director and Isachsen field manager, agreed to support the PNL expedition. He provided them with accommodation while they were at Isachsen, radio monitoring while they were on the ice, aircraft re-supply, and fuel for their stoves and tractors.

After the problems of the first field trip, many improvements had been made to the PNL equipment. Food, clothing, sleeping bags, tractors, and sleds had all been rethought and improved. From the “science” point of view, the most important new acquisitions were new sensitive hydrophones and low-noise electronics.

This year’s crew consisted of Allen Milne, Tom Hughes, Carl Kelly, John O’Malia, Dick Herlinveaux (seconded from the Pacific Oceanographic Group in Nanaimo [BC]), Phil Langleben from the McGill Ice Research Group, and Bill English, the deputy superintendent of PNL, who accompanied them for part of the time. Figure 67 shows John O’Malia in a relaxed moment.

Again, the RCAF provided transport for both crew and equipment. A special C-130 Hercules flight took them directly from Victoria (BC) to Isachsen (NU).

It was very cold (-45°C) at Isachsen at the end of March, and the tractors, in particular, gave them a lot of trouble, but after a week of preparation they headed westward out of Isachsen looking for a good location for an ice camp. As had been the case at Resolute in 1959, large ridges of ice near the shore barred their way. However, at Isachsen it was even worse. The ice there is heavier and thicker than at Resolute, and the wind-fetch is longer, so the shore ridges are higher and even more impenetrable (Figure 68). Milne says that they walked for kilometers along the shoreline looking for a gap in the 50-foot-high ridges of piled-up ice. Eventually, they found a weak spot that yielded to the diligent application of axes and ice picks, and they were through.

Figure 67: *John O'Malia enjoying the moment near Isachsen (NU), 1961. Photo credit: DRDC.*

Unfortunately, in the diligent application of his axe, Carl Kelly cut his foot. This accident is noteworthy partly because it was one of the very few that happened to the group in its 40 years (or so) of Arctic expeditions. The cut, about an inch and a half long, was sewn up with fishing line, compliments of Dick Herlinveaux, and the crew went back to work. At the end of the field trip Carl had the stitches removed by a doctor in Victoria, and he seemed none the worse for his misadventure.

Four days after they left Isachsen, and eight kilometres off shore, they found a suitable piece of ice for an ice camp. The water was deep enough (457 m), and there was a smooth refrozen lead (a lead is an opening in the ice that exposes the sea water) large enough to serve as a runway for their aircraft re-supply.

Again, they measured sound transmission losses. This time the shot-run stretched off to the northwest to a maximum range of about 33 km from the recording camp.

The most interesting discovery that year was the nature of the ambient noise. They found that as the temperature went down, the volume of ice-cracking noises went up. It seems that when the air temperature goes down, the surface of the ice tries to shrink, but is actually prevented from shrinking by the still-warm ice below. If the ice is new and saline, it is fairly plastic, and the surface ice deforms to accommodate the shrinking. However, if the ice is old and salt-free, it is much more brittle, and, instead of deforming plastically, the ice surface cracks. That year there was lots of old ice around, and it was the continual snapping sound of these small cracks that they were hearing. When the ice stopped cooling, the cracking sounds stopped, and the ocean became very quiet.

The other type of ambient noise that was new to them was a fairly high-frequency hissing noise. It was low enough in volume that it would not have been heard with the insensitive equipment of the previous trip. This hissing noise turned out to be the sound of snow particles drifting and bouncing across the ice surface. It was present only when the wind was high enough to "lift" the snow.

These two mechanisms were new and important discoveries.

Figure 68: *Rough ice off Isachsen (NU). Photo credit: DRDC.*

8.2.1.3 1961—August/September—ICEPACK 2

This third field trip to the Arctic was different yet again. It took place during the late summer when ice conditions are quite different than they are in the spring. It was anticipated that acoustic conditions might be quite different also. Interestingly, the large amount of open water and thin ice meant that the camp could be delivered to the ice by icebreaker.

Al Milne, Tom Hughes, Bill Burroughs, Robbie Robson, and Elton Pounder (from McGill) met the CCGS LOUIS S. ST. LAURENT at Resolute. This was much to Capt Tooke's surprise since he had not been told of the addition to his tasking. However, he took the news with good grace and got into the spirit of the thing by suggesting that they should head toward M'Clure Strait where they would likely find the heavy ice that would be suitable for a summer-time ice camp (Figure 69). The scientific group was in agreement with this, so they and all their equipment were taken to a site north of Banks Island where they set up camp on a sheet of heavy (4.5-metre-thick) ice. The approximate location is given as no. 3 in Figure 65 on page 82.

They took water samples and ice cores, and they measured the usual parameters, ambient noise, and transmission loss. Another first was the use of a helicopter—a Bell 206—to carry the shot party out to suitable ranges. They also measured backscatter from the ice by setting off underwater explosions near the camp and measuring the reverberations.

Figure 69: *A summertime field camp on an old floe in M'Clure Strait. Photo credit: DRDC.*

8.2.1.4 1962—April/May—POLARPACK 1

There were several new features associated with the 1962 field trip. The measurements were performed in the deep water of the Arctic Ocean, the transmission-loss experiments were done in concert with the Americans, and, for the first time, their ice camp was set up and supported by aircraft.

The Americans had been using two ice islands as bases for operations. These 40-metre-thick ice-islands, named T-3 and ARLIS 2, had probably broken off one of the ice shelves that are attached to the northern coast of Ellesmere Island (refer to Chapter 3 for some of the history of T-3). The locations of these ice islands and the two PNL ice camps are shown in Figure 70, and the ice camps are also shown as 4(a) and 4(b) in Figure 65 on page 82. The main experiment was to make transmission-loss measurements through the deep water between the ice islands and the PNL ice camps. The crew consisted of Al Milne, Tom Hughes, John O'Malia, and Dick Herlinveaux.

The first ice camp was staged from Mould Bay, which is shown in Figure 65, page 82. Two DC3 aircraft were used for this job. They were equipped with wheel-skis, where the wheels could be raised or lowered through the skis so that the airplane could land either on the ice or on a gravel runway.

On the first trip out to find a suitable piece of ice, everyone was fairly tense. No-one aboard—neither the pilots nor the scientists—had ever landed on untested ice in a fixed-wing aircraft. At a distance of about 370 km from shore, they found a refrozen lead that looked large enough and smooth enough, and they exercised their plan for landing on the ice. While one DC3 circled and watched, the other aircraft went into action. It touched down, rolled a short distance and took off again while the pilot and passengers

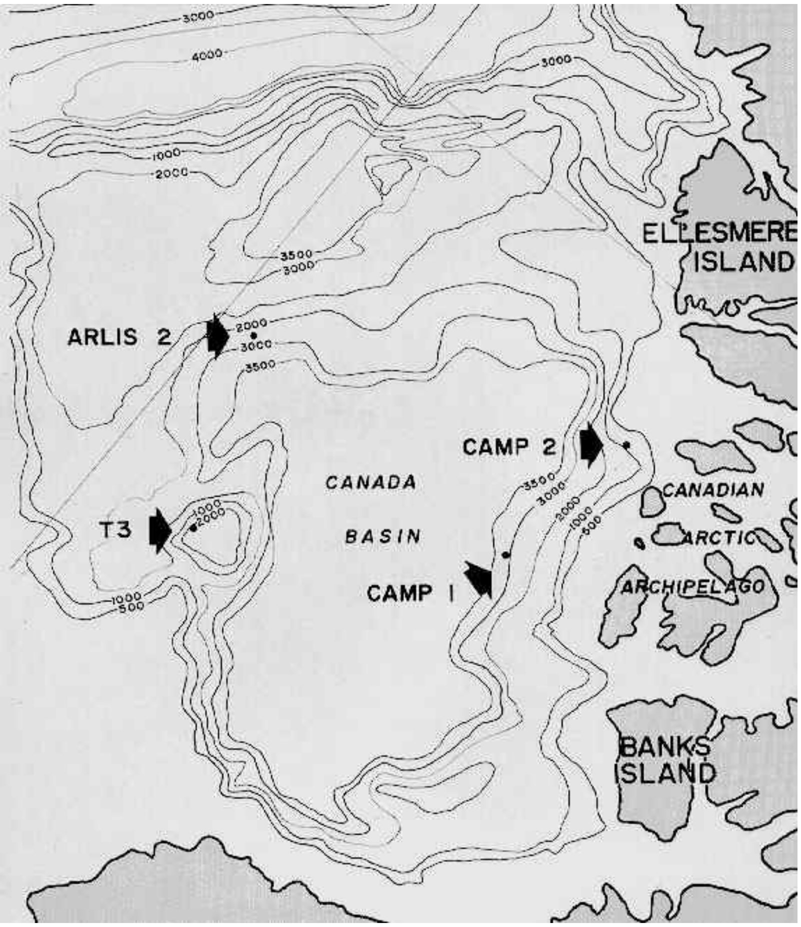

Figure 70: *Ice island locations and camp sites. Map taken from a DRDC report (POLARPACK 1, 1962).*

looked for any evidence of thin ice—such as wet snow. They made a second and third touchdown, and on the third Al Milne and John O'Malia jumped out and drilled a hole while the aircraft circled. Once they found that the ice was three feet thick, they waved down both circling aircraft. Had there been an accident, the second aircraft was prepared to initiate rescue operations with the aid of the helicopters in Mould Bay (NU).

After the camp was established, the transmission-loss measurements began. Large explosives (50 lb or 22.7 kg) were detonated by the Americans at the two ice islands, and slightly smaller explosives (16 lb or 7.3 kg) were detonated at the ice camp (for recording at the ice islands).

When this experiment was completed and a suitable amount of ambient noise data had been collected, the camp was packed up and moved back to Mould Bay. From Mould Bay they were taken to Isachsen, where Fred Roots assisted them with a Single Otter to get out to their second ice camp, which was 145 km from Ellef Ringnes Island over water 550 m deep (Camp 2 in Figure 70).

A second set of large explosions was initiated, and when it was completed, Fred sent out a helicopter to assist with a shorter-range set of shots. The locations of these explosions were determined by the helicopter's Decca receiver, a navigational aid that had been used in World War II, but was new to Arctic researchers.

8.2.2 Arctic Acoustics 1963–1970

8.2.2.1 Introduction

The previous sections detailed PNL's initial forays into the High Arctic and discussed the rather unique problems that they had to overcome. During these first few years, the Arctic field trips went from being a rather frightening step into the unknown to being scientific expeditions that could be planned with confidence. They made innovations and improvements in many things: the logistics of getting to the Arctic, in clothing, in food, in shelters, in transportation on the ice, and in their scientific equipment. The group was now confident that they could go north and survive in reasonable comfort, and they were almost sure of bringing back good scientific data. Although improvements continued to be made, they came at a slower rate, and they addressed scientific equipment and comfort rather than survival. This section, therefore, concentrates on the *science* that they were doing, rather than on how they coped with the harsh climate. Again, the locations for the expeditions are given in Table 1 and Figure 65 on page 82.

The two topics that continued to have a high priority were the measurement of underwater ambient noise and the measurement of acoustic propagation loss. The knowledge of both these parameters is important if one wishes to design an acoustic system to detect submarines. The ambient noise tends to vary with both location and season, and the propagation loss is quite dependent on the water depth and the roughness of the ice.

Measurements during the dark of the winter were first made in February 1963 (ICEPACK 3) and then again in January and February 1964 (ICEPACK 5). The cold was intense, particularly during ICEPACK 5, when the temperature was seldom above -50°C and was occasionally down to -65°C. The continual darkness at that time of year made travel slow and tentative. One improvement was in communication back to Victoria (BC). John Ganton, a new engineer, was a radio amateur (a Ham), and, by means of a "phone patch," they were able to have rather stilted conversations with their wives.

During that very cold, very dark trip in January/February 1964, they had their one and only serious medical emergency. Dick Herlinveaux developed serious stomach cramps, and it was evident that he needed medical attention, preferably in a hospital. They were at the end of their experimental program, so they decided to pack up the whole camp and return to Isachsen (NU).

The evacuation off the ice did not start well. Their two new Thiokol track-tractors had been fitted with special, new-fangled NiCad batteries, which were reputed to work well even when they were very cold. Unfortunately, no one had told the PNL crew that a different type of electrolyte was necessary if they were to be used in very cold conditions. So, after a few days of disuse in that bitterly cold weather, the Thiokol engines wouldn't even turn over. When Al looked into the battery cells he saw a little fluid on top and nothing but ice below.

No problem. They would use their big Onan motor-generator to thaw out the batteries and recharge them. But the Onan was too big and too cold to start by hand, and its battery (lead-acid, in this case) quickly ran itself flat. The Onan would not start and things were getting serious.

All they had left was their Tiny Tiger, a small hand-portable motor generator that was based on a model-airplane engine. For its size the engine was powerful—1 HP—but, even so, it was just a model-airplane engine (Figure 71). However, it did have the virtue of starting upon demand. After several hours it had charged the Onan battery, and then the Onan charged the Thiokol batteries. The Thiokols started, and all was well.

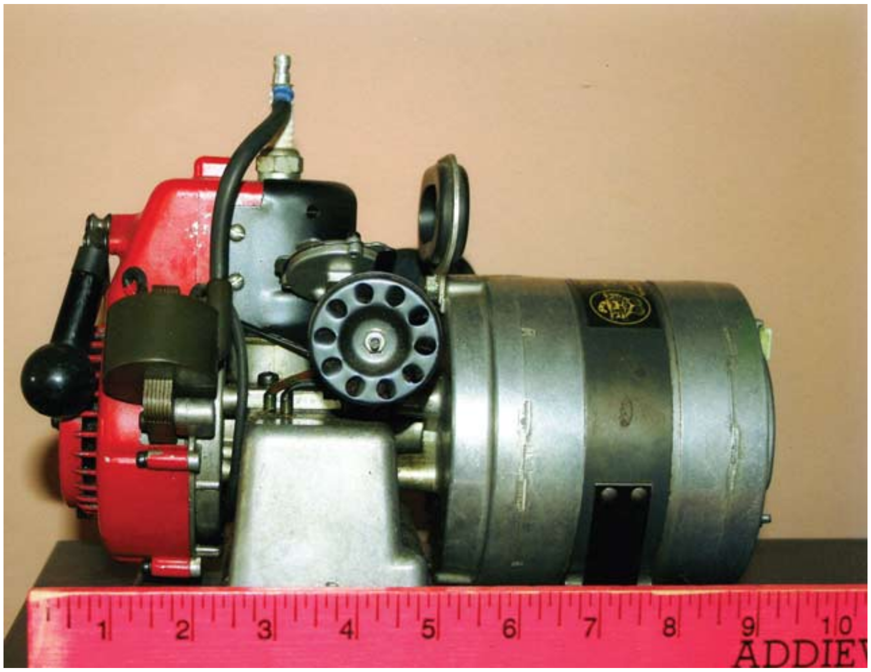

Figure 71: *A Tiny Tiger motor-generator. The markings on the ruler are in "inches." Photo credit: John Ganton.*

They took Dick back to Isachsen with the expectation that he would be taken out in two-days time by Hercules. However, when the Hercules arrived overhead the weather had closed in. The Hercules pilot could not see the runway, and he had to leave. Dick's health did not improve, and eventually, as John Ganton says, Al pushed the panic button and requested a medical evacuation. John says he was very impressed that within 24 hours of "pushing the button" they were in Edmonton (AB). And this was at a time when the military probably had fewer than ten Hercs in total.

An interesting sidelight to this evacuation was the fact that the Hercules brought a nurse to look after Dick during the flight south. Al Milne called her [45], "a lovely young nurse who did much to buoy Dick's morale." John Ganton called her [47], "a wee bit of a thing." Anyway, there was much interest and excitement at Isachsen since she was going to be the first female ever to set foot there. Everyone came down to the runway to welcome her and take pictures. However, in the enduring way of flight crews everywhere, the Herc crew convinced her that if she ever set foot off the plane into that ravening hoard of women-starved Arctic animals, no one could hold out much hope for her continuing chastity. And, much to Isachsen's disappointment, she believed them. She never left the plane, and she never experienced the reverence that is always accorded to such a precious object.

It turned out that Dick had an infection brought on by diverticulitis. He recovered quite handily after a short period of hospitalization.

8.2.2.2 Acoustic Backscatter from the Ice

Backscatter measurements, which were started during ICEPACK 2 and ICEPACK 3 (Figure 72), were continued during the late-summer field trips in 1963 and 1964. In August 1963, during ICEPACK 4, the icebreaker, CCGS LOUIS S. ST. LAURENT, was to take them west through M'Clure Strait to the

Beaufort Sea, where they were to make reverberation measurements under the polar sea ice. In the event, the LOUIS never even made it to M'Clure Strait. It was turned back by heavy ice in Viscount Melville Sound. They retreated to Prince Regent Inlet (labelled as no. 6 in Figure 65 on page 82), where there was solid ice cover, albeit no polar ice, and reverberation measurements were made under this somewhat smoother ice.

Figure 72: *ICEPACK 3. This is about as bright as it gets in February that far north. Photo credit: DRDC.*

They suffered a similar setback in September 1964, during ICEPACK 6, when this time the CCGS SIR JOHN A. MACDONALD attempted to take them west through M'Clure Strait into the Beaufort Sea. The SIR JOHN A. broke off part of a propeller in the heavy polar ice of M'Clure Strait, and they had to go back to the softer ice in Byam Martin Channel (labelled as no. 8 in Figure 65 on page 82). They got started with their backscatter measurements, but the icebreaker soon had to go back to its ship-escort duties. Ray Brown, the Chief Scientist, was quite disgruntled. "Twenty-nine days away and only one day's field work!"

POLARPACK 2, in April 1965, and POLARPACK 3, in August of the same year, were both successful expeditions in the heavy ice of the Beaufort Sea, west of M'Clure Strait. POLARPACK 3 was novel in that it was a joint Canadian-American expedition. The Americans provided the icebreaker, USS STATEN ISLAND. The American Chief Scientist, Dr. Alan Beale, found it impossible to join the expedition, and he called on Al Milne to act as Chief Scientist. The PNL crew joined the ship in Barrow, Alaska, and the STATEN ISLAND headed north. They set up a recording camp on the ice, and then used the ship as their "shot" vehicle; Bill Burroughs and John O'Malia detonated explosive charges off the stern of the vessel as it pushed its way through the ice to a maximum range of 60 km.

The ice was very thick and hard, and, even before the shot run started, a small hole had been punched in the ship's bow. The damage curtailed the expedition somewhat, since the captain was anxious to get back to Barrow for repairs.

8.2.2.3 Acoustic Stability Under Ice

A new idea that Al Milne and John Ganton had been considering had to do with the detection of submarines under the very stable ice surface. The plan was to send acoustic pulses from an underwater transmitter to a receiver several kilometres away. They reasoned that in the absence of surface waves the acoustic environment was almost completely fixed, and, therefore, all received pulses would be identical. If a submarine should pass nearby, the reflections from its hull would cause a change in the received pulse. Very small changes should be detectable, and, therefore, the system might well be very sensitive.

They first tried this idea during ICEPACK 4/66 (April 1966), at an icecamp in M'Clure Strait. They had problems with the acoustic transmitter and had to content themselves with quite short ranges. During ICEPACK 4/68 (April 1968), also in M'Clure Strait, they had better success. They experimented with source-receiver separations of 1 and 2 km, and they showed quite clearly that at these separations the received pulses were very stable.

During ICEPACK 4/69 (April 1969), again in M'Clure Strait, they went after much greater separations between transmitter and receiver. They set up a projector at an icecamp, and they installed receiving hydrophones at ranges of 16, 32, and 48 kilometers. A new feature in the experiment was that the acoustic data from the three receivers was broadcast (via very high frequency [VHF] radio) to a cliff-top camp set up on Melville Island (NT), about 15 km to the north (Figure 73). Tom Hughes, Borg Haagensen, and Warren Wall manned the icecamp and the transmitter, and Al Milne and John Ganton looked after the recording at the cliff-top camp. Again, they found very stable pulse shapes, which changed only slightly as the tide caused the ice to rise and fall.

8.2.2.4 Measurement of Ice Drift

Now that Al Milne and John Ganton had proven their hypothesis that acoustic pulses are very repeatable under fixed ice, they needed to know where the ice was stable and how long it would last without moving.

To do this they built buoys that could be frozen into the ice. The so-called "sono-drift buoys" were fifteen feet long and three inches in diameter (about 4.6 m long, 7.6 cm diameter)—a shape that allowed them to be lowered into a drilled ice hole. The buoys had a flotation collar to keep them from sinking once the ice broke up, and they had a hydrophone underneath to measure ambient noise. A radio receiver listened for a signal from an overflying aircraft, and when it heard the proper interrogation, a transmitter broadcast the signal from the hydrophone up to the aircraft where it was recorded. It was analyzed later.

Figure 74 shows the long tube of the sono-drift buoy electronics laid out on a table, and Figure 75 shows one of the buoys being installed through the Arctic ice.

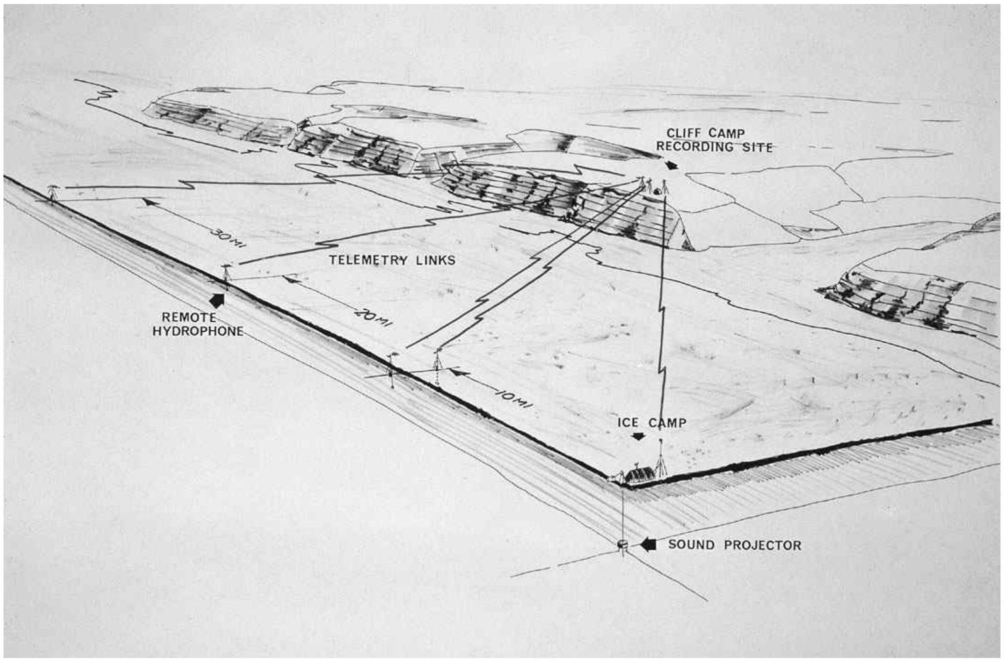

Figure 73: *An artist's rendition of the set-up in M'Clure Strait, April, 1969.*

Figure 74: *The Ice-Buoy laid out on the table—left. The people, left to right, are Archie Ferguson, Bob Weir, Ray Hale and John Ganton. The idea for the experiment was Ganton's, and he supervised the project. Bob Weir looked after the engineering and the construction. Photo credit: DRDC.*

Figure 75: *An Ice-Buoy being prepared for installation through the ice. Photo credit: DRDC.*

Twenty-two of these buoys were built at DREP. Two were tested just off Resolute Bay, and, in April 1970, the other twenty were installed in M'Clure Strait and Viscount Melville Sound (as shown in Figure 76).

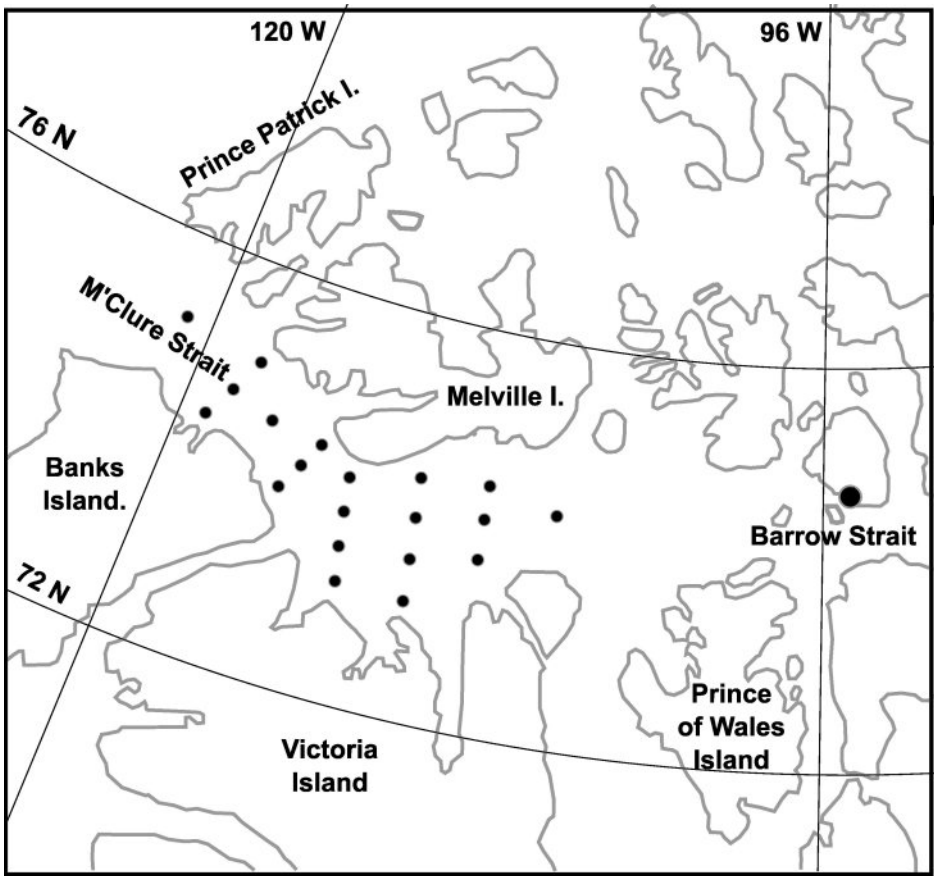

Figure 76: *This map shows the locations of the twenty sono-drift buoys when they were first deployed in the ice.*

Every two weeks from April to September 1970, the buoys were interrogated by an overflying "Argus" aircraft doing a "sovereignty" patrol out of Comox (BC). The locations were determined (primarily by the analysis of radar returns off the shore cliffs), and a sample of ambient noise was collected. Capt Stannard (Stan) Toole, a seconded officer at DREP, looked after this work. The overflights were discontinued after the middle of September when only three buoys responded; by that time all the rest had been crushed or otherwise destroyed.

8.2.2.5 Ambient Noise, Long-term Measurements, RIP Packages

The practical purpose of this under-ice acoustic research is to be able to design a system to detect submarines as they pass by. To do this effectively, one must know the loudness and the nature of the background noise that is masking the signal put out by the submarine. And, since some regions are noisier than others, this ambient noise must be known in the particular locality where the detection system is to be deployed. In addition, some seasons of the year are particularly noisy. Consequently, year-round measurements must be made in order to build a system that is effective but not grossly over-designed. The ambient-noise measurements made during field trips were very short-term, and nearly all measurements to-date had been made when the channel was completely covered by ice.

This shortfall in their knowledge was recognized very early on, and the first steps to do something about it were taken in January 1965 (ICEPACK 7), when a sensitive hydrophone plus a recording package were installed in Barrow Strait (NU) not too far from Resolute Bay (NU). The installation was carried out in total darkness, the only light being the headlights of the tractors. A line of bamboo poles, each with a flag, was erected in the ice so that the recording package could be found several months later. Indeed, when they returned in April the flags were still there, and the recorder was still working.

The next project to measure long-term ambient noise was much more ambitious. Starting in 1966 the PNL engineering section designed and built five packages for recording underwater sound. They were called recording instrument packages, the irony of the acronym (RIP) being deliberate. The main contributors to the design were John Ganton, Graham Dennison, Bill Burroughs, and Allen Milne.

In August 1967 (ICEPACK 8/67), just fifteen months after the project had been approved, the five units were lowered from the icebreaker CCGS LABRADOR. The locations are shown in Figure 77.

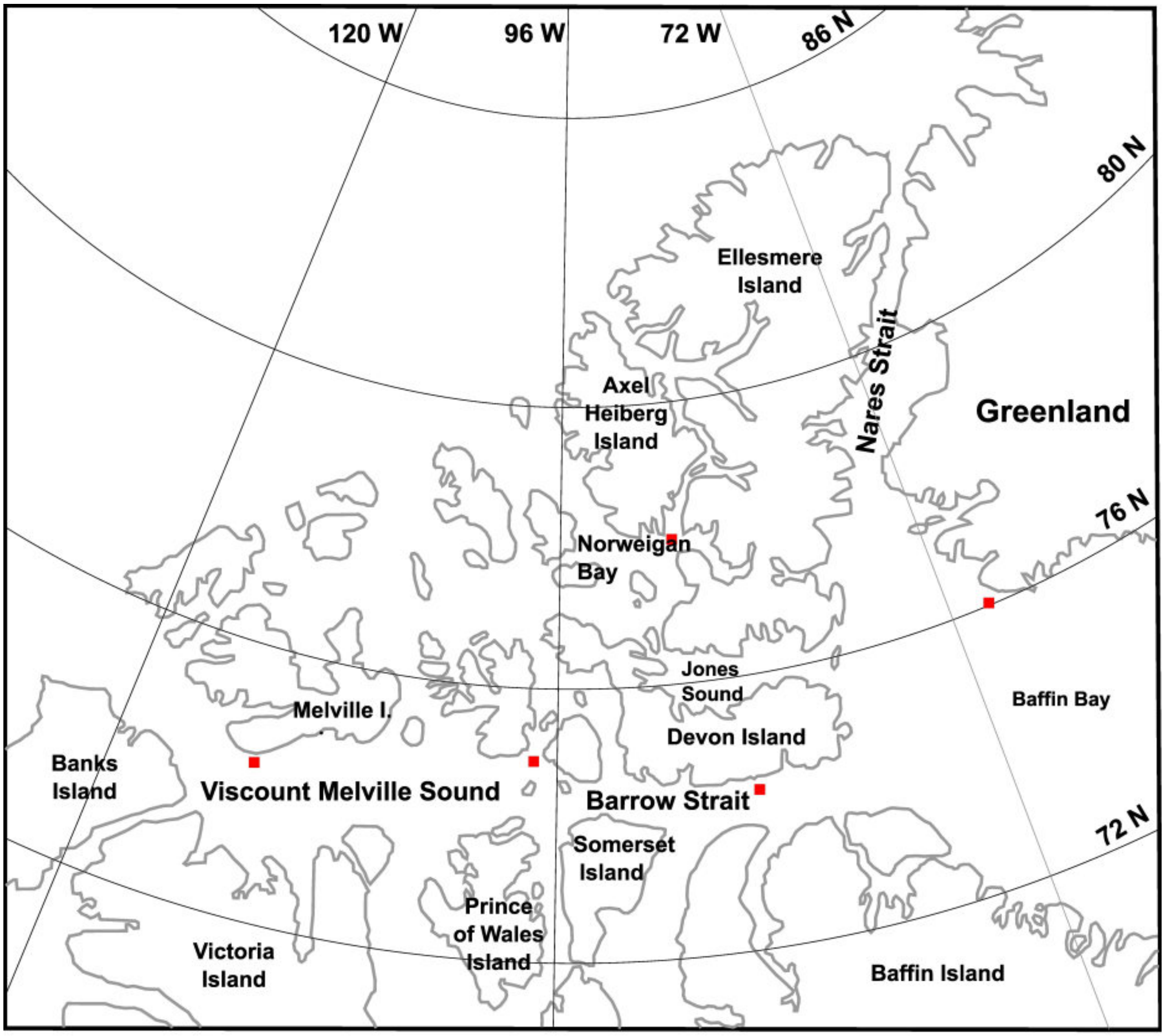

Figure 77: *Locations of the five long-term Recording Instrument Packages (RIPs). (Marked in red.)*

For the whole of the following year each system sampled and recorded the ambient noise power in each of ten different frequency bands.

The next year, during ICEPACK 8/68, the packages were recovered. In the absence of the modern marvel of GPS, the ship operators had to be much more inventive in order to know where the RIPs were located. At some locations they used the radar signatures of the nearby cliffs (which they had carefully recorded when the RIPs were installed). At other locations they measured radio "transponder" distances from known shore sites. Sometimes they used both.

When they were close to being "on top" they signalled the RIP with a coded acoustic message. This caused an explosive bolt to blow, which, in turn, released a float that rose to the surface pulling a line that was attached to the RIP resting on the seabed. At the surface a radio beacon on the float turned on, and a vial of green dye emptied into the water. Had it not been for these aids, they say, the pilot in the overflying helicopter would have had great difficulty in finding the float. Once the float was found it was only a matter of time before the RIP was up on the ship's deck.

Four of the five RIPs were recovered. The one on the east side of Baffin Bay, which was in 430 metres of water, had an impressively large iceberg grounded on it. When the coded acoustic message was sent, there was no satisfying explosion to indicate that all was well. It was concluded that the iceberg had, in fact, destroyed the RIP.

Another feature of this expedition was the presence of the PISCES I, a miniature manned submarine. Al Milne had, with some difficulty, raised enough interest (and money) to have this vehicle brought along. His reasoning, in part, was that if none of the RIPs were recoverable, the trip could still be useful for other scientific studies such as submarine geology, sea-mammal sounds, and oceanographic work.

The PISCES was used to inspect and photograph the RIP in Lancaster Sound before it was recovered. The water had very little ice in it, so the PISCES was in no danger from that source. Once the released float had been found, the PISCES just followed the rope down to the bottom. Figure 78 shows a photograph of this RIP.

When the four recovered RIPs were opened it was found that, on average, they had recorded data for almost half the time. Fortunately, the good records were from the fall and early winter, a period when measurements had not previously been made. Milne expressed great satisfaction at learning about noise characteristics during this time—both when the surface first froze over and then, later, when the ice became shore-fast.

The principal causes of failure were leaky electrical cable connections that lasted only for several months before they failed.

8.2.3 Investigation of Chokepoints

From 1959 to (approximately) 1970, the Arctic Acoustics work had been motivated primarily by the desire to "do science." The fact that the work might be useful to the military was acknowledged and—perhaps—even advertised in the right circles, but the driving force had been the desire to learn about such things as the ambient noise and propagation loss under ice-covered waters: what was its magnitude, what were its characteristics, and why was it as it was? Everything new was soon published in the open literature, the results being eagerly awaited by the scientific community. However, events were in the wind, and the days of openness were soon to end.

Figure 78: *A photo of the RIP in Lancaster Sound before it was raised to the surface. The hydrophone is in the little cage at the top of the package. Batteries and electronics are in the pressure vessels. The winch carrying the recovery rope is visible at the back. Photo credit: DRDC.*

One of the dramatic events of the era was the Manhattan incident. It caused the Canadian people (and the government) to become very aware of the Arctic and their tenuous hold over it. In August and September of 1969, the American icebreaking supertanker SS MANHATTAN crossed the Arctic through the Canadian Arctic Archipelago from east to west, and then it turned around and crossed through the islands in the other direction. The purpose of this expedition was to explore the feasibility of transporting oil from Prudhoe Bay (AK), to the eastern United States. To the chagrin of Canadians they did this without asking permission of the Canadian government. The Canadians held the view that the waters inside the archipelago were inland waters and were to be treated as sovereign Canadian territory. The Americans, on the other hand, maintained that the channel through the archipelago was wide enough to be considered international waters, which meant that they did not need anyone's permission for their transit. The conflict caused a furore in the Canadian press, which claimed that this was just another step in the *d*e facto takeover of the Arctic by Americans. The Canadian Prime Minister P.E. Trudeau and his embarrassed government responded by passing the Arctic Waters Pollution Prevention Act (AWPPA), which gave Canadian officials substantial powers (at least on paper) to stop and search vessels transiting the islands. And the Act managed to do this without ever using the word "sovereignty," a word that had very hostile connotations to the Americans.

Although the Manhattan incident heightened the awareness of Canadians toward the Arctic, it did not cause the government to put more resources into Arctic defence. The war in Vietnam was raging, and the Cold War was still at its height. Fear of the Soviets was a much stronger motivator than a short-term squabble with the Americans. It is noteworthy that much of the Arctic research during the subsequent

30 years or so was carried out in close cooperation with the Americans. Another possible reason for ramping up military interest in the Arctic was the good work that Al Milne and his crew had been doing over the past ten years. Milne's pioneer work had made it quite clear that it was indeed possible to do this type of research in the Arctic, and, furthermore, the installation of acoustic detection systems looked to be quite feasible in the not-too-distant future.

In 1971 funding for Arctic research was increased [48], and the lab hired several new people for Arctic acoustics work. Ronald Verrall, John Ozard, Dan MacIntyre, and Gary Brooke were physicists hired into the Arctic Acoustics Group, and Mervin Black was an engineer hired nominally into the engineering section, but who spent almost all his time working with the Arctic people. A number of smart new technical people were hired about the same time. Dave Baade, Steve Taylor, and Linda Churcher were hired into the Arctic Acoustics group. Jim Perkins, Bob McLean, and Ken Ashcroft joined the Applied Technology group, but they spent the majority of their effort on Arctic-related work. They were all very important to the success of the Arctic Acoustics program. The Magnetics Group, which was just starting to be interested in Arctic work, hired Ron Kuwahara, a physicist.

An examination of the map in Figure 79 shows that there are three major sea routes leading from the Arctic Ocean through the Arctic Islands to the Atlantic Ocean: there are several east-west routes, but all of them funnel through Barrow Strait; there is the main north-south route, known as Nares Strait, between Canada and Greenland; and there are a number of northwest-to-southeast routes that pass through Jones Sound. Each of these routes has at least one narrowing—or chokepoint—a detection system placed at each of these three chokepoints would detect all submarines passing through the archipelago.

After 1970 the acoustics work in the Arctic was concentrated on the chokepoints. The focus became that of measuring acoustic parameters throughout the year at these three locations. The important parameters were those that bore directly on the design of an underwater acoustic system that could detect submarines—namely, ambient noise, transmission loss, and inter-hydrophone coherence (needed to estimate how much gain and directional information one could get out of an array of hydrophones). To make these long-term measurements, much effort was spent on installing underwater hydrophone systems and cabling them to a shore site where the signals could be recorded or, alternatively, sent on to an inhabited town for recording.

8.2.3.1 Nares Strait—The North-South Passage, Wrangel Bay

Of the three routes through the Arctic, the north-south route between Canada and Greenland is probably the most important. It provides the shortest route (of the three) between the USSR and the North Atlantic. In the late 1960s, John Ganton recognized this importance, and, at his urging, a plan was drawn up to install a couple of hydrophones in order to measure ambient noise on a year-round basis. In 1970 Ganton and John Wilson did a reconnaissance of the area and made a plan to install a system the following year. Their location of choice was Wrangel Bay (NU), which is about 56 km south of CFS Alert (Figure 80).

In April 1971, a group from DREP, consisting of John Ganton, Al Milne, John Wilson, Ted Jackman, Borge Haagensen, Dick Herlinveaux, and Archie Ferguson, descended upon Alert (NU). Using a helicopter for transportation, they erected and tested two VHF repeater sites on the tops of two high points between Wrangel Bay and Alert. In spite of some quite bad weather, the telemetry link was installed and tested by 6 May.

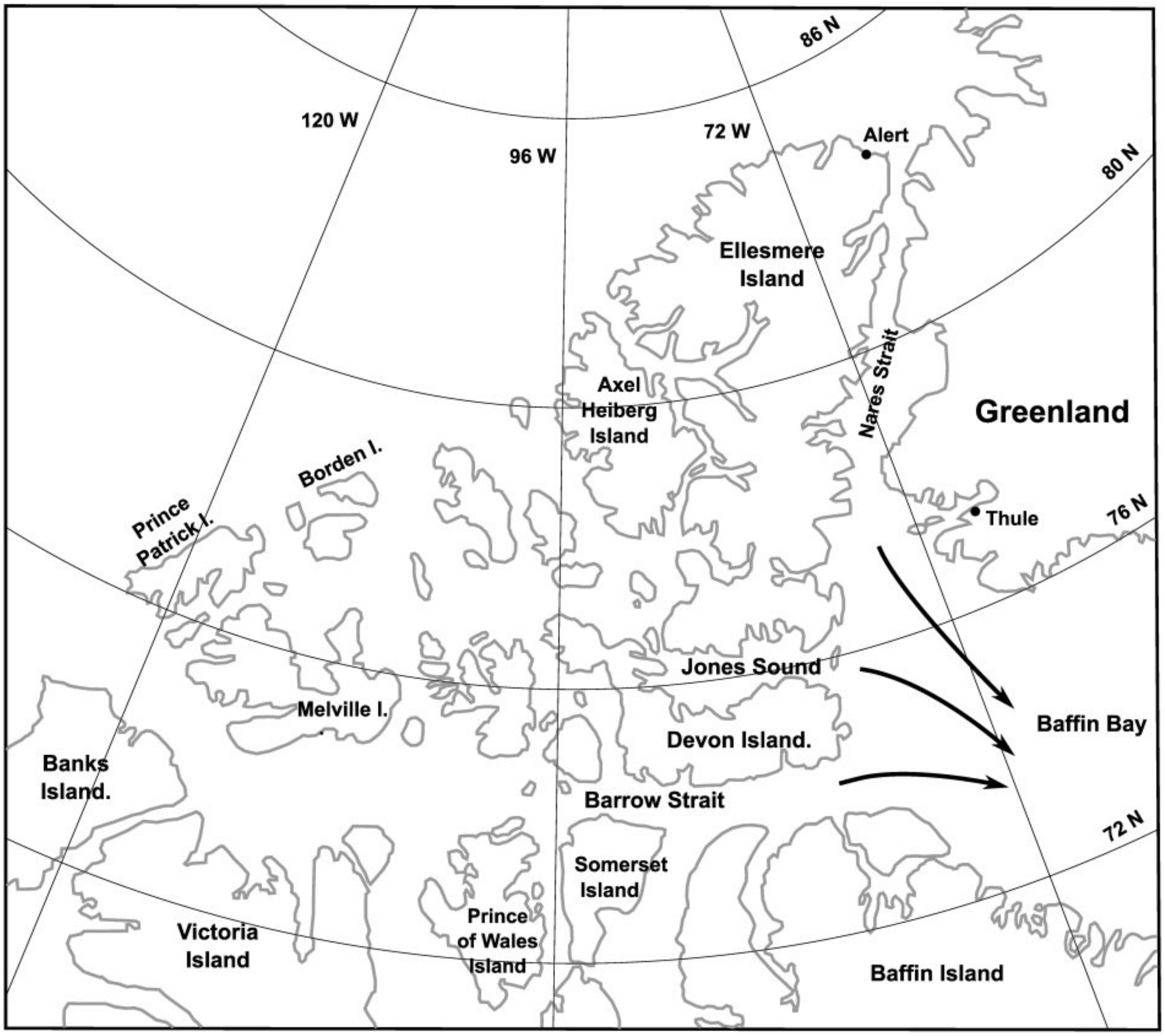

Figure 79: *It can be seen from this map that there are three principal routes through the Arctic Islands.*

Each antenna mast was built to pivot in order to facilitate access to the antenna itself. Figure 81 (page 103) shows the antenna pulled down for maintenance. The weight of the batteries in their box would bring the mast back upright as shown in Figure 82 on page 104.

It may seem that they had put the cart before the horse in that they had installed the telemetry system before there was any data to telemeter. However, the hydrophones, which were to be the source of this data, were installed later that year when the channel was sufficiently ice-free.

In August 1971 four hydrophones were laid in Robeson Channel just outside the entrance to the Bay (Figure 83, page 105). They were laid and cabled to shore by the catamaran shown in Figure 84 (page 106). For protection against the pressure and grinding action of the ice, the cables were brought around a hook of land at the north side of the Bay. This hook can be seen in Figure 83 (page 105). For extra protection

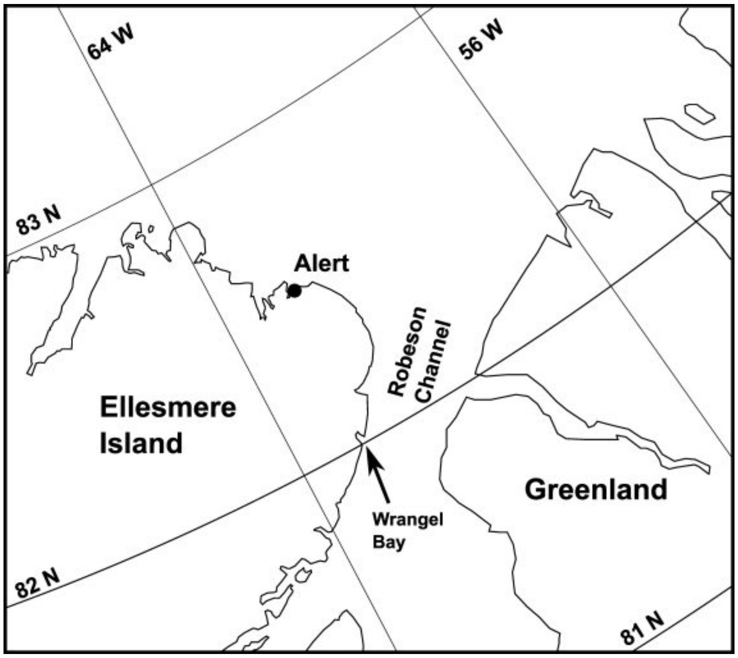

Figure 80: *The northern section of Nares Strait is known as Robeson Channel. Hydrophones were placed off Wrangel Bay, and the data was telemetered to Alert.*

from the ice, the cables were trenched into the bottom. Navy divers used high-pressure water hoses and explosives to make the trench. Unlike several other similar DREP installations, this cable protection was a success; the cables remained unmolested by the ice for many years. Figure 85 (on page 107) shows some of the crew that installed the system that August.

In the spring of 1972 (the following year) acoustic work continued at Wrangel Bay (NU). The ice was solid and unmoving, and a camp was set up about 8 km offshore from Wrangel Bay. Two holes were drilled, a hydrophone was lowered down each, and their cables were brought into a warm recording tent. The two hydrophones were placed at different depths to get some idea of the depth dependence of propagation loss and ambient noise. The hydrophones installed the previous summer were still working, although they were plagued with intermittent flow-noise, particularly when the current was high. This so-called “flow-noise” is caused primarily by tight cables vibrating in the water flow and coupling their vibrations to the hydrophones. It can completely swamp the real water-borne noise. The hydrophones could be used, however, when flow-noise was low. Ambient noise was recorded, and a transmission loss experiment was carried out with all hydrophones recording the blasts. A helicopter with a crew of two flew out to a number of ranges, drilled holes through the ice and detonated explosives at several depths. The shots were recorded at both the ice camp and the shore camp.

As is often the case, things did not go exactly as planned. At the site 8 km north of the ice camp, the helicopter pilot delivered the “explosives” crew to their desired location and then shut down the helicopter. Turning off the helicopter was the usual practice since letting it run, even at an idle, used fuel at a surprising rate. This time, however, the helicopter would not start after the blasters were finished. An igniter in the engine was malfunctioning and needed to be replaced. The pilot contacted the Wrangel Bay camp and explained the problem. John Ganton, at Wrangel, then tried to contact the CFS Alert radio operator (known informally as Alert Radio), but there was no-one listening. Becoming a little concerned,

Figure 81: *The mast was pivoted on a tripod with the battery box acting as the counterpoise for the antenna. Photo credit: DRDC.*

John, who was an amateur radio operator, then switched to the amateur bands. He found traffic on the 20-metre band, but had trouble breaking into the conversation. He eventually used the emergency call "Pan, Pan, Pan," and that got everyone's attention. A Ham in BC called the MOT office in Alert and got them to radio Wrangel Bay. The helicopter mechanic at Alert then called Thule, Greenland, and arranged for an igniter to be dropped to the helicopter from an overflying Hercules. Luckily, a BOXTOP resupply of Alert was in progress, and there were several Hercules aircraft in the vicinity.

Meanwhile, the DREP crew on the helicopter, John Wilson and Gordon Robinson, were walking the eight kilometres to the ice camp, and Al Milne and Ron Verrall were walking out to meet them, flagging the route as they went in case the weather deteriorated. After they met, Verrall returned to camp with Wilson and Robinson, and Milne continued on to the helicopter.

By the time the igniter was dropped, many hours had gone by, and the helicopter, which had a lead-acid battery, was much too cold to start. It was now obvious that nothing more could be done that day, and Al Milne and the pilot started the long walk to the ice camp, where they arrived at about midnight, very tired and hungry (it was still broad daylight, of course).

Since Alert had no aircraft capable of landing on the ice and snow of Robeson Channel, help had to be requested from Resolute Bay. The following morning a Twin Otter flew up from Resolute, picked up the mechanic and a fresh battery at Alert, picked up the pilot at the ice camp, and then flew out to the helicopter. After a quick fix everything worked, and the emergency was over.

Figure 82: *VHF repeater being set up on a high point between Wrangel Bay and Alert. The mast was guyed in place after the battery box had pulled it upright. Photo credit: DRDC.*

All is well that ends well, and all that was lost was a day's work and several hours of Twin Otter time. However, the thought of what might have happened if the helicopter had been much farther from the ice camp or if the communications had not worked gave everyone pause for reflection. Ever afterward, emergency gear was thoroughly checked and double checked.

Figure 83: *Looking northwest toward Wrangel Bay and Ellesmere Island. The hydrophones were installed just out of the Bay, and the cables were taken around the little hook of land that juts into the Bay from the north. Photo credit: DRDC.*

In the spring of 1974 the four-hydrophone array was tested to see whether it had directional capabilities. In other words, could it give the operators an estimate of the direction to a source of sound? To make this measurement, a group from DREP drilled a series of holes through the ice of Robeson Channel in a rough semi-circle (with a radius of about 2 km) centred at the hydrophone array. Down each hole they lowered a J-15 acoustic projector and made recordings at different frequencies.

The biggest problem in this series of measurements was making the holes through the ice. The J-15 is not small, and it needed a hole roughly 60 cm in diameter. While John Ganton and Dan McIntyre made measurements with the J-15 at one hole, John Wilson and a gang of helpers from CFS Alert worked on drilling the next. The group memory says that Wilson used a thermal drill, but no-one remembers details. Again, the flow-noise caused by the strong currents of Robeson Channel gave problems, and the measurements had to be made during quiet periods.

However, the results of the measurement were positive. When the flow-noise was low, the hydrophone array was capable of determining a rough direction to the source.

In the summer of 1976, two larger and supposedly better, 14-element linear hydrophone arrays were installed just off Wrangel Bay by the Director of Maritime Combat Systems (DMCS). The VHF telemetry

Figure 84: *A catamaran was the cable-laying platform. It was light, shallow-drafted, stable, inexpensive, and it had a large working platform—like a raft. It was propelled by two outboard motors. The operator here is Capt Stannard (Stan) Toole, an airforce officer who was seconded to DREP at the time. Photo credit: DRDC.*

system was replaced by an overland cable, which was deemed to be more secure. One of the fascinating aspects of this installation was that the cable was laid over hill and dale all the way from Wrangel to Alert by helicopter. The helicopter suspended a large reel of cable below it, and the cable unwound as the helicopter slowly covered the ground. Much to the surprise of some, the installation worked very well.

Although the overland cable worked well, the underwater system had its problems. This hydrophone array, just like the one installed in 1971, was plagued by loud flow-noise. It had been laid under tension over the rocky seabed, and some of the hydrophones and cables were suspended off the bottom. As before, the water currents caused these suspended cables to vibrate, and this produced the unwanted self-noise.

During the following decade DREP gained a reputation for building quiet hydrophone systems, and in 1986, at the request of DMCS, DREP built two 7-element arrays and deployed them off Wrangel Bay. To keep the hydrophones and cables from moving in the current, Dave Baade used a technique to introduce slack into the cables after they were deployed. He inserted corrodible magnesium links into the “tension” cables that were used during deployment. The magnesium links dissolved after a couple of days, and the hydrophones, with no tension members to suspend them off the bottom, settled into the ooze. They were still connected by electrical cables, of course, but these were over-long and had lots of slack, so they also settled down amongst the rocks and away from the current. This system was quite successful.

Figure 85: *Some of the Wrangel Bay installation crew. From left to right: Bill Burroughs, DREP engineer, Capt Stan Toole, seconded officer, John Wilson, DREP engineer who designed the fold-down antenna mast, J. Greenblatt, DREO scientist, Archie Pennie, senior DRB management, Ed Bryant, cook, Eric Banke, DREO scientist. Photo credit: DRDC.*

Baade also designed and had built two wooden catamarans for laying the cable (Figure 86 on page 108). They were light, easy to sling by helicopter, and they had a shallow draft. Most important, perhaps, was that they were very inexpensive. Even though the "cats" were abandoned after their job was done, these cheap boats saved the taxpayer many thousands of dollars—compared to what had first been planned.

It should be noted that during all these installations the heavy ice of Robeson Channel prevented the boats from getting more than about 1 km off the mouth of Wrangel Bay. In the summer of 1986 they waited and watched for six weeks before they got out even that far (Figure 86).

After 1972 the main DREP acoustic effort moved south to Barrow Strait and Jones Sound (NU). CFS Alert was not used again as a base of operations until the mid 1980s, and then it was the Arctic Ocean—not Robeson Channel—that became the main interest.

Figure 86: *The two cable-laying catamarans in an ice-choked Wrangel Bay. The operators had to wait until the ice had been blown out of the Bay before they could lay the hydrophones and the cable. Photo credit: DRDC.*

8.2.3.2 Barrow Strait—The East-West Passage, Gascoyne Inlet

Figure 79 (on page 101) shows that there are several passages through the Arctic Archipelago that funnel through Barrow Strait. The obvious chokepoint here is the section of Barrow Strait that lies between Devon Island (NU) and Somerset Island (NU). The map in Figure 87 shows the area in more detail. Barrow Strait, south of Gascoyne Inlet, is only about 70 km in width, and Gascoyne is reasonably close to the town of Resolute Bay, which simplifies the logistics of working at Gascoyne Inlet.

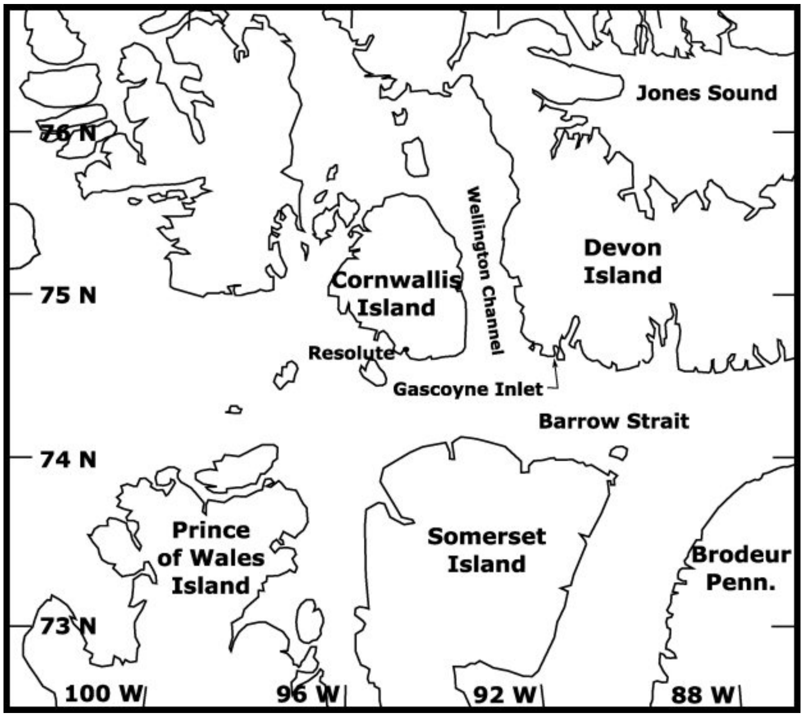

Figure 87: *The chokepoint for the main east-west passage is the section of Barrow Strait that lies between western Devon Island and Somerset Island.*

In August 1971, Al Milne, accompanied by Ron Verrall, walked the area and determined that Gascoyne Inlet (NU) was deep enough and protected enough from ice pressure that it would make a suitable location for bringing cables ashore. The creek shown on the map in Figure 88 contained running water from a melting snow-pack, which was very convenient for camp operations in the fall. There was an old raised beach, flat and smooth enough for a Twin Otter landing strip, and the surrounding countryside was a fairly high plateau, which facilitated the radio transmission of data to Resolute Bay. One small disadvantage was that the Radstock Bay area, which is just east of Gascoyne Inlet, is a mating and denning region for polar bears. Bears are naturally curious, and camps usually smell of food, so it is no wonder that the Gascoyne installation had more than its share of unwelcome visitors.

In the fall of 1972 the CCGS LOUIS S. ST. LAURENT carried out a more detailed underwater survey of the area, and nothing was found that would prevent the use of Gascoyne as a cable terminus.

In 1973 the Arctic acoustics effort was focused on Barrow Strait and on Gascoyne Inlet. In the spring an ice camp was set up on the strait south of Gascoyne Inlet. Figure 89 shows Allen Milne beside a hole in the ice of Barrow Strait. The hole was made by explosives—obviously for some large piece of equipment.

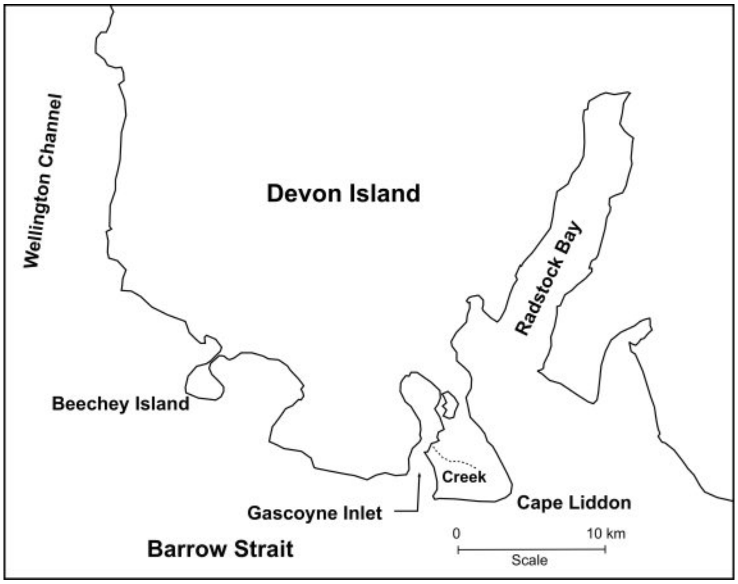

Figure 88: *A map showing Gascoyne Inlet in more detail. A camp was set up near the mouth of the little creek, and cables were brought ashore to the camp.*

Figure 89: *The results of blowing a hole in ice that is about 1.5 m thick. Three one-pound charges were used. Generally, most of the broken ice in the new hole has to be removed by shovel. Photo credit: DRDC.*

The ambient noise was found to be very low, as is typical of narrow, fairly shallow channels that are covered with unmoving ice. Acoustic transmission loss was also measured, and it was found to be fairly high in the shallow (150 m) water that is typical of the northern half of the Strait. Propagation was somewhat better in the southern half of the channel, which is almost twice as deep.

In the fall of 1973 the first bottom-mounted hydrophones were installed by a team on the CCGS SIR WILLIAM ALEXANDER. A simple six-element horizontal array and a three-element vertical array were lowered to the bottom and then cabled to shore at Gascoyne Inlet. From Gascoyne the signal streams were sent via UHF radio to Resolute Bay, where they could be monitored at any time of the year. The radio link involved three repeaters (four hops), all looking like the one shown in Figure 90.

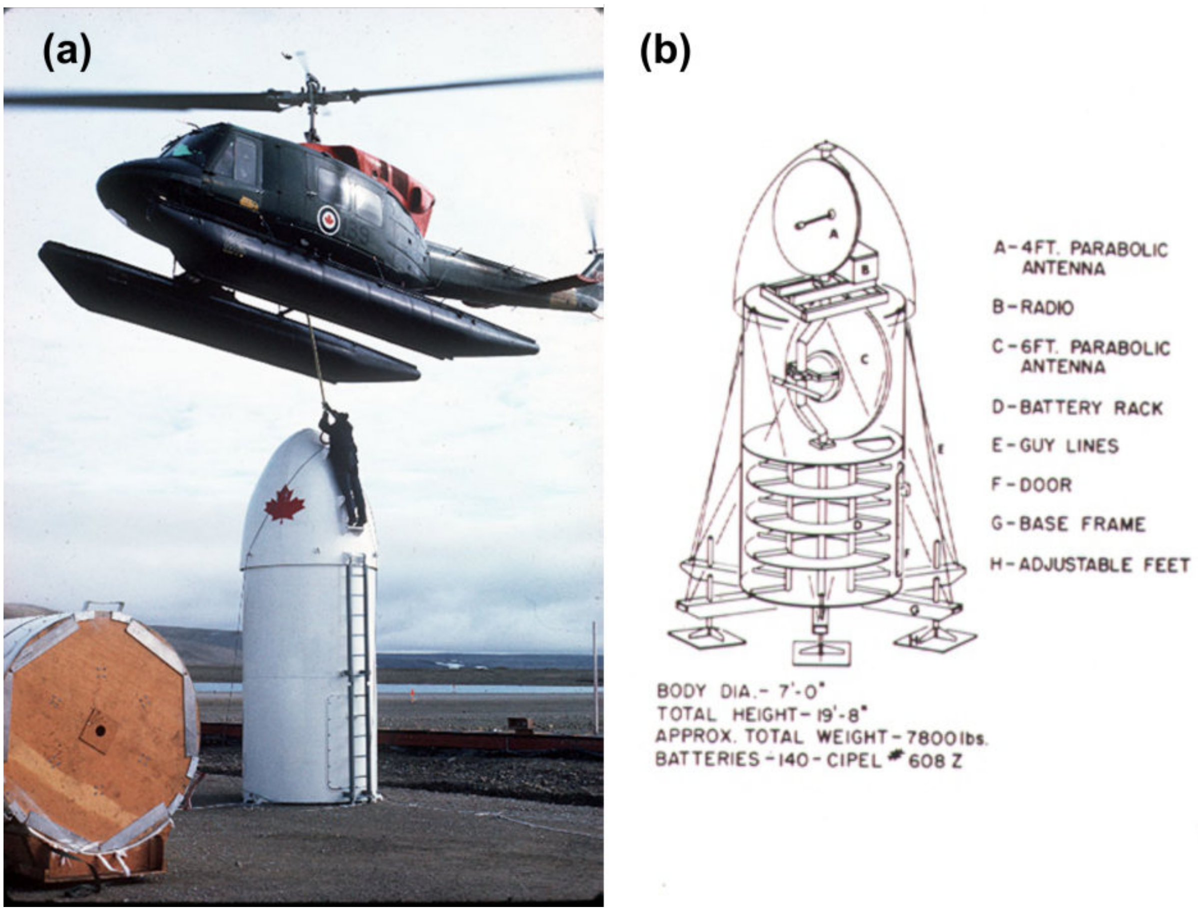

Figure 90: *(a) A fibre-glass repeater "silo" being hooked to a military helicopter for slinging out to one of the three sites. (b) A drawing showing the internal layout of the silo. Photo credit: DRDC.*

All three repeater silos were placed on high ground, and in the winter they spent much of their time in fog—collecting hoarfrost and rime ice. The silo in Figure 91 has 30–40 cm of frost covering it, and this was typical. However, the resulting attenuation to the UHF signal was never enough to cause a failure in the data stream.

The batteries powering the radio were primary cells (zinc and carbon), and they had to be replaced every two years. This was done in the summer with helicopters air-lifting 140 batteries from a ship to each of the various sites.

Figure 91: *Silo showing the frost that had collected on it during the preceding winter. Photo credit: DRDC.*

In the spring of 1975 the cables coming ashore at Gascoyne Inlet were destroyed by ice action, thus ending the flow of data. In the fall a more sophisticated seven-element array was deployed by a team on board HMCS PROTECTEUR. Figure 92 shows this array being lowered into the water. The hydrophones are each enclosed in a smooth aluminum ellipsoid in an attempt to decrease the flow-noise. (It should be noted in passing that the ellipsoids did not work well. A much better solution was to wrap the hydrophones with a thick layer of open-cell foam.)

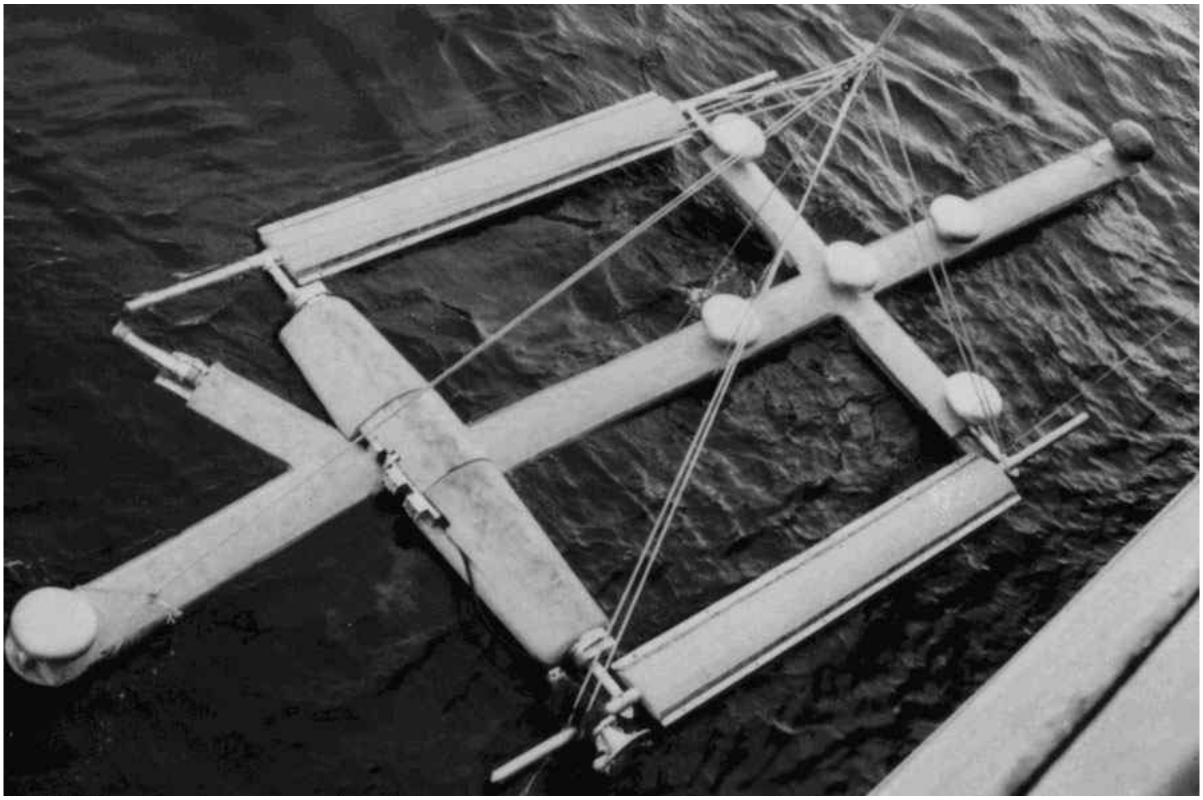

Figure 92: *Hydrophone array being lowered into Barrow Strait from HMCS PROTECTEUR. Photo credit: DRDC.*

Cables from this new array were run ashore at Gascoyne Inlet, and Navy divers trenched the cables into the bottom in an attempt to protect them from the destructive action of the ice. As before, the data was transmitted to Resolute Bay (NU) via the silo repeaters.

Studies of Barrow Strait, Viscount Melville Sound and M'Clure Strait (Figure 79 on page 101) continued until 1979, with a different location being occupied every spring. As before, ambient noise and propagation losses were measured. In addition, the acoustic properties of the bottom were studied in order to help explain (and model) these propagation losses. As an example of this work, the Canadian Science Ship (CSS) HUDSON did an air-gun reflection survey in 1976 to determine the compressional and shear velocities of the bottom. Also measured was the spatial signal coherence from both stationary and moving sources. This measurement helped to predict the "gain" that an array of hydrophones might provide. Although all the scientists were interested, Gary Brooke was most involved with this modelling work.

After 1975 the work at Gascoyne Inlet was sporadic. In spite of a nice hook of land that "should have" protected the cables from ice pressure, the cables turned out to be quite vulnerable, and they were in frequent need of repair. In the fall of 1983 the CCGS SIR JOHN A. MACDONALD brought Navy divers to Gascoyne Inlet, and they repaired (and reburied) the cables that went across the shoreline. Then, in 1985, when the cables again needed repair, a different approach was attempted.

A drill rig—usually used in the mining and oil business—was flown to Gascoyne, and a slanted hole was drilled from a spot reasonably high on the shore (Figure 93). The intention was for the drill to punch through the sloping bottom and to enter the water at a point that was deep enough that the cable would be protected from ice scour.

Figure 93: *Drill rig drilling slanted hole at Gascoyne Inlet. The hole passed through the gravel and rock and entered the water through the sloping bottom. Photo credit: DRDC.*

The project did not go as smoothly as was hoped. Drilling continued long after the ocean bottom should have been reached. Reluctantly, Dave Baade, who was supervising the project for DREP, came to the conclusion that the drill stem was bending under its own weight, and the drill path was under the Inlet's bottom. To make matters worse, time was running out, and something had to be done quickly.

He decided to drill a much shorter hole, one that would give the drill stem less time to bend down out of the intended path. To do this, they moved the drill rig down to a lower "bench," closer to the water, and they aimed the drill to penetrate the bottom at a depth that was not quite as deep as had been originally planned. The new hole was drilled quickly and without a hitch. A bobbin, pulling a string, was "blown" down the pipe with a flow of water, and the buoyant bobbin floated to the surface. The string pulled a heavier rope through the pipe, and the rope pulled the cables (Figure 94).

This technique for protecting the cables as they crossed the shoreline worked very well, and the hydrophone system kept operating until the end of the Cold War—when it was declared superfluous.

Figure 94: *The shore end of the pipe that is casing the hole. This picture was taken in 2009. Photo credit: DRDC.*

At the request of DMCS (Director of Maritime Combat Systems), the Gascoyne Inlet system was abandoned in the early 1990s, and the "silo" repeaters were taken to Resolute Bay for storage. Gascoyne Inlet was not used again until "global warming" and "thinning Arctic ice" became hot political topics and the Arctic was "rediscovered" late in the first decade of the 2000s.

8.2.3.3 Jones Sound—The Middle Passage, Grise Fiord

The third submarine route through the Arctic Archipelago is through Jones Sound (Figure 79 on page 101). Of the three major routes, this one was given the least priority, presumably because the narrow channels and very high currents in the western reaches of Jones Sound were dangerous to a submarine. Nonetheless, appreciable time, effort, and money were spent studying the acoustic properties of the Sound, enough so that an effective detection system could be designed—if and when desired.

There were two possible locations for a chokepoint detection system: one was across Fram Sound (NU), and the other was across Jones Sound south of Grise Fiord (NU) (Figure 95). Fram Sound has the advantage that it is narrow. On the other hand, the currents through Fram Sound are very high, and the weather is frequently foggy because of nearby open water (caused by the high currents). Moreover, the location is very remote from any human habitation, and this makes maintenance very difficult.

The town of Grise Fiord (NU), at the eastern end of Jones Sound has people, better weather, and an established air-strip. Also, the water currents are much smaller. On the other hand, it has the disadvantage that the Sound is much wider at this point, and this would mean a longer and more expensive detection installation. Also, there are no readily available places to bring cables ashore. The sea is very shallow for at least a kilometre off the town, and ice sits on the bottom for most of the winter and spring. Just north of the town, where the fiord begins, the water is much deeper, but the cliffs come right down to the sea, so this location is not cable-friendly either. On balance, however, it was felt that the problems of the Grise Fiord area could be solved more easily than those of Fram Sound.

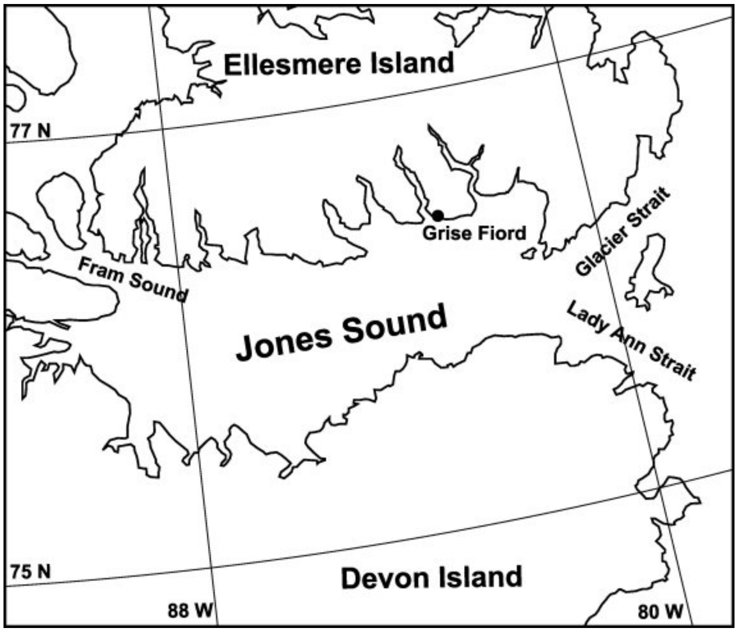

Figure 95: *Jones Sound—the middle passage through the archipelago.*

A preliminary investigation into the use of Grise Fiord began in the spring of 1974. While the Gascoyne Inlet camp was being built, Ron Verrall took a short break to visit Grise Fiord and the Royal Canadian Mounted Police (RCMP) officer who lived there. They discussed possible routes for cables, both in the water and over the fore-shore. Poles were suggested for carrying the cables above ground, but the Mountie warned that high winds occasionally sweep through the town. He pointed out that the village church had been blown down twice. Also, they discussed the possibility of using one of the RCMP buildings to house recording packages.

On the way back to Resolute Bay, Verrall did a quick reconnaissance of Fram Sound. The aircraft landed at the Bay of Woe, which is on the north shore of the Sound. This bay had been identified as the most likely location for bringing cables ashore should the Fram Sound area be chosen as the array site. Harold Serson, of DREO (the Ottawa Defence Lab), was already there doing a bathymetry survey and measuring currents. He confirmed that the bathymetry was quite suitable for bringing cables ashore, but he also confirmed that the weather was generally foul.

As the Twin Otter was leaving the Bay of Woe, it exhibited some very unusual bad manners for such a lovely airplane. One of its ski-wheels snagged the small steel cable that Serson was using for his bathymetry and whisked it away from him and his assistant. Luckily, the cable wasn't attached to anything, and no-one was hurt. The occupants of the aircraft knew nothing of this until they arrived at Resolute and found about 200 metres of eighth-inch steel cable trailing out behind the Otter. Fortunately, Serson had a spare line.

In the fall of that year (1974), on the exercise known as "NORPLOY 74," the HMCS PRESERVER laid three hydrophones at various locations in Jones Sound south of Grise Fiord and ran cables ashore to recording packages mounted in the RCMP building. They then dropped a series of explosives in order to measure acoustic propagation to these hydrophones. Ambient noise was recorded until the precariously placed cables failed later in the year. This was the first serious attempt at measuring the acoustic parameters of Jones Sound. In the spring of 1976 an ice camp was set up on Jones Sound, and the propagation-loss measurements were repeated, this time under conditions of continuous ice cover.

In the fall of 1981 a more permanent installation was attempted. By then it was realized that bringing cables ashore at the town of Grise Fiord was virtually impossible. Instead, the cables were brought ashore at a cluster of small rocky islands about six kilometres west of the town of Grise Fiord (NU) (Figure 96), and the data was telemetered (via VHF) to the town. This collection of two or three small islands was not named on the map, so, out of operational necessity, it was given a name. It was called “Fantasy Island” after a TV series that was popular at the time.

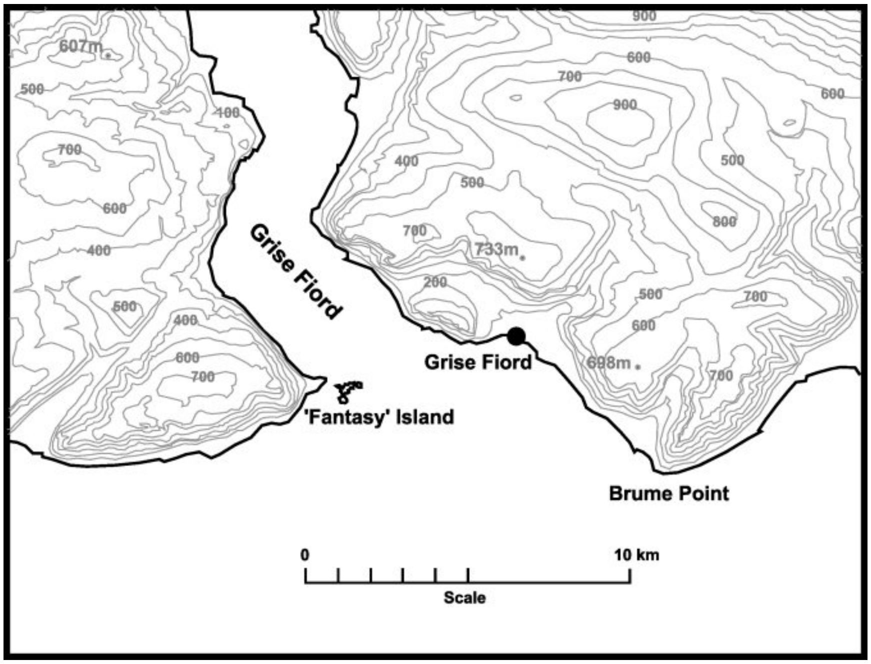

Figure 96: *Grise Fiord—both town and inlet. Cables were brought ashore at “Fantasy Island” in 1981.*

In preparation for the cable installation, a couple of small wooden buildings were built on the island to house the electronics and the batteries and to provide (primitive) living conditions for the scientists and technicians (Figure 97 on page 118). A radio telemetry link was established between the island and a small DREP building in the town of Grise Fiord, and a suitable recording station was set up in this hut. This represented quite a lot of work, and it was done in a remarkably short time. The people involved were Jon Thorleifson, Matt Schmidt, Francis Lai, Richard Anderson, Bob McLean, and Ken Ashcroft.

Once the shore preparations were made, the CCGS SIR JOHN A. MACDONALD laid an array of five hydrophones at 76°16’N, 83°16’W and cabled them to shore at Fantasy Island. At the shoreline the cables were trenched into the rock and gravel by Navy divers in order to protect them from the destructive action of the ice. The divers used explosives and high-pressure water for this work.

Once the system was connected and working, the team on the SIR JOHN A. then did a sound propagation measurement—dropping explosives at 19 locations. This work lasted from 15 September to 22 September. Of the five hydrophones laid, only two were operational, but they worked until the late summer of the following year (1982).

Figure 97: *One of the buildings on Fantasy Island. The background shows the steep cliffs on the other side of the fiord. The town of Grise Fiord is to the right of the cliffs. Photo credit: Steve Taylor.*

This “shot run” during the fall of 1981 measured acoustic propagation when the Sound was free of ice. For comparative purposes, a similar set of measurements was made in the spring of 1982 when the Sound was completely covered with ice.

As mentioned above, the system failed during the fall of 1982. A year later a team on board the CCGS SIR JOHN A. MACDONALD returned and repaired the cables, both at Jones Sound and at Gascoyne Inlet. That was the last time that substantial work was done at either of these locations. Interest had switched to the far north.

8.2.3.4 Arctic Sub-surface Surveillance System Project

The story of the chokepoints would not be complete without a mention of the Arctic Subsurface Surveillance System (ARCSSS) Project. In 1987 the White Paper on Defence [49] made it clear that the Canadian government was concerned about Arctic sovereignty. In its conclusion it said, “For example, Canada’s capacity for surveillance and enforcement could be enhanced through…the development of underwater listening posts, or … ”

As an outcome of the White Paper, a Defence Services Contract was put in place to develop an Arctic Subsurface Surveillance System. Two consortia were awarded partially-funded requests for proposal. One was headed by MacDonald Dettwiler and Associates (MDA) of Richmond, BC, and the other was headed by Litton Industries. They were each to study the problem and come up with a workable solution, complete with a costing. The winner would install the system, and that is where they would make their profit. The studies and the competition were supervised and judged by the Director of Maritime Combat Systems (DMCS). DREP supplied both consortia with its knowledge of the underwater acoustics and the physical environment at all three locations.

It is generally considered that MDA won the competition, but the estimated installation costs were very large, especially at the Robeson Channel chokepoint. Moreover, in 1994 when the study came to fruition, the Berlin Wall had been down for five years, and the perceived threat was waning. Consequently, the Department found itself short of funds, and the project was shelved.

8.2.4 Looking out into the Arctic Ocean

8.2.4.1 Introduction

After a decade of research at the three chokepoints, the authorities decided that enough was known about these regions that detection systems could be built if and when the military decided they were necessary. The next step was to investigate the northern approaches to the archipelago. It would be advantageous, so the thinking went, to be able to detect submarines before they entered the archipelago. Moreover, it was hoped and expected that the sound propagation in the deeper waters of the Arctic Ocean would be better than that in the shallower channels, and this might well mean that the submarines could be detected at large distances from the shore.

Two immediate questions were, “Where does one put the hydrophones so that they can ‘see’ out into the Ocean?” and “How does one get the data back to a shore site for recording, analysis, and further transmission to the south?” The simplest solution was to lower hydrophones through the very thick ice of the ice plugs and ice shelves that line the north coast of Ellesmere Island, the archipelago’s most northerly island. From this heavy, unmoving ice the data could be telemetered to a shore site.

The north coast of Ellesmere Island, as shown in Figure 98, contains many long inlets and fiords, and most of these inlets are plugged with very thick ice which does not move from one year to the next. At that time the northern half of Nansen Sound contained what was called “plug ice.” It was 5.5–6 m thick, and it was locked in place by the surrounding land. About 0.5 m of the ice surface melted every summer, and the same amount froze to the bottom of the ice sheet every winter. Other inlets contain much thicker ice, and these large bodies of ice are called “ice shelves.” The Ward Hunt Ice Shelf in Disraeli Fiord, for example is about 45 m thick, and the ice in Milne Fiord ranges in thickness from 10 m to 100 m. Many of the smaller bays, not named in Figure 98, contain ice that is similar to the ice in Nansen Sound—about 5 to 6 m in thickness. This ice is known as multi-year landfast sea ice (MLSI). Since all this ice is permanent (or, at least, relatively permanent), any of these plugs or shelves could support hydrophones. As well as being unmoving, these massive chunks of ice have the further advantage of being a bulwark against the grinding and crushing action of the polar pack ice. The problem of bringing cables ashore across a very dangerous interface does not exist here.

Figure 98 indicates the various field camps that DREP established during the years from 1980 to the mid 90s. The numbers (in red) are each matched by an entry in Table 2, which gives a short description of the site, its location, and the year (or years) that it was used.

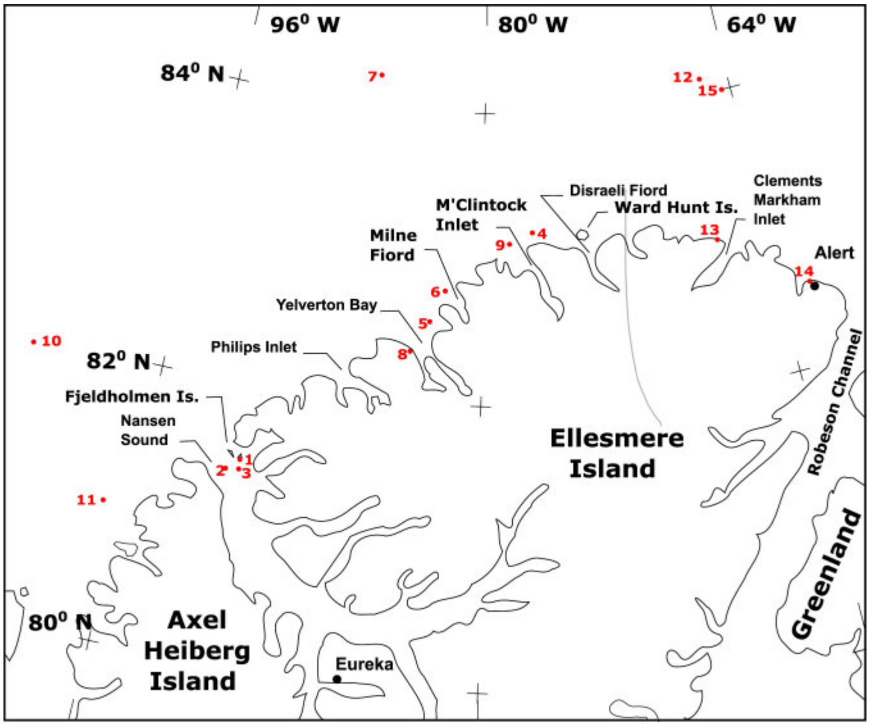

Figure 98: *A map of the north coast of Ellesmere Island showing the major bays and inlets. Most of these inlets contained ice that was thick and permanent. (Some—but not all—still do.) The red numbers correspond to DREP field camps and other relevant sites along the north coast of Ellesmere Island. See Table 2 for descriptions of each site.*

Table 2: *Field Camps, etc. along north coast of Ellesmere Island. The number in the left-hand column has a corresponding number in Figure 98.*

No.	Description	Year(s)	Coordinates
1	Camp on Fjeldholmen Island	1980–1989	81°29'N, 91°38'W
2	First acoustic array on plug ice of Nansen Sound	1980–1985	81°25'N, 92°25'W
3	Second acoustic array on plug ice of Nansen Sound	1986–1989	81°26'N, 91°53'W
4	Building on Ward Hunt Ice Shelf	1982–1983	83°05.8'N, 76°36.6'W
5	Yelverton Ice Camp (data telemetered to shore)	1983–1984	82°34.3'N, 82°51'W
6	Ice camp on heavy ice of Milne Fiord	1983	82°43.7'N, 82°03'W
7	Ice camp on Arctic Ocean	1983	83°13'N, 87°05'W
8	Yelverton Bay Shore Camp	1983–1984	82°21.5'N, 83°56'W
9	Ice camp on northern edge of M'Clintock Ice Shelf	1984	83°01.5'N, 77°58'W
10	Ice camp northwest of Nansen Sound	1986	81°55'N, 102°30'W
11	Hobson's Ice Island, suitably located to give assistance to ice camp	1986	81°07'N, 96°47'W
12	Ice camp about 100 km north of Ellesmere Island	1987	84°04.5'N, 66°54'W
13	Stuckberry Bay shore site (east of Stuckberry Pt.)	1989–1994	82°55.6'N, 66°40'W
14	Jolliffe Bay	1993–1996	82°30.8'N, 62°41'W
15	Spinnaker Array Site	1996–1998	84°N, 66°W approx.

8.2.4.2 Nansen Sound

The first and most concerted effort of any of the far-north installations was at the mouth of Nansen Sound (NU). The plug ice was thick (5.5 m) and unmoving, but it was thin enough that a mechanical drill could go through it. Also, the water is fairly deep (500 m) at the mouth of the sound, which is good for sound propagation. Finally, Eureka (NU), the weather station, was sufficiently close that the logistics were quite manageable.

In 1980 a camp was established on the smaller of the two Fjeldholmen Islands (Figure 99 and Location No. 1 in Figure 98 on page 120). Holes for a 10-hydrophone array were drilled through the ice at a spot 14 km WSW of the island (Location No. 2 in Figure 98), and the data was telemetered back (via VHF) to the shore camp on the island.

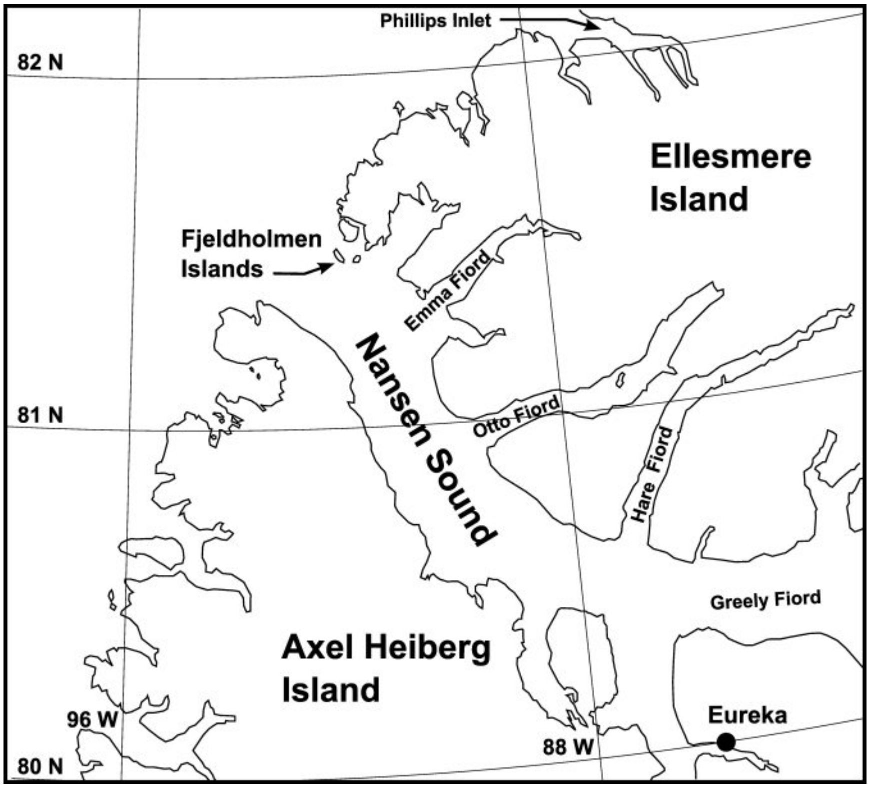

Figure 99: *Map of Nansen Sound. The DREP camp was established on the smaller of the Fjeldholmen Islands. It is also shown as Location No. 1 in Figure 98.*

A small building was set up on the ice to hold the electronics and the batteries, and to act as a terminus for all the cables coming from the hydrophones (Figure 100 on page 122). The building was set on wooden piles drilled into the ice. The reason for this form of suspension was that the ice surface melts every summer, and if the building were not supported on pilings it would get wet, and, moreover, it would take on a list as its support melted out from under it. Figure 100 shows what happens as a result of a summer's melt. The water flows down cracks in the ice, and the building is left perched high above the ice. For this reason the building was made so that it could be lowered down on the posts. When necessary, the posts could be melted out with a hot-water drill and set lower in the ice.

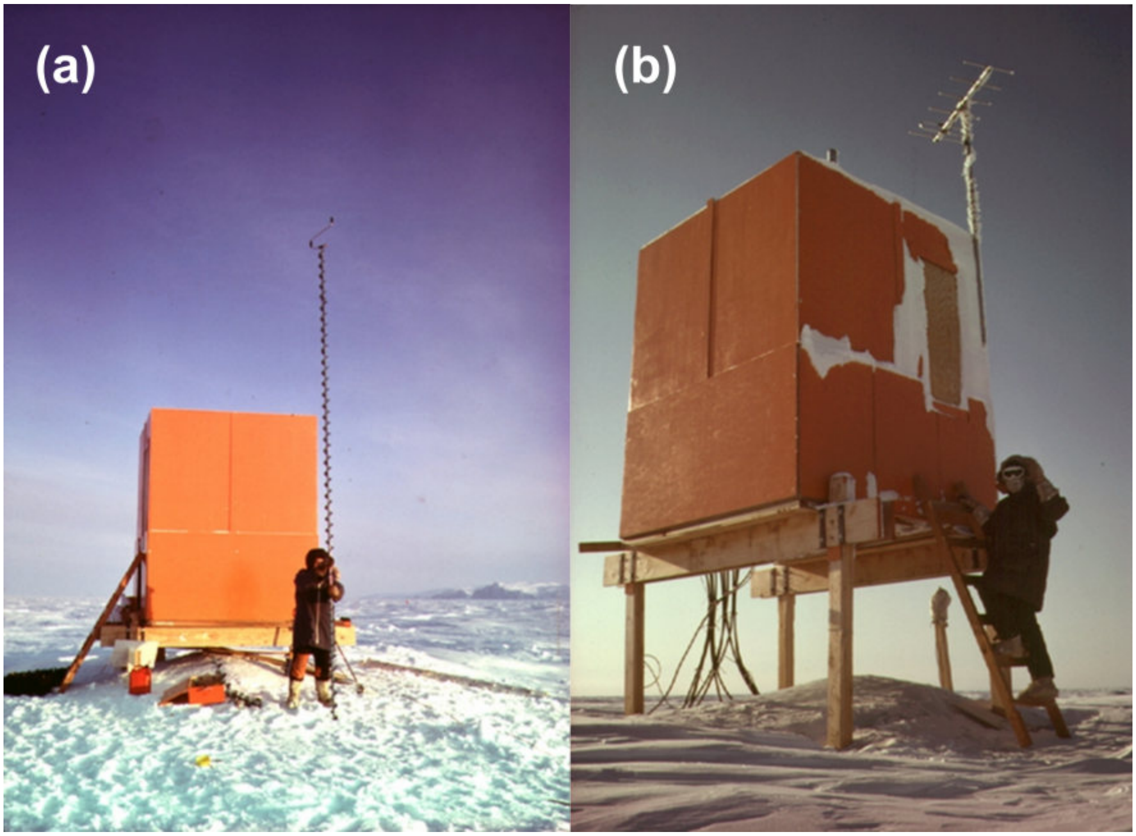

Figure 100: *Battery hut on the ice of Nansen Sound. (a) The auger indicates the thickness of the ice. (b) A year of surface melt has dropped the ice away from the building. The cables from the hydrophones are visible, as is the VHF antenna sending data to the shore camp. Photo credit: DRDC.*

Figure 101 shows two of the three buildings at the shore camp. One building was a kitchen hut, and the other was the electronics (science) hut. Both contained bunks for sleeping. The third building (to the left of the picture) was a small shelter for a diesel-electric generator.

Interest was maintained in the Nansen site for many years, even as several other coastal sites were investigated. Acoustic transmission losses were measured along several paths out into the ocean, and ambient noise measurements were made on a continuing basis.

In the summer of 1985 the battery hut out on the ice fell down. There had been an unusually strong summer's melt, and the pilings were no longer rigid enough to take the twisting loads (Figure 102).

From the shape of the moat around the building, it was evident that the building had absorbed the heat of the sun and then had re-radiated its heat to assist with the natural melting of the ice. Moreover, the whole Nansen ice plug had loosened up, and, although the individual ice chunks had not moved very far, they had moved some, and they had rotated.

In the following spring (1986) a new hydrophone array and building were installed not too far from the previous one (Location No. 3 in Figure 98 of page 120.) This time the building was painted almost entirely white in hopes that it would not heat up so much, but this turned out to be wishful thinking. An

Figure 101: *Two of the three buildings at the Fjeldholmen Island shore camp. Photo credit: DRDC.*

inspection trip in 1988—after the main field trial in Alert—revealed that it, too, had suffered from loose pilings and had collapsed. It was re-leveled and stabilized once again.

The Nansen site fell out of use soon after 1988. It was then abandoned until 1996, when a clean-up of the shore camp was started. Two of the three buildings were taken down and burnt, and all metal objects (stoves, generators, barrels, etc.) were flown out to Eureka (NU). This job took several years of off-and-on work. It was not finished until 1998. The plug ice, itself, vanished sometime around 2000. The Sound is now filled with one- and two-year ice.

8.2.4.3 Ward Hunt Ice Shelf

The next location that was investigated as a possible hydrophone site was the Ward Hunt Ice Shelf. The Shelf is a sheet of ice about 45 m thick. It is attached to the land and extends from slightly east of Ward Hunt Island westward almost to M'Clintock Inlet (Figure 103). Its north-south width is approximately 13 km. Maps made in the 1950s show the Shelf as being bigger in both length and width than it was in the early 80s. Since then it has continued to decrease in size, this break-up usually being attributed to climate change.

Figure 104 shows the undulating surface of the Shelf in the foreground. The rough ice on the left of the picture is the Arctic pack ice. Although the pressure of the pack can be enormous, it is not enough to affect the extremely thick ice of the Shelf. It is this solidity that makes the Shelf a safe platform from which to hang a hydrophone. Other pictures of the Ward Hunt Ice Shelf can be found in Figures 2 (page 6), 5 (page 10), and 106 (page 126).

Figure 102: *Battery hut after its supporting structure had collapsed. Photo credit: DRDC.*

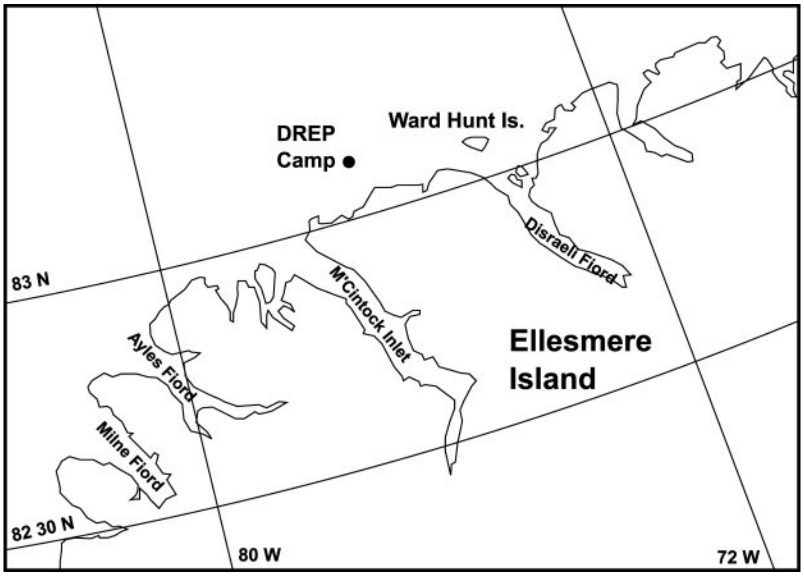

Figure 103: *A section of the north coast of Ellesmere Island including the region of the Ward Hunt Ice Shelf. The DREP camp—established in 1982—was at the outer edge of the Ice Shelf.*

In 1982, an airplane-load of building materials and other freight was dropped by parachute onto the Shelf from a military CC-130 (Hercules). Unfortunately, because of bad weather, the DREP people had not

Figure 104: *Looking east along the northern edge of the Ward Hunt Ice Shelf. The scale of the Shelf's rolls is deceiving. The wavelength of the rolls is typically 200–300 m, and the peak-to-trough vertical extent is 3–6 m. The edge of the Shelf and the Arctic pack ice to the north can be seen at the left of the picture. Ellesmere Island is in the background and to the right. Photo credit: DRDC.*

yet arrived at the Ice Shelf to mark the spot where they wanted the drop. The result might have been a disaster, but the Hercules pilot did a good job of choosing a spot, and the camp was built right where the freight landed. The camp site is shown in Figure 103 and as Location No. 4 in Figure 98 (page 120). It was a little less than 1 km south of the northern edge of the Shelf.

A prefabricated building was put together and supported on pilings, just as had been done in Nansen Sound (Figure 105). The new building was substantially bigger than the ones at Nansen, with provision for a cooking and eating area as well as room for all the electronics.

The biggest problem in the operation was drilling a hole through the 45-metre-thick ice. (For comparison, 45 metres is the approximate height of a 15-story building.) A hot-water drill designed for this purpose had been built but only briefly tested. Problems remained, and a lot of innovation and several exhausting days were needed to make a hole for a single hydrophone. Needless to say, the drill was modified substantially for the next field season. An account of this drilling can be found in Reference [50].

A hydrophone was lowered through the hole into the ocean below, and explosives were dropped from a Twin Otter at a number of ranges north of the Ice Shelf. The sound propagation was poorer than had been expected, and the ambient noise was louder. These were disappointing results. However, the hydrophone was left in place to be used for further measurements the following year.

As a matter of interest, Figure 106 shows the Ice Shelf and the building as it looked late the following summer.

Figure 105: *A building under construction on the Ward Hunt Ice Shelf. Note that the pilings supporting the building are sitting on top of the ice. They were melted down into the ice later. Photo credit: DRDC.*

Figure 106: *The Ward Hunt Ice Shelf in late summer. The red DREP camp building, which can be seen mid-picture, gives some scale to the size of the rolls. The troughs are filled with refrozen melt-water. Photo credit: DRDC.*

8.2.4.4 Yelverton Bay

The following spring (1983) a camp was built on the ice of Yelverton Bay (NU) at 82°34.3'N, 82°51'W (Location No. 5 in Figure 98 on page 120). The ice here was not Shelf ice. It was only 6 m thick—more in the nature of multi-year landfast sea ice. Two prefabricated buildings were assembled and supported on pilings. One was for accommodation and for the electronics, and the other was to house a specially-quietened diesel-electric generator.

Two temporary (tent) camps were also established, one on Milne Fiord (last remaining epishelf lake), and the other 40 nautical miles north of Yelverton (Locations No. 6 and No. 7 in Figure 98, page 120), and the Ward Hunt camp was again occupied. The reason for all this activity was to take advantage of some very large explosions that were to be set off by the CESAR (Canadian Experiment to Study the Alpha Ridge) experiment. The CESAR scientists, with the help of the military and four Hercules loaded with equipment, set up a camp on a long refrozen lead at 85°56'N, 112°35'W. In order to investigate the nature of the earth's crust at this location they detonated many explosions, the largest of which was 454 kg (1000 lb). These shots were recorded at all four DREP sites.

In order to be able to record the hydrophone signals during the summer and fall, a radio link (VHF) was set up between the ice camp and a small (one-hut) camp placed on a high ridge on the west shore of Yelverton Inlet (Location No. 8 in Figure 98 on page 120). This telemetry link was very similar to the one in Nansen Sound between the ice camp and the shore camp at Fjeldholmen Island. Ron Verrall and Ken Ashcroft occupied the Yelverton site in August 1983, while Jon Thorleifson and Jim Perkins went to the Nansen Sound camp to record the passage of an underwater source.

The spring of 1983 was also unusual for the large number of aircraft mishaps. The Canadian Hydrographic Service (CHS) was doing a bathymetry survey in nearby Phillips Inlet, and two of their helicopters had accidents. Although the machines were badly damaged, the injuries to the occupants were fairly minor. A third helicopter en route to the Arctic ran out of fuel and had to be rescued on the Boothia Peninsula. A fourth helicopter was skewered by a fork-lift in Resolute Bay. The military Twin Otter that was assisting the DREP people to set up the remote camp landed on old ice that had a rolling surface, and, just as the aircraft was coming to a stop, the fuselage at the rear of the plane touched an ice chunk. The metal cladding was ripped, and a strut that held a guide pulley was bent slightly. The pilot decided that the better part of valour was to call for a rescue, which was promptly executed by two helicopters from the CHS camp. The final mishap occurred to the military helicopter that was sent north to repair the damaged Twin Otter. The pilot was perhaps not sufficiently experienced with Arctic flying, and he set the helicopter down at the Yelverton camp without bouncing it sufficiently hard to test the strength of the snow crust. As its main rotor slowed, the increased shaking caused the skis to break through the crust. This tipped the helicopter backward, dropping the spinning rear propeller to a point just short of the ground. Nothing was damaged, but the participants were rather horrified at what might have happened if the rear propeller had dropped a little further. Several hours were spent shovelling the helicopter level again.

The Yelverton ice camp was used for two years. Then, sometime during the fall of 1984, the Yelverton ice sheet, which had not moved for at least 40 years, broke up, and the camp and its contents floated away. The camp's position was reported by an Argos satellite transmitter that had been established at the camp for the purpose of sending back ambient noise data. Also, an overflying Twin Otter spotted the camp in the spring of 1985, and, with the help of the OMEGA navigational system, determined its latitude and longitude. In May, a two-person salvage and clean-up expedition from DREP (R. Verrall and J. Perkins), with the aid of a helicopter, found the runaway camp (on two separate pieces of ice). All equipment that could be carried by helicopter was taken back to the Yelverton shore camp.

8.2.4.5 Other Locations Off the North Coast of Ellesmere Island

In April 1984 M'Clintock Inlet was investigated as a possible detection site (Location No. 9 in Figure 98 on page 120). A tent camp was set up on the thick ice about 300 m from where the land-fast ice ended and the pack ice began. The experiments included the measurement of propagation loss necessitating the recording of signals from sources at varying ranges from the receiver.

By this time, interest in the heavy sheets of ice attached to the Ellesmere coast was waning. This was partly because most of the principal locations had been investigated, and their acoustic characteristics were known, but it was also because these sites did not provide the coverage that had been anticipated. The propagation losses were higher than expected, and the ambient noise levels were nowhere near as low as they were in the channels of the archipelago. Interest was slowly switching to sites that were much further off-shore.

The first such investigation, in 1983, was 40 nautical miles north of Yelverton. The work at this location, no. 7 in Figure 98 on page 120, is mentioned above. The next site, in 1986, was about 90 nautical miles northwest of the mouth of Nansen Sound (Location No. 10 in Figure 98 page 120). It was the most westerly of all the northern Ellesmere sites investigated by DREP. Its location was partly driven by the fact that the Ice Island, Hobson's, was just west of Nansen Sound (Location No. 11 in Figure 98) and was occupied by the Canadian Hydrographic Service. Advantage was taken of the logistics help that could be provided.

A long-range shot run (out to 400 nautical miles) was carried out. Large, 60-lb (27.3-kg) Geogel explosives were used as the sound sources.

In 1987 a camp was set up on the ocean about 130 km northeast of Ward Hunt Island (Location No. 12 in Figure 98 on page 120). This location was at the edge of the continental shelf where the depth increases relatively quickly from about 500 m to about 2000 m. Large (60-lb or 27.3-kg) Geogel charges were again used to measure propagation losses. It was anticipated that this would be a good place to put an acoustic detection system since sound propagation from the deep ocean to the edge of the shelf was expected to be good. Nine years later the SPINNAKER array was, in fact, placed quite close to this spot.

8.2.5 Project SPINNAKER

Interest in placing a detection system well offshore started in 1983 with propagation measurements at an ice camp approximately 80 km north of Yelverton Inlet (Location No. 7, Figure 98, page 120). Tentative surveys continued in 1986 and 1987 with offshore ice camps. These surveys are described above.

In 1988 collaborative work began with American scientists from the Naval Research and Development Center (NRaD) in San Diego, CA, and this work continued for the next decade. Both countries were interested in the general problem of putting detection systems in deep Arctic waters—where the usual shipborne method of laying cable was quite impractical, if not impossible. New techniques had to be developed.

The group had two major engineering tasks to complete—tasks that had never been attempted before. The first was that of deploying a large array of hydrophones on the ocean bottom from an ice surface that was by no means stationary. The other was that of laying a cable between the hydrophones and the shore in an ocean that was completely covered with ice.

After several years of joint acoustic work north of CFS Alert, a formal project was initiated in 1992. This joint Canadian-American project was to lay a large array of hydrophones on the ocean bottom at the edge of the continental shelf—at approximately 84°N, 65°W, about 180 km from CFS Alert—and to bring the data back to Alert on a fibre-optic cable.

The undertaking was known as "Project SPINNAKER," named after a popular brew-pub in Victoria (BC) at which some of the first planning meetings were held. The work was divided into two main tasks. The Americans would design, build, and deploy the hydrophone array, and they would look after multiplexing the signals together and building the optical driver that powers the fibre-optic cable. The Canadians would be responsible for laying a 2-mm-diameter fibre-optic cable between the array and the shore. And, of course, both groups would help each other in any way they could, the problems of logistics being a particularly important joint item.

Jon Thorleifson of DREP headed the Canadian contingent, and Barbara Sotirin of NRaD led the American team.

DREP gave a contract to International Submarine Engineering (ISE) of Port Coquitlam (BC), to build an autonomous underwater vehicle that could "fly" underwater, close to the bottom, and lay the 2-mm cable.

ISE, in close cooperation with DREP, spent the next several years in designing and building such a vehicle. They had to concern themselves with power supply, navigation, obstacle avoidance, protection of the electronics from sea water, storage and deployment of 200 km of fibre-optic cable, maintenance of proper buoyancy as hundreds of pounds of cable left the vehicle. In addition, the vehicle had to be dividable into segments—like a worm—so that a helicopter could carry it in pieces out onto the ice. The vehicle was named "THESEUS" after the Greek hero who laid a string into the centre of the labyrinth at Knossos. THESEUS, with a displacement of 10 tonnes, remains the world's largest autonomous underwater vehicle (AUV) to date.[2]

One of the concerns was the problem of where and how to bring the cable ashore. The general problem of "where" came first. For a few years the planning proceeded on the assumption that the available laser cable-drivers were not powerful enough to drive the necessary 180 km of fibre-optic cable. This meant that the cable could not come ashore at Alert (NU); it had to be brought ashore somewhere closer to the hydrophone array. Stuckberry Bay, which is about 65 km northwest of Alert, was chosen as the landing spot (Figure 107 and Location No. 13 in Figure 98 on page 120). The Bay was full of multi-year landfast sea ice which would protect the cable from the destructive pack ice. From Stuckberry Bay, the data would be telemetered to Alert via microwave with a repeater at Mary Peak (NU). Interest in Stuckberry lasted from 1989 to 1994.

Fortunately, from the point of view of simplicity, reliability, and economy, the fibre-optic drivers became more powerful, and several years into the project it was realized that the cable could, indeed, come all the way to Alert, and a repeater would not be necessary. At that point all interest in Stuckberry Bay vanished.

The next concern was "how" to bring the cable ashore. Experience had taught DREP that this was a very crucial problem, and that failure to address it properly would result in the cable's being crushed, ripped out, and destroyed by the ice. The general consensus was that the only safe way to bring it across

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[2] Editor's note: in the last decade this largest AUV record has fallen. Larger AUVs are becoming increasingly common today.

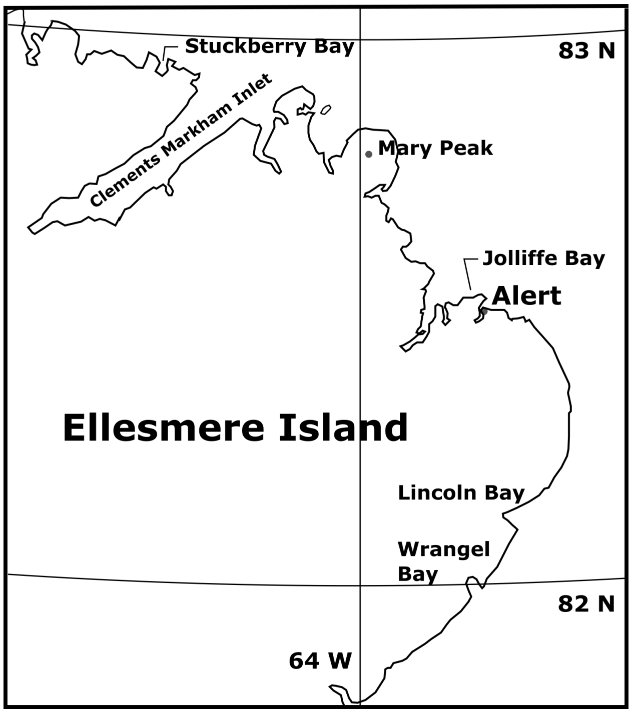

Figure 107: *Map showing the location of Stuckberry Bay and Jolliffe Bay.*

the dangerous fore-shore was to drill a curved hole from up on the land through the rock to a point on the ocean floor that was well below the deepest keels of the pack ice. It takes bedrock to keep cable safe from the ice.

Several sites in the neighbourhood of Alert were investigated. The off-shore water depths had to be suitable, and the rock had to be "competent" (capable of holding its shape after the drill passes through it). In 1993 test holes were drilled at likely spots to test the quality of the rock. Jolliffe Bay (NU) had the best all-round features, and it was chosen as the spot to bring the cable ashore. See Location No. 14 in Figure 98 on page 120.

In 1994 Foundex Ltd. drilled a curved hole through the rock from a point well up on the shore of Jolliffe to a point at the bottom of the bay. The depth here was about 35 m, well below (and safe from) the keels of the pack ice in the area. A fibre-optic cable was fed through this hole in preparation for the main cable-lay in 1996. An informal description of the drilling project can be found in Reference [51].

In 1995 a dress rehearsal was held at Alert and Jolliffe. A very large tent was set up on the ice of Jolliffe Bay, and inside this tent about 31800 kg of ice was removed to make a slot for the vehicle (Figure 108). THESEUS was taken out to the ice in sections and put together. After several days of preparation, it was sent off on a short cable-laying trip. Everything went well, and THESEUS returned safely—to the relief of all concerned.

Meanwhile, the Americans had spent much time and effort learning to build small, energy efficient hydrophone packages that would work for roughly three years on just a few small batteries. They also perfected their technique of laying a large, complicated array of hydrophones under pack ice that might not be stationary. And, to send the data from all these hydrophones to shore, they built an optical cable

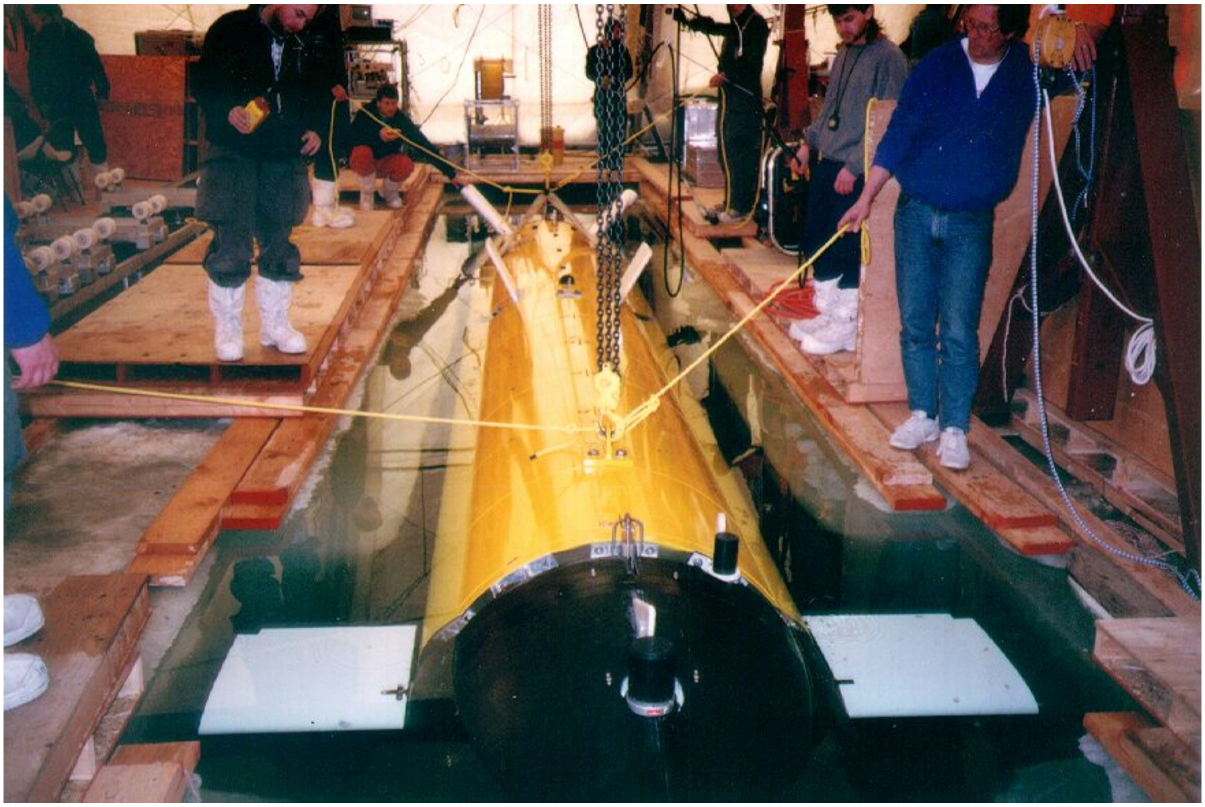

Figure 108: *The cable-carrying vehicle, THESEUS, sitting in a hole made through the ice of Jolliffe Bay. The slot is 40 ft (12.2 m) long and 4 ft (1.2 m) wide at its narrowest. The ice is 5.5 ft (1.7 m) thick. THESEUS is being readied to head off on one of its long cable-laying trips. Photo credit: DRDC.*

driver that handled the full 180 km with plenty of reserve signal. It was powered by canisters full of D-cells. Their whole system worked well.

The next year (1996) was the year of the grand performance. The camp was set up again, another slot was cut through the ice, and THESEUS was again made ready. The Americans deployed their array from the ice (Location No. 15 in Figure 98, page 120), and prayed that the ice would stay stationary until THESEUS arrived with the cable. After a few days of unexpected (and nail-biting) delays, THESEUS left Jolliffe, and 24 hours later it delivered the cable to the waiting (and still stationary) ice camp. THESEUS's cable was cut and spliced to the Americans' array cable, and THESEUS returned (completely autonomously) to the camp at Jolliffe [52].

The hydrophone system worked flawlessly for about three months, and then it failed. It turned out that the problem was with the cable. It had broken in a number of locations. The two following springs (1997 and 1998) were spent finding and fixing breaks. Unfortunately, the cable was never completely repaired. Moreover, no definite reason was ever found for the cable's propensity to break [52].

This project signalled the end of DREP's acoustic work in the Arctic. The lab had been officially closed in 1995, and the SPINNAKER work had been done under the auspices of the Halifax lab, DREA (now called DRDC – Atlantic Research Centre). The Arctic group then broke up, some going to DREA or DREO to work on other defence projects, but most finding positions elsewhere. They were given to understand that Canada would have no interest in the Arctic in the foreseeable future [53].

8.3 Electromagnetic Research in the Arctic

8.3.1 Introduction

During World War II the magnetic nature of a ship was sometimes the agency of its destruction. A large chunk of steel, such as a ship or a submarine, affects the magnetic field around it, and the changing field produced by a passing ship can be detected by a suitable sensor. During the war a common scenario was a ship passing over a mine that was sitting on the bottom of a harbour or a shallow channel. The mine detected the changing magnetic field and detonated.

This effect was studied actively after the war. On the one hand, people wanted to be able to detect ships reliably and at greater and greater ranges, and, on the other hand, they wanted to be able to shield their ships so that they could not be detected.

Much of the early work at PNL (later DREP) involved detection. A big problem was the background noise that masked the desired signal of a passing ship. This noise is predominantly due to naturally occurring electromagnetic phenomena such as the fluctuations of the earth's magnetosphere. In 1955 Sir Charles Wright was hired under contract to help PNL scientists investigate some of these effects. Sir Charles was an able and enthusiastic physicist and administrator who is best known, perhaps, as a participant in Captain Robert Scott's ill-fated expedition to the south pole.

It was realized quite early on that much of the observed background noise was world-wide in its extent. Electromagnetic signals at one location were often matched closely by signals observed thousands of kilometres away. Some of the fluctuations were caused by world-wide lightning, and some originated from mechanisms that also cause the aurora. The Arctic connection in this early work was the 1961 "Conjugate Point Experiment" in which electromagnetic fluctuations at Great Whale River in northern Quebec were compared with fluctuations at Byrd Station in Antarctica, these two locations being at opposite ends of one of the earth's magnetic lines of force. It was found that the signals were strongly correlated in spite of the enormous distance between the two stations.

From this work DREP scientists developed techniques that would significantly reduce the interfering "noise" in a magnetometer. Using one or more sensors to help cancel the noise in another, the desired magnetic signal (of a ship going by, for example) could be pulled out of the background noise. Bob Sturrock was the DREP expert on noise cancellation. With advances in spectral analysis and numerical algorithms, his techniques got more and more sophisticated and computationally demanding. Fortunately, the concurrent increase in computer power allowed him to implement these advanced algorithms. Later, they found that they could use the same noise-cancellation techniques on electrical sensors—as described below.

Not only is a ship a source of anomalous magnetic fields, it is also a source of electric currents that flow through the surrounding water. Anytime dissimilar metals, such as a bronze propeller and a steel hull, are immersed in an electrolyte, such as sea water, the combination forms an electric cell (a battery), and current flows. These so-called "corrosion currents" may be large (up to many tens of amperes). The current in the water diminishes, of course, as one gets farther away from the ship, but it can be detected for a considerable distance by sensors placed in the water. Oscillating currents, produced when the ship's propeller rotates, are even easier to pick out of the background.

In 1970, Erwin Lokken returned from the Centre for Maritime Research and Experimentation (then known as SACLANTCEN) in La Spezia, Italy, enthused with the idea of using electric field sensors to detect submarines. By this time the Arctic had become important in Cold War strategies, and the Navy needed to be able to detect submarines passing through the islands. Also, the 1969 transit of the US tanker, MANHATTAN, through the Northwest Passage had raised the importance of the Arctic in the eyes of the Canadian people and their government (Section 8.2.3). It was natural, then, that Lokken should make electromagnetic detection of ships in the Arctic the top priority of the Magnetics Group.

From a scientific point of view, they could look forward to an investigation of the magnetic phenomena in the auroral zone and to a study of the effect of ice cover on the electromagnetic signals emanating from passing submarines.

8.3.2 Preliminary Studies

Some of the earlier Magnetics Group work consisted of placing magnetic detection “loops” close to Esquimalt, BC. This was supplemented by placing magnetic sensors in Dabob Bay, Washington, in cooperation with US researchers. The Magnetics Group also installed detection sensors at the joint US/Canada torpedo test range at Nanoose Bay, BC.

Following the success of these early experiments, and given the changing political Cold War perspectives, emphasis then moved to northern waters.

8.3.3 Investigations at Assistance Bay

The first task was to find an Arctic site that was suitable. It had to be on the shore, of course, since the group wanted to detect passing ships and submarines all year—not just during periods when they could camp on the ice. They wanted a location that was on a major channel through the islands, and, for the purpose of easy logistics, they preferred it to be near one of the Arctic towns. Moreover, they wanted to be close to the “Acoustics” camp being established at Gascoyne Inlet (NU).

In 1971 Erwin Lokken and John Wilson investigated a number of possible sites. They settled on Assistance Bay (NU), which is on Cornwallis Island only 20 km (as the raven flies) from the town of Resolute Bay (Figure 109).

Assistance Bay opens onto Barrow Strait, which is part of the principal east-west route through the islands. Also, since the location was at the head of a bay, the cables crossing the foreshore would get some protection from the grinding action of the ice. The bay had been named after HMS ASSISTANCE, which had over-wintered there in 1850 during the search for the missing Arctic explorer Franklin. Its visit was evidenced by tin cans that could occasionally be found on the beach.

Lokken’s thinking was that, since their site was on the same island as Resolute, they would not have to rely on aircraft for transportation. They could go across country in the summertime, and they could travel on the ice in the spring. Also, he reasoned, they could go nice and slowly, thus giving the electronic packages a much gentler ride than they would experience in a vibrating and shaking helicopter.

They drove the cross-country route with a pick-up truck once—and only once. Ron Kuwahara says that the ride was unimaginably brutal. The ground was littered with fairly large rocks that made travel rough at any speed. And, to make matters much worse, there were snowdrifts that had to be hit hard or the truck would founder. So, they went fast, they hung on, and they suffered.

At one place they drove into a shallow puddle and discovered that they were driving on a thick layer of slimy mud over permafrost. The wheels spun their way down into the muck until the truck was resting on

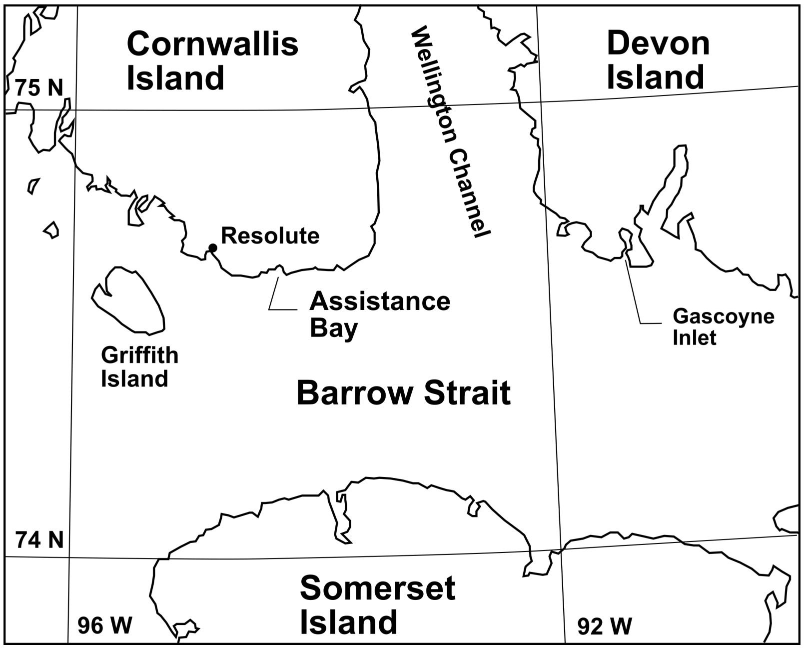

Figure 109: *Assistance Bay (NU) and its relationship to Resolute and to Gascoyne Inlet.*

its floorboards. They were stuck solid. Kuwahara says that he hiked to an army encampment (fortuitously nearby) and found that the commanding officer (CO) had an armoured personnel carrier (APC). More than that, he had the time and willingness to help.

After that trial run, all electronics went by helicopter.

For the spring journeys, Thiokol tractors (Figure 110) and snowmobiles were used to carry freight and pull sleds along the sea ice between Resolute Bay and Assistance Bay. This was a smoother route, but it was still not the Queen's Highway. The blown snow was hard, rolling and rough, and the sharp ice ridges were hard on the tracks and wheels. Moreover, the steel in the Thiokols' axles and springs seemed to get brittle in the extreme cold. On one of the trips, an axle broke, the front wheel (plus axle stub) came right off, and the whole track landed in the snow. Luckily, another Thiokol was there to pull the broken vehicle the rest of the way, or it might now be sitting at the bottom of the ocean (to misquote Shakespeare, "The road to true knowledge never did run smooth").

The research camp at Assistance Bay was built up during April 1972, following months of preparation in the south. Erwin Lokken, Art Shand, Dave Edwards, Bob Sturrock, and Ron Kuwahara drove two Thiokols and two Ski-Doos (with sleds) back and forth between Resolute and Assistance Bay, and they assembled the buildings once the pieces were all out at the bay. By the end of the month the camp contained a large wooden laboratory, a Parcol sleeping shelter (Figure 111), a cooking hut and a diesel-electric generator, complete with shelter.

However, time ran short, and they had time for only a few preliminary electromagnetic measurements before they had to go home.

In Victoria, during the summer, they built an electric-field array several thousand feet long. It was sent north on the CCGS LOUIS S. ST. LAURENT to be deployed off Assistance Bay in September.

Figure 110: *Thiokol tractor. Photo credit: Ron Kuwahara.*

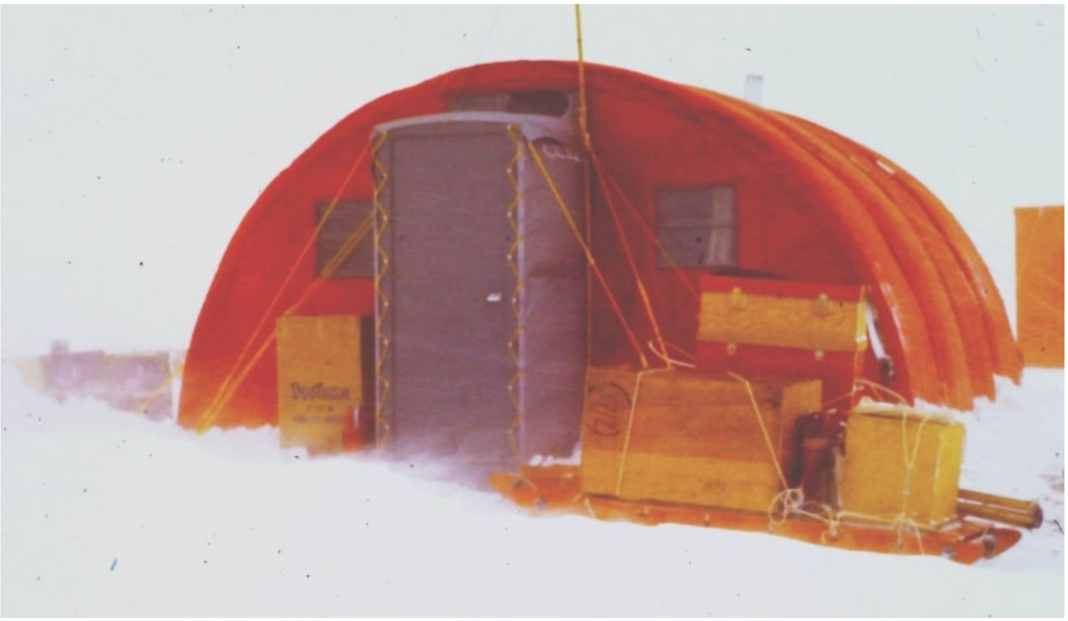

Figure 111: *Parcol sleeping shelter at Assistance Bay on a bad day. Note the zero visibility and the snow swirling around the door. Photo credit: Ron Kuwahara.*

In August, six DREP scientists and technologists arrived at Assistance Bay and prepared the shore facilities, reference sensors, and all the electronics. Then they waited for the LOUIS. When the ship arrived, the bay was filled with ice—blown there by a south wind. The LOUIS went away—temporarily, of course—to do other jobs, but the delays kept adding up until Barrow Strait started to freeze over. The short cable-laying window had closed, and nothing could be done until the following year.

In 1973 fortune smiled on them. The CCGS SIR WILLIAM ALEXANDER successfully laid a cable from several kilometres offshore in to Assistance Bay (Figure 112). Out at its end, the cable contained four (electrical) electrode pairs, and closer to shore it contained two pairs of electrodes. A team of Navy divers used a back-hoe, high-pressure water, and explosives to dig a trench through the fore-shore in order to protect the cable in this problematic section of its run (Figure 113).

Figure 112: *CCGS SIR WILLIAM ALEXANDER bringing cables ashore at Assistance Bay. Photo credit: Ron Kuwahara.*

Note that electrical sensors come as "pairs," often separated by 150 m or more. The voltage between these two electrodes is a measure of the electric current that is flowing through the water. The individual sensors are zinc rods encased in a 15-centimetre-diameter PVC pipe about 2 m long. The pipes were perforated with holes to give the water access, and they were covered with a canvas sock to minimize the flow of water. These sensors could be incorporated into a cable, as they were in 1973, or they could be lowered through a hole in the ice with their cables running to a heated tent. This was the procedure when Barrow Strait was frozen over. The equipment installed in 1973 all worked well. They tested it on "targets of opportunity" (freighters going by), and, since there usually are not many of them, they made their own simple electric source. To simulate the electrical signature of a passing ship they towed two electrodes on a cable behind a Navy Zodiac and powered the pair with a car battery and a simple switch that turned the voltage on and off once per second. This created a one-Hertz pulsed current in the water. For convenience a duplicate sensor array was installed at Nanoose Bay on Vancouver Island (BC). Here they could experiment with various signal processing strategies before trying them out in the Arctic.

The success of the 1973 trial was quite encouraging. Right through until 1977 they continued experimenting with different sensing and electronic equipment and with different array orientations and frequencies. Ron Kuwahara and Don Evans arranged sensors so that they measured the gradients of the

Figure 113: *A trench through the foreshore. Note the yellow cable. It was buried later. Photo credit: Ron Kuwahara.*

electric currents—rather than their magnitudes. This configuration helps accentuate the desired signal at the expense of the unwanted background noise. Looking for the optimum, they played with many different spacings and orientations. For their sources they used sub-surface boats and surface ships of opportunity. When ice conditions allowed, they towed their own sources from small boats.

Kuwahara also did some theoretical work predicting the "electrical" source strength of the passing boats and ships. He was able to verify these numbers by their measurements at Assistance Bay.

Investigations (both practical and theoretical) continued on noise cancellation in the extremely low frequency (ELF) band (3 Hz to 30 Hz). They collaborated with Dr. Harry Dosso and Dr. John Weaver (of the University of Victoria [BC]), who did modelling work and theoretical work at both quasi-static and ELF frequencies.

The 1977 spring trial was a major effort by the Magnetics Group. As well as the Assistance Bay site, the group set up an ice camp near Griffith Island, which is just off Resolute Bay (Figure 109 on page 134), and deployed an array of sensors through the ice. At this camp all equipment was run on batteries since a rotating generator would have produced unwanted electrical noise. They were assisted in this work by a submarine which acted as a "source."

The Assistance Bay site was then used regularly by the Magnetics Group from 1978 until 1984 for both late winter and summer experiments. Peter Holtham took over the role as Chief Scientist for the field trials as Ron Kuwahara moved on to investigate airborne magnetic anomaly detection (MAD) systems.

In 1978 electromagnetic measurements were made at two widely separated (720 km) sites: Assistance Bay on Cornwallis Island and Mould Bay (NT) on Prince Patrick Island (NT) in the western Arctic. The simultaneity of the recordings was ensured by the use of new over-the-horizon techniques for receiving a signal from a GOES satellite. These satellites are geostationary, and conventional wisdom said they could not be observed at such high latitudes, but Peter, Ray Hale, and Jack Toews developed techniques to detect the extremely weak signals and use them to synchronize their recordings. Interestingly, the participants remember quite clearly that the accommodation and food at Mould Bay were far superior to what was available at the Assistance Bay camp, giving delight to some and chagrin to others. In the late '70s Bob Sturrock and Erwin Lokken continued their vessel detection studies, and in 1983 Holtham extended the technology to detect higher-frequency signals (60 Hz) from ship-borne electrical sources.

Experiments were also performed to see how the local coastline bathymetry affected background electromagnetic signals in the ocean, culminating in 1980 and 1981 in experiments to verify the University of Victoria laboratory model results being made by Dr. Harry Dosso and his student Garry Heard, a co-author of this book.

In 1984, DREP introduced the US Magnetics Group (then located at Naval Surface Weapons Center, White Oak, MD) to the Arctic, so as to get their feet wet, or at least cold. These players aided DREP significantly in some of the subsequent POLAR PACK experiments.

There is a nice side story associated with these years of work out of Resolute Bay. The winter at Resolute Bay was cold, colourless, and very dark, and when the DREP contingent arrived in late March, the Resolute population was thoroughly sick of their long winter. Dave Edwards, a DREP technologist and charmer extraordinaire, arrived every spring with an enormous bunch of daffodils in bud—a bouquet that he presented to the airport manager's wife. When you realize that the airport manager was the top man in Resolute, you will understand why the Magnetics Group could do no wrong and why they got pretty well everything they asked for.

After many years, the Assistance Bay site was retired. Much of the key information on arrays at this site had been measured, and Assistance Bay was no longer producing much that was new. The new questions were whether or not electromagnetic detection could be made to work in deeper channels, in regions of high currents, and under free and moving ice. A new site at a narrow section of Jones Sound had already been selected and an array installed, and the POLAR PACK experiments on the Arctic Ocean were starting to take place.

The Assistance Bay camp was therefore dismantled, except for one hut that was left as a shelter for travellers (primarily the local Inuit).

8.3.4 Active Shaft Grounding

A very interesting development came about—in part—because of the Arctic work. Don Evans, who had previously done work on "active" cathodic protection for ships, observed that the varying electrical currents they were detecting in the Arctic were due to oscillations in the corrosion currents. This rapid change in current was due to the rotation of the propeller shaft and the changing electrical resistance between the shaft and its bearings.

A way to get rid of the variations was to reduce the electrical resistance between the shaft and the hull to zero. Then the cathodic currents would be constant, and there would be no oscillating component to be detected.

In order to ground the shaft to the hull effectively, active electronics have to be used. One set of slip-rings measures the voltage of the shaft (relative to the hull), and, when this voltage is not equal to zero, a high-current generator draws (positive) current out of the shaft via another set of slip-rings and sends it to the hull. A high-gain feedback amplifier controls the current generator, with the result that the voltage difference between the shaft and the hull is kept very nearly zero. This technique is referred to as “active shaft grounding” or ASG, for short.

Don Evans and Ray Bucket developed a prototype unit that showed good possibilities—good enough that they were able to apply for a patent. Jacques Bédard then redesigned the system with more modern electronics and applied for a further patent. In the early 1980s, Canadian industry was encouraged to exploit this technology, and W.R. Davis Engineering Ltd. now makes a commercial version that has been sold to many of the navies of the world (Figure 114).

As a sequel, in the late 2000s George Schattschneider began working at the DRDC – Atlantic Research Centre on a new version of the ASG. This work is still on-going and is expected to result in further improvements in performance.

Figure 114: *A modern ASG system originating from Arctic research. The left-hand picture shows slip-rings, and the right-hand picture shows the control box. Photo credit: DRDC.*

8.3.5 Project SANGUINE

Project SANGUINE was a US Navy scheme to communicate with their submerged submarines with very low frequency radio signals. The usually quoted frequency is 76 Hz (for example, [54] and [55]). The problem with higher frequencies is that the strength of electromagnetic waves is attenuated as the waves pass through any conductor—and sea water is a conductor. Moreover, the attenuation increases as the frequency gets higher. At “reasonable” communication frequencies, such as 1 MHz or above, the submarine would have to travel on the surface to receive the signal. At 76 Hz, on the other hand, the submarine could travel at a depth of 30 m (or slightly deeper) and still receive a good signal. The disadvantage with such low frequencies is that the information rate is very slow—on the order of a few characters per minute.

Two large antenna farms were built by the US, one in Wisconsin and one in Michigan. Megawatts of power were fed into antennas many kilometres long, but the radiated radio signal was only 5 to 8 watts.

Much of the physics of electromagnetic propagation was common to both the submarine ELF communication system and the submarine/ship detection problem. Both required a sound understanding of geomagnetism and the earth's magnetic environment. Thus DREP's expertise in Arctic geomagnetism was of interest to US scientists. The Magnetics Group was also in a position to help test reception in unusual conditions—in remote regions, in the Arctic, and under ice. The Magnetics Group actively participated in the Sanguine research phase during the '60s and '70s.

The project received a lot of opposition, mainly from environmentalists in Wisconsin, who argued that the high power involved could give rise to severe ecological problems. The Sanguine project was ended in 2004.

8.3.6 Work in Jones Sound

Another big Arctic project for the Magnetics Group took place in 1981, and was part of a large DREP expedition in Jones Sound (Figure 95 on page 116). The CCGS SIR JOHN A. MACDONALD first laid sensors and cables to Fantasy Island for the Acoustics Group, and then it went to the western end of Jones Sound to install sensors and cables for the Magnetics Group.

The cable, with its multiple electric sensors was laid from Cape Hawes (NU) north toward the Bay of Woe (Figure 115). This was the largest electromagnetic (EM) array ever laid by DREP.

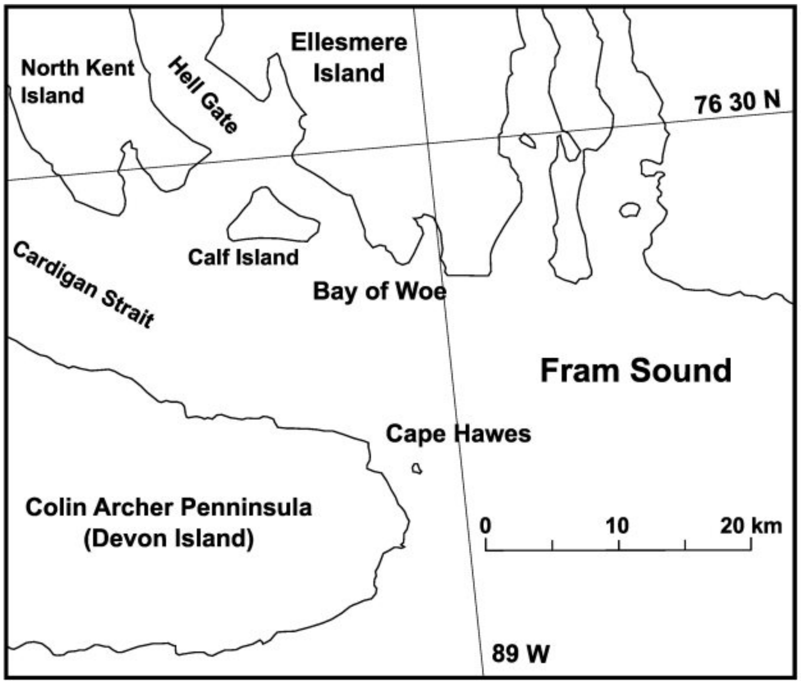

Figure 115: *Map of Fram Sound region.*

One of the great advantages of this location is the narrowness of Fram Sound (NU). This has particular appeal when the sensors, such as these electric units, do not have a large detection range. However, there are two big disadvantages to that location. The first, and most important, is the high current that flows through Fram Sound. It can be as high as four or five knots. The second disadvantage is the poor weather, particularly during the winter and spring. Widespread fog is very common, and this is caused by large areas of open water, which, in turn, is caused by the high currents. The satellite photograph in Figure 116 shows the open water in the narrows of Fram Sound, Hells Gate, and Cardigan Strait. The photograph in Figure 117 (page 142) looks up into the Fram Sound area. Besides showing the beauty of the region, the picture shows that the sea is virtually ice-free. This is noteworthy since the picture was taken in the middle of April 2012, the time of year when the general ice cover is at its heaviest.

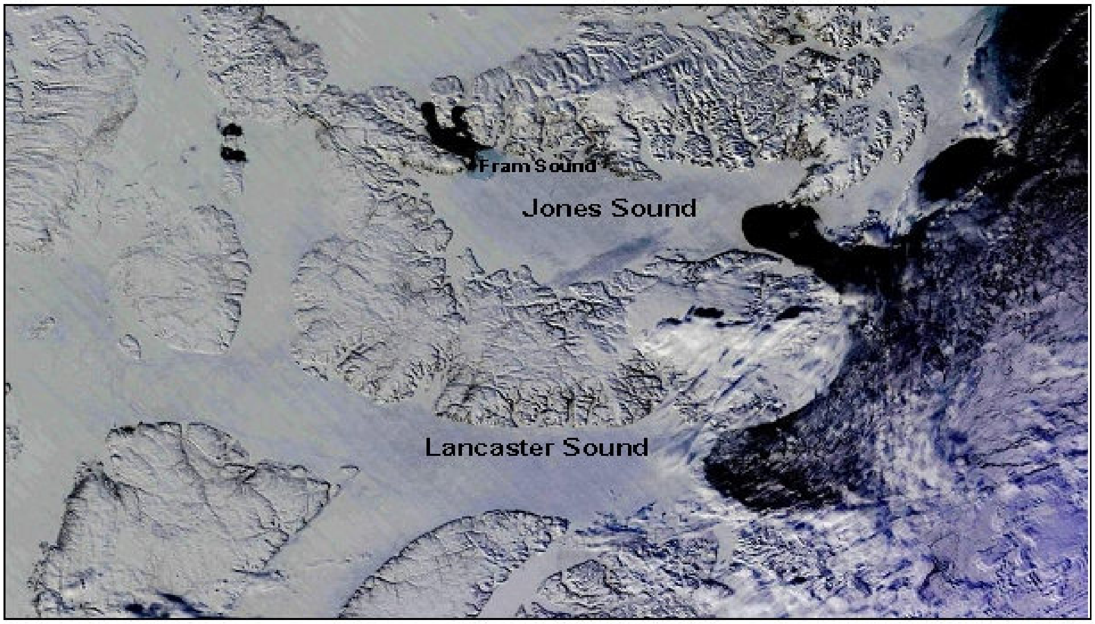

Figure 116: *A satellite photograph showing some of the easterly Arctic Islands. Note the open water in the region of Fram Sound. High currents keep the surface ice-free all years. This image was taken on 12 April, 2012. Photo credit: NASA/GSFC, Rapid Response.*

The CCGS SIR JOHN A. MACDONALD laid the sensors and their connecting cable in the late summer, so it was not particularly bothered by the fog, but the high currents caused no end of trouble. Peter Holtham, who was the Chief Scientist, says that they started with the cable on shore at Cape Hawes. As they started laying the cable, it was swept out in a large loop by the current and by the ice that was being carried by the current. The cable was tied at the shore in hopes that it would hold against the ice, but that hope was quickly shattered by moving icebergs, and the broken cable was taken out to sea. The rest of the array was laid successfully, but the ship had to leave the area immediately because a big storm was coming.

Three days later, after the storm had blown itself out, the SIR JOHN A. returned, and they started grappling for the wayward cable-end. Peter says that they hunted for it for at least ten days and perhaps as many as fourteen—he has lost track—and every day they worked from dawn to dusk dragging a grapple along the bottom while constantly fighting the current. Peter says that there was giant kelp down there—10 m long—bigger than anything he has seen in the Pacific, and they were forever snagging it. The false alarms were legion; they would pull up the grapple and find nothing but a tangle of kelp.

Figure 117: *Fram Sound. The camera is looking roughly north west. Photo credit: Cpl R. Dittman, Joint Task Force North.*

After many days, they found the cable about 1.5 kilometre from shore and about a kilometre from where they thought it should be. Their problems, however, were by no means over. He says, “You can pull a cable up off the bottom—as you know—with some effort, but this was an immense effort. We had a boat full of people pulling on it.” They would also tie the rope to a cleat on the boat and use the boat’s power. “Eventually,” he says, “it came up all figure-of-eighted and tangled with kelp.” “Killer kelp,” he calls it.

Now, with a bight in hand, they had to find the end of the cable. They under-ran about three kilometres that had been twisted into knots by the current and tangled with the kelp (Figure 118). Sometimes the kelp was still attached to the bottom, so they had to rip it up. It took several days of constant struggle to get to the end. At the end of each day, they would buoy the cable so that they could find it easily the following morning.

When they finally got to the end they were able to recover enough slack that they could pull the cable all the way to shore. Chris Gibb then set himself up in an unheated temporary shelter near the shore (a “Paul Bunyan” transport container) and spent the next 24 hours splicing the cable back together.

Once the splice was completed, they found that everything worked—and worked very well. Holtham says that it was a very successful installation, even though everyone initially had thought it had been a disaster. The high currents sometimes caused the cable between sensors to strum, and this produced an undesirable signal. However, Holtham and Sturrock generated an opportunity out of adversity by developing a technique for removing this type of noise, which, as Peter says, was not terribly difficult since the noise was nearly sinusoidal.

Figure 118: *Wrestling with the storm-tangled cable. Photo credit: Peter Holtham.*

The camp (Figure 119) consisted of three buildings, one each for living quarters, instrumentation, and generators. The camp was originally designed for a ten-year use, but changing interests moved the scientific focus to the polar ice pack, and the Cape Hawes camp was abandoned. It was dismantled and cleaned up in the late '90s, except for the small generator hut that was left as an emergency refuge for Inuit travellers.

8.3.7 Work on the Arctic Ocean

From 1982 onward, most of the Arctic work done by the Magnetics Group was done in collaboration with the Americans. Peter Holtham was the principal DREP scientist in all this joint work. They worked in the Arctic Ocean proper, sometimes well north of Barrow (AK). They were assisted by submarines that acted as "sources" (Figure 120).

The first of these efforts, in 1982, was in conjunction with the Applied Physics Lab from the University of Washington. There were just six people (one Canadian) in the camp, which was well up in the permanent pack ice. As Peter said, getting there was simple: you take an icebreaker up north, you put a ladder over the side, climb off, and then watch the icebreaker head south, not knowing whether you will ever see it again (there were no sat-phones in those days).

Another source of excitement at that camp was the big (1.5 metre diameter) hole through the ice that the acousticians maintained in Peter's tent. The relatively bright light in the tent attracted unusual and possibly never-before-seen creatures of the Arctic deep. To find a seal next to your bed was not unusual.

Figure 119: *Camp construction started at Cape Hawes. Floating ice is visible near the shore. The other side of Fram Sound can be seen in the background. Photo credit: Peter Holtham.*

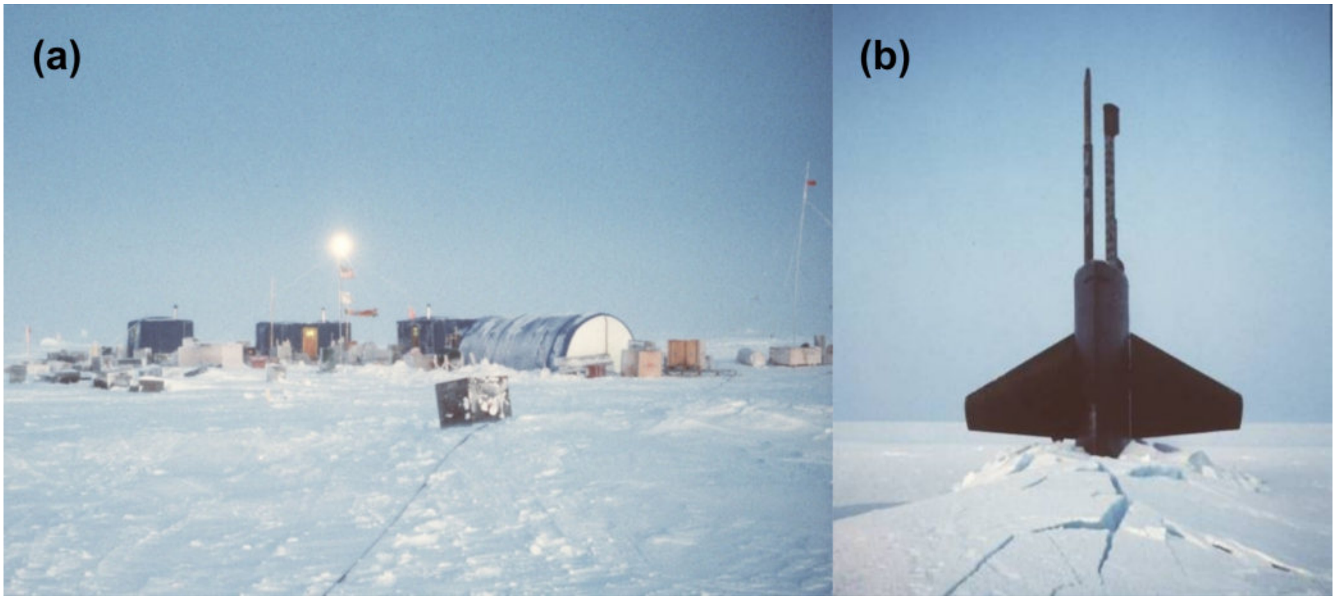

Figure 120: *A POLAR PACK ice camp and a "friendly" target. Photo credit: Peter Holtham.*

In 1986 Peter Holtham and Ken Ashcroft participated in a huge US camp on the Polar Pack. The fact that the Americans wanted their assistance demonstrated that DREP's Magnetics Group could provide electromagnetic capabilities that the US lacked. Sensors, fabricated by Chris Gibb, were dangled 100 m below the ice canopy, and they were connected to a new generation of electronics and "computery" conjured up by many dedicated DREP Applied Technology Section members (PCs were just coming of age). Both Ken and Peter found the 1986 trip the hardest of their careers. Not only did they have to deploy and operate the underwater sensors, but they had to man the recording systems during the submarine trials. As the boats operated 24/7, this did not leave much time for sleep. On the plus side, a very large amount of data was collected for later analysis back in the south.

This series of "adventures" ended with two operations to embed very high sensitivity helium magnetometers in the ice, one just north of Barter Island in Alaska in 1988 and the other north of Alert (NU) and not too far from the pole in about 1990. The second trial used the latest satellite technology to send back a long-term continuous stream of electromagnetic data. Relating to these trials are unconfirmed tales of broken ski struts on Twin Otters, unscheduled nights on the ice, attempts to light Coleman stoves at -40°C, the use of a blow torch to heat the Coleman gas tank, and mad scientists cutting pits in the ice with chain saws, but these stories all remain "classified."

8.3.8 Magnetics Work in the South in the 1990s

The emphasis of the Magnetics Group submarine detection research shifted in response to the end of the Cold War. From 1992 through 1994, DREP collaborated with several US research and naval entities to adapt DREP's Arctic capability to southern applications, namely to provide an advance warning to attacks on SSBN bastions in the Pacific Northwest.

Peter Holtham and Troy Richards, from DREP, together with their American partners, laid a long array of electromagnetic sensors across Juan de Fuca Strait starting at the US side at Neah Bay, WA. The array not only included detection technology honed previously in the Arctic, but also new technology for the quasi-DC electric field, for which amplifiers had been developed by George Schattschneider. The large zinc electrodes used in earlier experiments were also replaced by Silver-Silver Chloride electrodes, which were smaller, easier to deploy and not as electrically noisy. This new technology was to become standard for later surveillance and vessel signature ranging purposes.

Long array cables, with large attached lumps (the sensors), are particularly difficult to lay without getting them tangled or snagged. In previous Arctic lays, the many kilometres of cable were spooled in race-track form in the hold of the icebreaker, with long bights of cable coming up to the deck where the many sensors were stacked. Deployment was always nail-biting since any crossing of the cable would be disastrous. For Neah Bay, Peter Holtham, with the assistance of John Smith and David Hopkin of the Applied Technology Section, devised a new simplified process where the cable was figure-eighted around two long horizontal backward-pointing fingers supported by a deck-mounted frame. As the ship moved forward, the cable simply pulled off the ends of the fingers. "It was scary at first," said Peter, "since it was an untried technique, but it worked smoothly and we were soon all watching the scenery." It was a resounding success.

The high density of commercial shipping in Juan de Fuca, coupled with an ample number of submarines, led to a huge amount of experimental data. Every two weeks for two years someone from DREP had to go over to Neah Bay to "change the tape!"

8.3.9 The Magnetics Group's Arctic Farewell

The last Arctic trial made by staff of the former Magnetics Group, now under a new name at their new location in Halifax, followed a rekindling of interest in the Arctic due to sovereignty concerns.

Acoustics and Magnetics, long-time rivals yet obvious friends, met on the ice close to Alert (NU), in 2002, when Garry Heard, Peter Holtham, and Troy Richards began to assess the feasibility of developing long-needed hybrid acoustic-electromagnetic systems. This led to the ongoing hybrid approach that Garry and Peter honed during several Norwegian trials, and which Garry continued pursuing, both in the Arctic and the south. This promising new technology, which in theory should lessen the probability of missing a submarine, may well be the subject of a history of electromagnetics at the DRDC – Atlantic Research Centre in years to come.

9 Defence Research Establishment Suffield (DRES), Suffield, Alberta

9.1 Introduction

In June 1941 a research facility was opened at Suffield in southern Alberta. Called the Experimental Station Suffield, and administered by the Canadian Army, it was a joint British and Canadian operation specializing in biological and chemical defence issues. By the end of the war it employed 584 people who embodied a vast array of scientific and engineering skills. It controlled a large parcel of land known as the "Suffield Block," the name coming from the time of the Dominion Land Survey.

Farming had been attempted in the area, but the land was considered "marginal" due to the semi-arid climate, and most of the farms were abandoned during the "dirty" '20s and '30s.

The Block, comprising 2690 square kilometres, was expropriated during the war by the Province of Alberta on behalf of the federal government. The location and size of the Suffield Block is indicated in Figure 121.

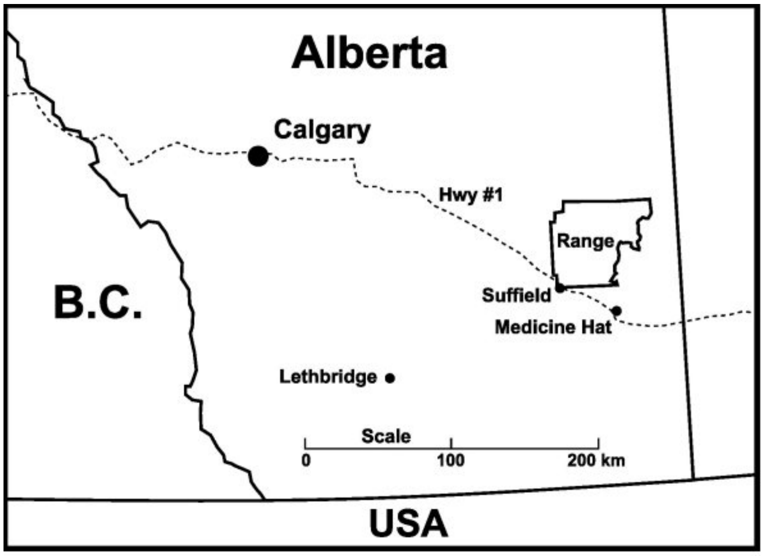

Figure 121: *A map of southern Alberta indicating the location and size of the Suffield Block (now called the Suffield Range). Its eastern border is the South Saskatchewan River (hence its winding nature).*

9.2 Organization After the War

After the war, the Block was transferred to the federal government in exchange for other assets.

In 1946 the British withdrew, and the station was left in the hands of the Canadian Army. In April 1947 the station was transferred to the Defence Research Board, and in August 1950 the station was renamed the Suffield Experimental Station. In July 1967, as part of a general standardization of DRB names, it was renamed the Defence Research Establishment Suffield (DRES).

On 1 December, 1971, the Canadian Forces Base Suffield was created and took over many of the support functions from DRES. The research establishment, although not part of the Base, was co-located with it.

In 1974 the Defence Research Board disappeared as an official body, and its functions and laboratories were taken over by the Research and Development Branch, which was headed by the Chief of Research and Development (CRAD) under the Assistant Deputy Minister Materiel (ADM[Mat]) of the Department of National Defence.

A further reorganization took place on 1 April, 2000, when the Research and Development (R&D) Branch was placed under the Assistant Deputy Minister Science and Technology and renamed Defence Research and Development Canada (DRDC). The Suffield lab became DRDC Suffield, which is now the DRDC – Suffield Research Centre.

9.3 Vehicle Mobility in the Arctic

The Station is still involved with defence against chemical and biological agents, but its proximity to the very large Suffield Range allows it to work on various problems having to do with explosives, such as mine-clearance and structural response to shock and blast. It is also involved with such engineering problems as the mobility of vehicles that travel off-road.

In the category of vehicle mobility, Suffield Research Centre has endeavoured to help the Canadian military with their problems of transportation in the Arctic.

They have done a study of the Arctic mobility of a large number of off-road vehicles, both commercially available and under development. The report “A Review of Commercial and Research Vehicles for Arctic Mobility” by J. Giesbrecht [56] discusses the problem in general and points out the features (both good and bad) of 21 candidate vehicles plus three commercial vehicles retrofitted for travel over snow. There is a short section on air-cushion vehicles, and the report finishes with an extensive bibliography.

G.J. Irwin investigated the nature of vehicles travelling over snow, and he studied the traction of various vehicles in different snow conditions. In particular, he developed a simple, portable device that allows the user to estimate the traction of a given vehicle in the snow conditions under consideration [57, 58].

Work in mobility in the Arctic is continuing.[3] In September 2011, Suffield Research Centre issued a contract for the development of a quiet hybrid electric snowmobile [59] to be used for covert military operations in the Arctic.

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[3] Editor’s note: Recall that this book was completed in 2012. The Vehicle Mobility project successfully completed following the completion of this book.

10 Defence Research Establishment Valcartier (DREV), Valcartier, Quebec

10.1 Introduction

At the beginning of the Second World War those running the war effort felt that the Canadian Armed Forces would need scientific support. The National Research Council (NRC), being the senior research establishment in the country, was asked to establish a number of defence-oriented laboratories. One of these new labs was the Experimental Explosives Establishment at Valcartier, Quebec.

During the war, three organizations—all related to armaments and explosives—were established at Valcartier: the Explosives Experimental Establishment of NRC, the Artillery Proof and Experimental Establishment, and the Trials Wing, which reported to the Directorate of Artillery at Army.

In March 1945, just before the surrender of Germany, the three organizations were amalgamated into the Canadian Armament Research and Development Establishment (CARDE), and in 1947 CARDE became part of the just-established Defence Research Board (DRB).

The first Chief Superintendent after CARDE became part of DRB was Dr. W. Littler from the Ministry of Supply. The next Chief was Dr. Carleton Craig from McGill University who accepted the position in 1949. After Dr. Craig, all Chief Superintendents came from within the DND staff.

In the beginning there were only twenty scientists (both civilian and military). However, CARDE went on to become the largest Canadian defence research establishment, and it, more than any of the other laboratories, concentrated on armaments and weaponry.

Like the other defence research establishments, CARDE has gone through its share of name-changes and reorganizations. In 1969 both it and its budget were decreased in size. Its name was changed to Defence Research Establishment Valcartier (DREV), and its research was redirected to smaller projects specifically requested by the Armed Forces. On 1 April, 2000, DREV was renamed Defence Research and Development Canada – Valcartier, and more recently its name became the DRDC – Valcartier Research Centre.

10.2 Arctic Work

CARDE's connection with the Arctic had to do mostly with anti-ballistic-missile systems. Intercontinental ballistic missiles (ICBM) were expected to come over the pole from the Soviet Union, passing through (and over) the heavily ionized auroral zone on their way to the eastern United States. The concern was that the radar used to detect the ICBMs would be adversely affected by this auroral zone. Perhaps the ionosphere would block the radar. Perhaps it would generate false targets, and perhaps it would cause the bearing to the ICBM to be in error. A study of these possible problems was started in 1959 at Fort Churchill (MB), and at Prince Albert (SK). And, in order to place sensors up into the ionosphere (above 100 km, say) rockets were the vehicles of choice. Balloons would not go high enough and satellites would not go low enough.

CARDE's forte was in the development of these rockets. As far back as 1951 they had worked on a missile development program, and, although their missiles never went into production, they learned a lot about the problems of detection, tracking, and hypersonic flight. In particular, they developed new fuels that propelled rockets higher and faster.

In 1957 Bristol Aerospace designed and built a simple rocket fuselage specifically as a test-bed for studying high-power solid fuels. It was made to accommodate a wide range of burning times and launch angles. The first test flight was at Fort Churchill (MB) in 1959.

Subsequently, the design was modified to be lighter and more suitable for its new role. This rocket was named the Black Brant, after a goose that breeds in the Arctic and winters in Baja California.

The first model, the Black Brant I, could raise a 68-kg payload to an altitude of 150 km. It was soon followed by the Black Brant II in 1960, which could lift a payload of 100 kg to a height of 200 km (Figure 122). The National Research Council (NRC) used 60 Black Brant IIs between 1960 and 1974 [60]. The Black Brant series has continued to expand, and over 800 rockets of the various models have been launched world-wide, with NASA being the largest customer. The modern versions have reached altitudes of more than 1500 km. For comparison, the International Space Station (ISS) is maintained at an altitude between roughly 310 and 400 km [61].

Figure 122: *The Black Brant II rocket, developed by CARDE and Bristol Aerospace, was used extensively at Fort Churchill to probe the ionosphere. Photo credit: DRDC.*

At the time of writing, the present model is the Black Brant XII [60].[4]

CARDE contributed in other—but related—ways to ballistic-missile defence. In 1962 they began a study into the chemistry of the upper atmosphere. They wanted to understand the reactions that produced the phenomena that were observed during a vehicle's very high-speed re-entrance into the atmosphere. Associated with this was the continued study of flight dynamics and the physics of re-entry.

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[4] Editor's note: The model XII appears to remain the current model as of 2022.

DREV has at various times participated in other Arctic field work. In the late summer of 1989, Paul Pace, George Fournier, Ghislain Pelletier, Denis Bonnier, Jacques Tremblay, and Gilbert Tardiff joined Canadian Forces auxiliary vessel (CFAV) QUEST Cruise Q176 with Garry Heard as Chief Scientist (Section 12.4). The DREV team carried out atmospheric and underwater imaging studies using gated laser systems. In the recent past, the DRDC – Valcatier Research Centre was heavily involved with the Northern Watch Technology Demonstration Project (Section 12.6). Valcartier is responsible for the electro-optical atmospheric imaging and meteorological studies.

11 Defence and Civil Institute of Environmental Medicine (DCIEM), Toronto, Ontario

11.1 Pre-DRB

In 1939 the Department of National Defence first acknowledged the importance of organized research into the "human factors" of its military. Their first step was fairly small, being limited to the relevance of aviation medicine to defence. An inter-departmental committee was established in June, 1939, chaired by Sir Frederick Banting, one of the discoverers of insulin. This committee, known as the Associate Committee on Aviation Medical Research, began studies on pressure physiology at the Banting and Best Institute, University of Toronto (ON).

In 1940 the No. 1 Clinical Investigation Unit (CIU) was established in Toronto to investigate the effects of cold and high altitude on human reactions and capabilities.

In 1941 the first human centrifuge in any of the allied countries was brought into operation, and it was used to help design and test the first anti-"G" flying suit, which was first initially used during Operation TORCH (the invasion of French North Africa in November 1942).

11.2 As Part of DRB

When the Defence Research Board (DRB) was created in 1947, one of its more important responsibilities was in the field of military medicine. In particular, DRB was directed to investigate the environmental factors and hazards particular to the military. The objective, of course, was to improve military performance in the face of such hazards.

In order to investigate such human factors, a new Defence Research Medical Laboratory (DRML) was built at Downsview in the early 1950s, with the official opening on 12 February, 1954. In 1968 the laboratory was renamed the Defence Research Establishment Toronto (DRET).

Operating in parallel with this DRB establishment was the RCAF Institute of Aviation Medicine (RCAF/IAM), which had grown up after the war. In 1968, after unification of the military, it was renamed the Canadian Forces Institute of Environmental Medicine (CFIEM). Three years later, in a push toward greater efficiency, CFIEM and the DRB lab (DRET) were amalgamated under the name Defence and Civil Institute of Environmental Medicine (DCIEM).

Along with the other Defence Research labs, DCIEM was reorganized in 1974 into a closer relationship with the military. It became part of the Research and Development Branch of the Canadian Armed Forces (this organization was informally called CRAD—for Chief of Research and Development). In 2000 the branch was reorganized again, becoming Defence Research and Development Canada (DRDC). The Toronto lab is now called the DRDC – Toronto Research Centre.

11.3 Arctic-Related Research

The Toronto lab's cold-weather research was concerned almost entirely with the effect of cold on military troops. Their mandate, after all, was to study "the environmental factors and hazards particular to the military." And, as well as quantifying and measuring the deleterious effects, they suggested ways of mitigating them.

Since DCIEM needed actual humans for many of their studies, their work was often carried out in cooperation with a military exercise in the north. One example of this was Exercise NEW VIKING, which was an exercise meant to familiarize military personnel with living, moving, and fighting in the Canadian Arctic. Exercises of this name were held every year (sometimes two per year) from 1970 to 1974. The northern locations varied between Churchill, Coral Harbour (NU), and Frobisher Bay (now called "Iqaluit"). DCIEM took advantage of the exercise to monitor various physiological effects of troops under stress. In particular, Reference [62] reports on the vitamin C status of the troops during northern operational training. It also examines the effects of a vitamin C supplement on the frequency and severity of colds.

Another exercise in which DCIEM participated was Exercise NORTHERN RAMBLE, which took place in May 1972 in the vicinity of Churchill and involved the First Battalion Royal Canadian Regiment. The lab's general aim was to study human effectiveness in the cold of the Subarctic. More particularly, they studied the energy expenditure and the caloric requirements for various tasks and functions. They also studied the state of hydration of the troops, who were living on hard rations for the duration of the exercise. Reference [63] discusses this study and its results.

A study that was not part of a military exercise but, nonetheless, used military volunteers as subjects was called KOOL STOOL. It was a joint Franco-Canadian study that took place in Churchill during January and February, 1976. It used volunteers from the 1st Canadian Airborne Regiment of Canada and the 13th Airborne Dragoons from France. As the name suggests, it was basically a study of the effects of exposing the body to the cold. They ran experiments to see whether the human body could be quickly adapted to the cold by means of immersing the body in cold water until the rectal temperature dropped to 35°C. This treatment, known as the "French Bath," was done nine times per day for two weeks, with weekends off. The immersion time generally increased from 25 minutes to about 40 minutes as the subject's tolerance increased and his core temperature took longer to drop. The responses of this group to subsequent cold-exposure tests were then compared to the responses of a non-prepared group. The results were generally as you might expect: those who were prepared did better. Details can be found in Reference [64]. The exercise also studied the microclimate of tents, and it compared a number of parkas and other cold-protective equipment.

As well as studying the physiological and psychological effects of the Arctic environment on the troops, DCIEM also promoted the development of cold-weather clothing, tents, sleeping bags—anything to improve the performance of the troops in cold country. As mentioned above, part of Exercise KOOL STOOL was devoted to this. In the spring of 1973 two military officers under the auspices of DCIEM took a party into the St. Elias mountains of the Yukon and conducted a test of 14 tents ranging in size from a small emergency three-man tent to a large ten-man tent [65]. They examined the problem of large temperature gradients in tents (freezing on the floor to 150°F [66°C] at the peak), and they measured the build-up of carbon monoxide, which was particularly high when the Coleman stove was being used to cook rations or to melt water. They criticized the lack of head-room in tents that had high centres but low walls. They examined the problems of erecting and disassembling the tents, and they discussed the weight and volume of the packed tents and the relative difficulty of transporting such baggage. They also discussed the problems of guying the tents in deep, soft snow. Their results are well laid out, their discussion of the pros and cons of each tent is clear and convincing, and they were not afraid of making definite recommendations. In passing, they also made comments on other cold-weather gear such as stoves, lanterns, mukluks, crampons, head gear, sleeping bags, and sun glasses.

A continuing problem for someone sleeping in cold tents is the build-up of frost in his/her sleeping bag, the bag increasing in weight by several kilograms over the course of a voyage. The extra weight, *per se*, is not a great disadvantage; the hardship comes from the decrease in insulation. R.J. Osczevski has worked on this problem at the DRDC – Toronto Research Centre. In Reference [66] he gives a history and a discussion of the mechanisms of frost build-up, and he makes a number of suggestions as to how the problem might be ameliorated.

An interesting cold-weather project has been the development of the wind-chill index (or wind-chill factor or wind-chill equivalent temperature). As is well-known to all northern peoples, the cooling effect of air on an exposed surface (e.g., the face) is greatly increased when there is a wind, and the wind-chill index attempts to quantify this effect. The original wind-chill index (WCI) was based on an impromptu experiment by Siple and Passel [67] in Antarctica wherein they measured the cooling rate of water in a small plastic bottle as a function of the temperature and wind velocity. Their index gave the rate of cooling in kcal/m^2/h (later in watts/m^2), but this notion was too arcane for the general public, which preferred the use of the wind-chill temperature (WCT), a parameter that was less accurate but easier to understand. Ostensibly, the WCT was the temperature at which the rate of cooling would be the same if there were no wind. This equivalent temperature came into general usage in the 1970s. However, during the following decades the formula was criticized by many writers. One of several problems was that it exaggerated the effect of the wind; the calculated WCT was lower (colder) than it should have been. R.J. Osczevski at DCIEM concerned himself with the problem and came up with a better wind-chill model. Figures 123 and 124 (page 155) show several people subjecting themselves to a cold wind in order to verify his model.

Figure 123: *Military personnel being subjected to cold-weather tests. Photo credit: DRDC – Toronto Research Centre.*

An Internet conference in 2000, hosted by the Canadian Weather Service, resulted in a study by R.J. Osczevski (of DRDC Toronto) and M. Bluestein (of Indiana University) who developed a new WCT chart that was implemented in Canada and the United States in November 2001. Canada and the US use the same formula, but Canada quotes the wind-chill temperature in degrees Celsius, and the US quotes it in degrees Fahrenheit. Reference [68] provides more background on this topic, and it gives details of the various models.

Figure 124: *Wind-chill testing. Photo credit: DRDC – Toronto Research Centre.*

12 Defence Research Establishment Atlantic (DREA), Dartmouth, Nova Scotia

12.1 Origins of the Lab

In September 1939 German aircraft began laying “magnetic” mines in the harbours of Britain. Ships made of iron and steel can become surprisingly strong magnets in the presence of the earth’s magnetic field, and this magnetism can be used to trigger a mine as the ship passes over it. Both the British and Canadian establishments initiated emergency research to find ways of minimizing a ship’s magnetism, and this was the “first officially organized” naval research effort carried out by Canada [69].

The technique of reducing a ship’s magnetic field is called “degaussing.” (The “gauss” is a unit of magnetism named after Carl Friedrich Gauss, an 18th century mathematician and scientist.) Degaussing is not an easy task. First, sensors are used to measure the complicated magnetic field produced by the ship. Then a series of coils distributed throughout the ship are driven with electric current in such a way as to reduce the measured field as much as possible, and, finally, more measurements are made to check that the field has in fact been reduced. This often turns out to be an iterative process.

The magnetic field produced by a ship depends on the structure of the vessel, the installed equipment, and where and how the ship has been used. There is no direct and repeatable procedure for degaussing, and the variability in the problem requires specialized skills and mathematical modelling techniques. The National Research Council of Canada assumed the responsibility for the Canadian work, and by May 1940 it had recruited two graduate students who were the first of a group of scientists to work on ship degaussing. Soon they were joined by a group of military officers and two Dalhousie professors, Dr. G.H. Henderson and Dr. J.H.L. Johnstone. This research group formed part of the Halifax Dockyard Anti-Magnetic Mines Office, and they were housed in the Degaussing Experimental Office. This is generally considered to be the beginnings of the Naval Research Establishment (NRE). A more detailed description of the origin of the east coast laboratory can be found in Reference [69].

As the war continued, a number of special ranges were developed on both the east and west coasts for the purpose of degaussing ships. At one point there were three ranges in Bedford Basin, NS, and one in each of Sydney (NS), Vancouver (BC), and Québec City (QC). Before long, acoustic mines, which were triggered by the noise generated by a passing ship, were becoming a menace, and acoustic capabilities were added to a range near McNabs Island in Halifax Harbour.

12.2 Name Changes

During the early War years, changes in organizational structure in the fledgling research organization occurred rapidly. There was a rapid succession of name changes and office relocations. In March 1943, Cdr A.F. Peers was made Officer In Charge of the Torpedo School of HMCS CORNWALLIS and was given responsibility for the anti-magnetic mines office. This HMCS CORNWALLIS was soon moved to Deep Brook, NS, and the research side of the Anti-Magnetic Mines Office became the Experimental Section, HMCS STADACONA. In January 1944 the Experimental Section was renamed HMC NAVAL RESEARCH ESTABLISHMENT (NRE) with Dr. Henderson as superintendent.

The NRE name remained a constant until July 1967, when the laboratory was renamed Defence Research Establishment Atlantic (DREA) [70] as part of a unification process for all of the DRB laboratories. In 1974, the DRB itself was dissolved and replaced by the new office known as the Chief of Research and Development (CRAD). The recently renamed laboratories were placed under the control of CRAD.

The DREA name lasted for 33 years. In 2000, DREA was renamed Defence Research and Development Canada Atlantic (or "DRDC – Atlantic," for short), and its current name is DRDC – Atlantic Research Centre. Similarly, all the remaining laboratories were renamed to reflect the changes in management and organizational structure.

12.3 The Early Years

As the Second World War progressed, the problem of countering the German magnetic mines became manageable, and the research effort was expanded to address other concerns. Between 1942 and 1944 the group worked on ship structures (often to support changes in the degaussing coils and associated controllers), cathodic protection against corrosion, and anti-acoustic torpedo gear.

By the end of the European war, NRE was large and very busy, having added the investigation of electromagnetic propagation and undersea communication to its sphere of activities. However, it was not able to support the war in the Pacific directly, and its importance waned. In 1946 its staff was cut drastically. Fortunately for the organization, the defence need for scientific support had been clearly established, and a small group stayed on to build a peacetime establishment. Chapter 1 provides details on the formation of the Defence Research Board in 1947.

By 1952, DRB was well established with NRE as one of its laboratories in a brand new building on Grove St. in Dartmouth. At that time the NRE laboratory was the largest building in Dartmouth (NS) (Figure 125).[5]

Figure 125: *A picture of the former DRDC Atlantic Laboratory. In 1952 the main building was smaller. There have been four extensions added to the original building, and none of the outlying buildings was in existence in 1952 except for the historic "French Cable Building" in the foreground (centre). Photo credit: DRDC.*

The laboratory's research work continued to expand in scope, and before long it included active and passive sonar, sonobuoys, hydrofoils, seawater batteries, physical chemistry, metallurgy, and the relatively

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[5] Editor's note: This building was demolished in 2019 after a new building had been completed on the site.

new science of oceanography. All of this work was essentially driven by two major themes: undersea warfare and naval platforms.

The work in underwater acoustics continued to grow until it occupied the majority of the research effort at the laboratory. In the meantime, the work in degaussing and electromagnetism decreased in scope, with the majority of the work in these areas being pursued on the west coast at PNL/DREP (Section 8.3).

DREA never maintained a continuous Arctic research program. However, at intervals the lab exhibited surges of interest in the Arctic and in topics related to it. The remainder of this chapter summarizes their Arctic work.

12.4 Early Arctic Work

The first Arctic-related research, corrosion effects on icebreakers, was carried out in the late 1950s [71]. In the 1960s research began on acoustics in ice-covered waters with most of the early work being carried out in the Gulf of the St. Lawrence. The Gulf is not in the Arctic, but the work, which included ambient noise, reverberation, propagation loss, and polar front scattering, was applicable to Arctic waters. Figure 126 shows two digitized and enhanced scans of original Polaroid photographs of the ice cover in the Gulf between 2 and 4 February, 1964. The pictures were taken during an NRE trial that made use of the icebreaker CCGS SIR JOHN A. MACDONALD.

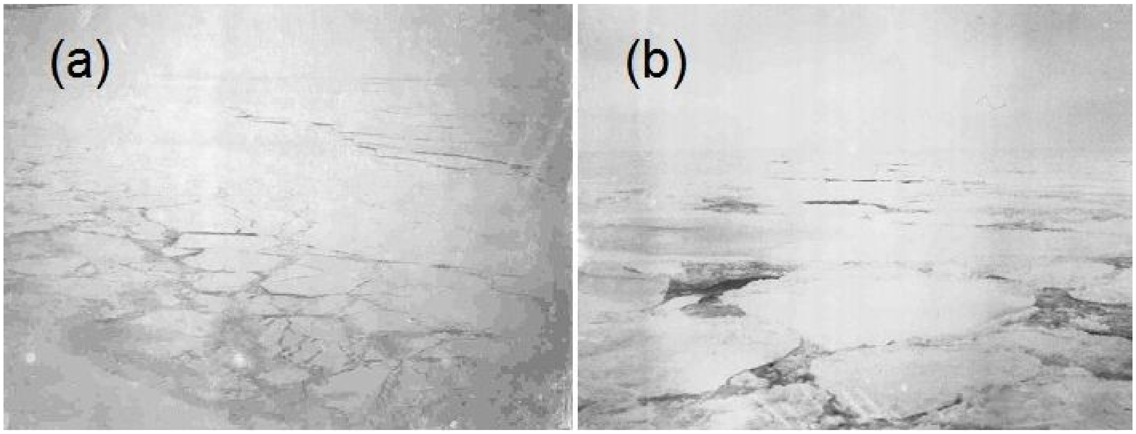


Figure 126: *Scanned copies of Polaroid photographs of the ice cover in February. (a) Feb. 2, 1964 and (b) Feb. 4, 1964. Photo credit: Ray Adlington.*

The research in ice-covered waters expanded to include semi-permanent sea-floor sensors, which were placed on the east side of the northern tip of Cape Breton (NS). However, the sensor cables that ran ashore to the field station were too exposed to the ice, and they were destroyed where they crossed the foreshore. This presaged the problems that DREP was to face later in the High Arctic.

The solution to the problem was to move the cables and the shore station to a more sheltered region where the persistent winds did not result in such damaging ice pressure. The red dot on Cape Breton in Figure 127 is near the location of Bay Saint Lawrence, where DREA established the Cape North Field Station and installed acoustic sensors on the sea floor. Various noise and reverberation studies were conducted at this location over a period of several years before the site was closed. Figure 128 shows what the field station looked like around year 2000. The shack had been left standing at the request of the land owner.

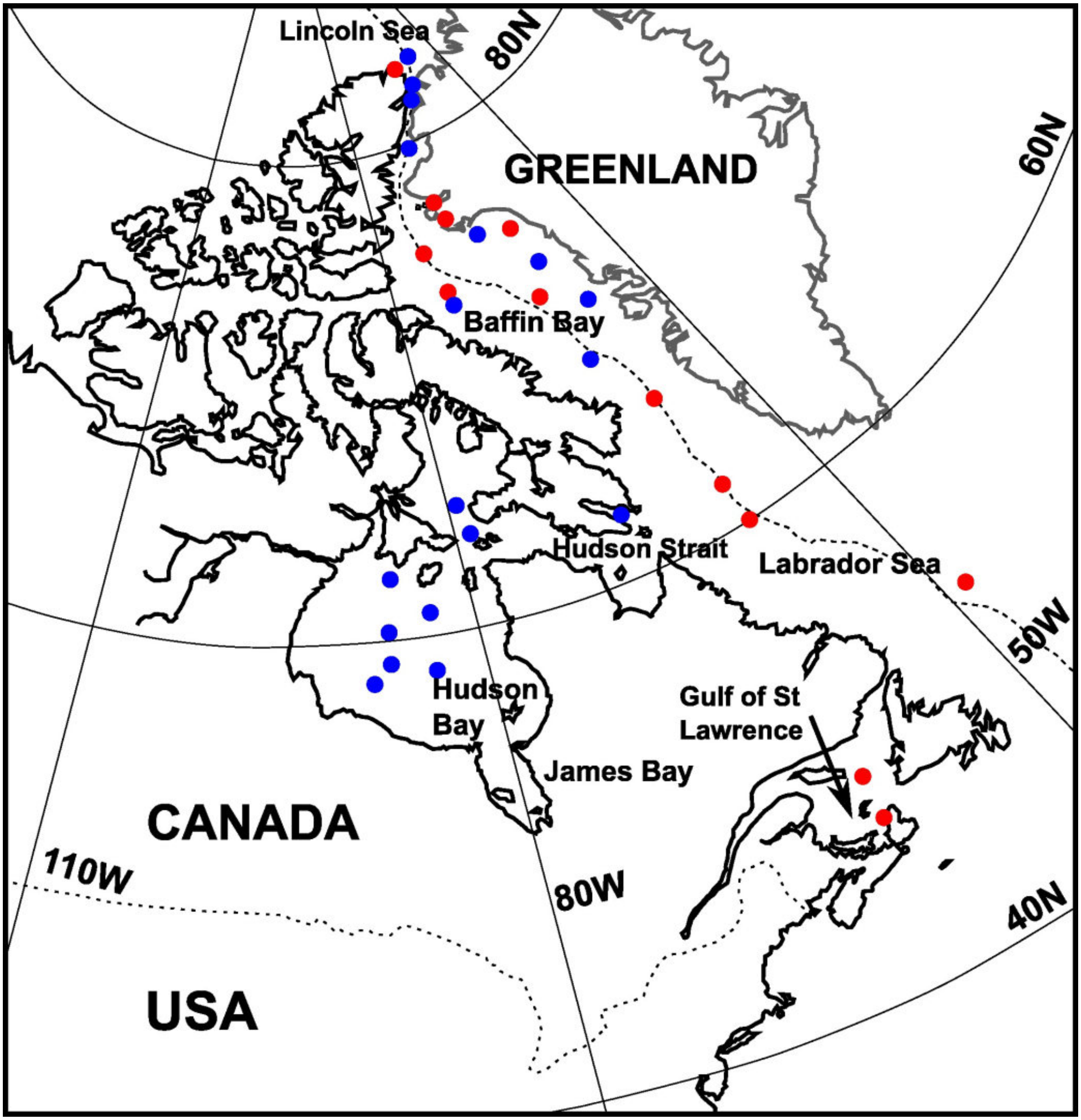


Figure 127: *A map giving the location of DREA's undersea work near Cape Breton Island and in Baffin Bay and Hudson Bay. Blue dots indicate the locations (often approximate) of sonobuoy installations, and red dots indicate where other types of sensors were used.*

Figure 127 shows a map of eastern Canada. The main intention of this figure is to show the large area of Baffin Bay and Hudson Bay that was investigated from the mid-1960s to the early 2000s. Blue dots represent the (very) approximate locations of sonobuoys deployed during the 1970s mostly by Argus aircraft flying Northern Patrols (Figure 129).

Figure 128: *The DREA Cape North Field Station as it appeared roughly 30 years after it was shut down. Photo credit: Garry Heard.*

Figure 129: *Maritime Proving and Evaluation Unit (MPEU) "SLARGUS" supported the DREA field trials in the 1970s. This particular aircraft had a Side Looking Radar; hence, the nickname. This photo shows the plane being refueled at Summerside in 1973. Photo credit: Art Millet.*

Unfortunately, details of the explosive sound source experiments of the 1970s and 1980s are not available and, therefore, their locations cannot be shown on this map. The same is true for sonobuoy drops from the 1980s. The red dots represent field work where the lab used sensors other than sonobuoys. In particular, they often used a small cross-dipole array (Figure 130). This array allowed the estimation of ambient noise levels, the direction to the noise source, transmission loss, and reverberation levels.

Figure 130: *The DREA crew photographed in 1972 on CFAV QUEST near Thule, Greenland. Back Row: (left-to-right) Art Millet, Harold Merklinger, Art Collier, Jack Wolfe. Front Row: (left-to-right) Lewis Hillier, Gary Cooper, M.W. Blades, Bill Kiley. The Cross-Dipole array is at the centre of the picture. Mt. Dundas, commonly known as Bottlecap Mountain, is just visible on the left. Photo credit: Art Millet.*

In 1970, work in the Arctic proper commenced with a NORPAT (Northern Patrol) mission flown by an ARGUS aircraft that dropped calibrated sonobuoys to measure the ambient noise and transmission loss in northern waters. Maj Gerry LaPointe led this work, and his results indicated a surprisingly high level of ambient noise in northern Baffin Bay (blue dots in Baffin Bay in Figure 127 on page 159).

The high noise levels were initially thought to be the result of some unidentified error. However, in 1971 Maj LaPointe repeated his noise measurements and confirmed the high levels. Comparison with data recorded on CFAV QUEST in the same year (Chief Scientist, Ray Adlington for cruise Q3) showed that the increased noise levels were due in part to the start of geophysical prospecting in Baffin Bay.

In 1972, QUEST went north again. Harold Merklinger was the Chief Scientist for the trip northward and John Moldon the Chief Scientist for the trip south. This trip was named CANUS BAFFIN and was QUEST cruise Q17. They worked in the Labrador Sea, Davis Strait, and Baffin Bay (Figure 127, page 159). ARGUS aircraft accompanied the ship for a least a portion of this trial. Figure 130 shows some of the science crew posing with their gear and Figure 131 shows the ship with Mt. Dundas near Thule in the background.

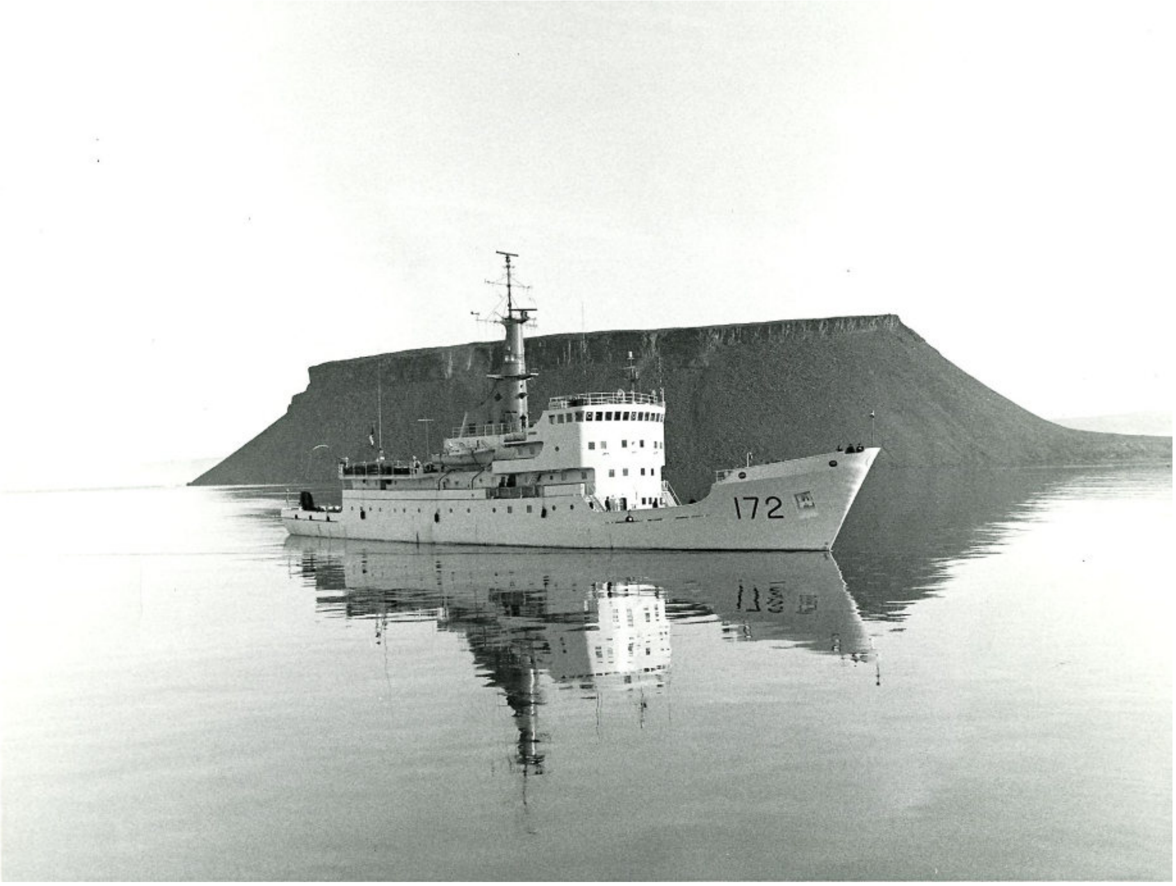


Figure 131: *CFAV QUEST in front of Mt. Dundas (sometimes called Bottlecap Mountain) near Thule, Greenland. Photo credit: DND.*

In 1973, further ARGUS flights (Figure 129, page 160) dropped sonobuoys and explosive sound sources in the Lincoln Sea and Nares Strait (again refer to Figure 127 of page 159 and the most northerly blue dots). The ARGUS also dropped charges in Wolstenholme Fiord (Figure 127, the second-most northerly red dot), while some of the crew (Harold Merklinger, L.W. Davidson, A.E. Millett, K.E. Anderson, and photographer C.R. Yool) worked from an American landing craft and detected the explosions with an acoustic Cross-Dipole array (Figure 130). The measurements in the fiords were primarily to look at reverberation effects.

One amusing part of the trial was the field laboratory, which is shown in Figure 132. An old bus that had long since had its engine removed was placed on a landing craft and used as a shelter. The recording equipment was installed on this bus, and batteries were used for the electrical supply. The strongest memory of the participants was just how cold they were. The landing craft was turned off to keep things quiet, and even in the summer the uninsulated "laboratory" provided little shelter and even less warmth.

Figure 132: *A old bus, missing its engine, was placed on a landing craft and used as a laboratory to conduct measurements in the fiords. Photo credit: C.R. Yool.*

Frobisher Bay and Thule were again visited by both aircraft and CFAV QUEST as part of cruise Q27 (1973). This trial had the objective of collecting underwater acoustic information in Baffin Bay, Davis Strait, and the Labrador Sea. Seven different sites were visited and these are marked as red dots in Figure 127 (page 159). During this trial Merklinger was able to confirm the high noise levels measured earlier by LaPointe. He showed that geological exploration activities, noise from rolling icebergs, and thermal cracking events were the cause.

In 1975, Harold Merklinger took the QUEST on cruise Q44 to Hudson Strait and Hudson Bay with the objectives of measuring underwater ambient noise and transmission loss (for the transmission-loss measurements they were supported by aircraft). They also gained familiarity with the water properties and ice conditions in the area, and tried out a low-light television system that was being developed by DREO. The noise levels measured during this trial were more in line with those measured by DREP at other Arctic locations. Also, icebergs are rare in this area, and this reinforced the observation that, when present, they are a major contributor to the ambient noise.

After the last CFAV QUEST northern trial in 1975 the lab stopped almost all its work in the Arctic for about ten years. The only Arctic-related work reported during the 1970s was concerned with the noise of ice breakers [72] and the anticipated noise of ships capable of transporting liquid natural gas (LNG) through heavy ice [73]. Undoubtedly, this topic was inspired by The Arctic Pilot Project, which was a proposal for shipping liquid natural gas from Melville Island through Baffin Bay down to the markets of eastern North America. The Greenland government was very concerned about the noise of the enormous icebreakers and its effect on their sea-mammal “fishery.” Consequently, an international conference on this subject was held in Toronto (ON). A summary of this project and its possible effects on marine mammals can be found in Reference [74].

Starting in 1986 there was another upswing in Arctic research at the laboratory. The CFAV QUEST was sent north in 1986, 1988, and 1989 on NORPLOY (Northern Deployment) trials in the company of HMCS CORMORANT. Dr. Joe Farrell was Chief Scientist for the NORPLOY ’86 trip northward, Q143, and Dr. Phil Staal for the trip south, Q144. Dr. John Stockhausen was the Chief Scientist for NORPLOY ’88, Q164. In 1989, Steve Hughes was Chief Scientist on the way north, Q175, and Dr. Garry Heard for the trip south, Q176.

All three NORPLOY missions were intended in part to support Canadian Sovereignty in the Arctic. NORPLOY ’86 focused on the study of ambient noise, propagation loss, and bottom properties. On the way north the CFAV QUEST towed an array that was used as a receiver, and HMCS CORMORANT towed a sound source. On the way south, DREA’s Shallow Water Group used the bottom-deployed Hydra Array [75] for similar purposes. During this NORPLOY, a CP-140 Aurora assisted them for six days while the ships made measurements at nine different locations. Midway through the exercise, the ships stopped at Nanasivic (NU) for a crew change, the crews being moved in and out of the Arctic by CF Hercules aircraft.

The objectives of NORPLOY ’88 were similar, but they specifically included the directionality of both noise and noise sources. Noise in the ocean is often directive, it does not sound the same or have the same level when you are able listen in selected directions. Similarly, noise sources can emit noise signals louder in some directions than in others. Understanding how the underwater noise changes in different locations is important for understanding how sonars work. The cruise also included some work on the coherent processing of distributed receiver signals. In a somewhat unrelated program, the crew tested an underwater propeller-viewing facility that was fitted to the ship. The ship visited a dozen different field locations and had five days of CF Aurora support. This was the only NORPLOY that was not split into two different sea trials.

NORPLOY ’89 again involved Maritime Patrol Aircraft (MPA) and HMCS CORMORANT. The primary objective of sea-trial Q175 (northbound) was the measurement of ambient noise, bottom properties, reverberation, and propeller performance. Some of the CFAV QUEST scientific crew for Q175 are shown in Figure 133. The scientific crew for HMCS CORMORANT included Gary Cooper, Ivan Bond, Lewis Hillier, Greg Baker, and Peter Bugden (Dalhousie University). The objectives of the southbound portion, Q176, were noise distribution and directionality, human factors, optical properties of sea water, atmospheric imaging, and navigation systems. The science crew for the southbound journey included Garry Heard, Doug Caldwell, Gary Shupe, Mark O’Connor, Mel MacKenzie, Bill Kiley, PO1 Whitman, plus the following group from DREV: Paul Pace, Georges Fournier, Ghislain Pelletier, Denis Bonnier, Jacques Tremblay, and Gilbert Tardiff. R. Kaufmann from DCIEM and Lt John Newton from CFFS were also participants. The crew for the southern leg (Q176) was taken by CF Hercules to Nanisivic, where the crew change took place. Lt Newton later became a Rear Admiral and the Commander of Maritime Forces Atlantic (2013).

Of course, any time a ship—especially a Navy ship—crosses the Arctic Circle, there is a special visit from King Neptune and his entourage. These NORPLOY trials were no exception.

All newcomers to the Arctic domain are called forward to receive a welcome and to pay some sort of humiliating price. Sometimes the new subject is shaved by the Royal Barber, and sometimes he (or she)

Figure 133: *The scientific crew for QUEST on the northern-bound portion of NORPLOY '89 (Q175). Left-to-right: Mike Haggarty, Ora Keirstead, PO1 Whitman, David Chapman, Bill Kiley, George Gill, John Olson, Tom Duffett (Dalhousie), Doug Caldwell, Roger (Gee Hung) Chan, Joyce van de Vegte (DCIEM), Steve Hughes, Wayne Higgins, and Dave Wheaton. Missing from picture: F. Desharnais, Bob MacDonald. Photo credit: Francine Desharnais.*

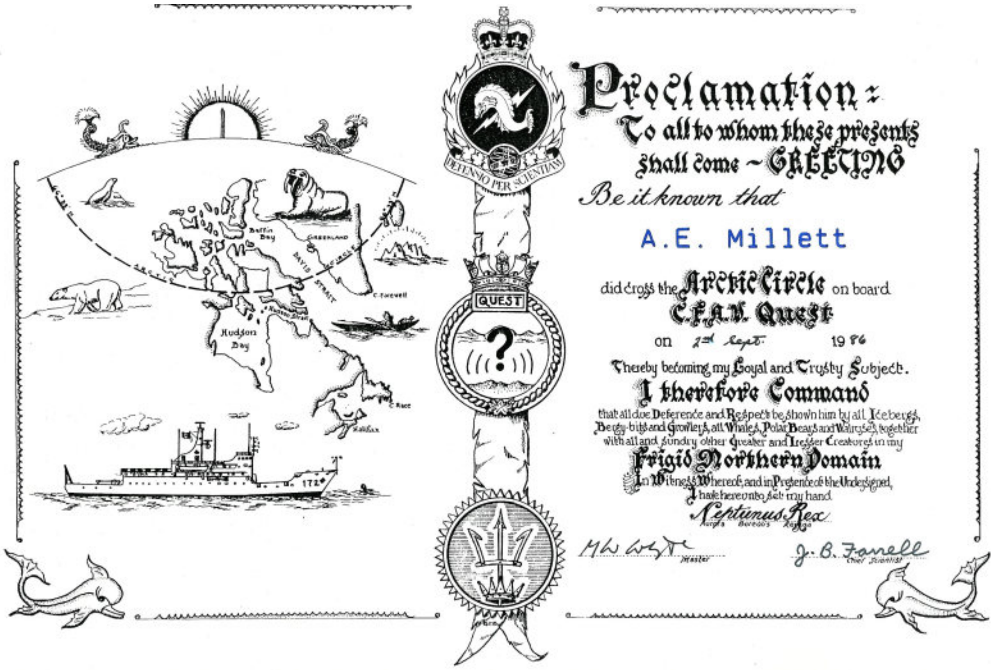
is made to eat something that is less than appealing. Figure 134 on page 166 shows Dave Wheaton being shaved (note that he did not actually lose any hair).

After having been welcomed to the North, the victims receive a keepsake certificate that will "protect" them on future trips (Figure 135, page 166).

HMCS CORMORANT accompanied each of the NORPLOY trials. It carried the deep diving submersible, SDL1, which was used to collect sea floor samples, observe sensors, and conduct other missions (Figure 136, page 167). Few people get to see the ocean depths, but occasionally a DREA person was given the opportunity of going down. Just like crossing the Arctic Circle, a deep dive is a significant event, and the crew of SDL1 issue commemorative certificates to each of their passengers. Art Millett was one of the volunteers who got the chance to go deep. His certificate is shown in Figure 137 on page 167.

Following these three NORPLOY missions there was another decade-long lull in Arctic interest. During this interval the collected data were analyzed (primarily by Francine Desharnais), and a series of papers on bottom properties were published.

Figure 134: *Dave Wheaton receiving a shave from the Royal Barber during the 1989 Arctic Circle Crossing ceremony. Photo credit: DRDC.*



Proclamation:-
To all to whom these presents
shall come ~ GREETING
Be it known that

A.E. Millett

did cross the Arctic Circle on board
C.F.A.V. Quest
on 2nd Sept. 1986
Thereby becoming my Loyal and Trusty Subject.
I therefore Command
that all due Deference and Respect be shown him by all Icebergs, Bergy-bits and Growlers, all Whales, Polar Bears and Walruses, together with all and sundry other Greater and Lesser Creatures in my
Frigid Northern Domain
In Witness Whereof, and in Presence of the Undersigned, I have hereunto set my hand
Neptunus Rex
Aurora Borealis Regina

Master

J. B. Farrell
Chief Scientist

Figure 135: *After having crossed the Arctic Circle newcomers are given an Arctic Crossing Certificate. This shows Art Millet's certificate received during NORPLOY '86.*

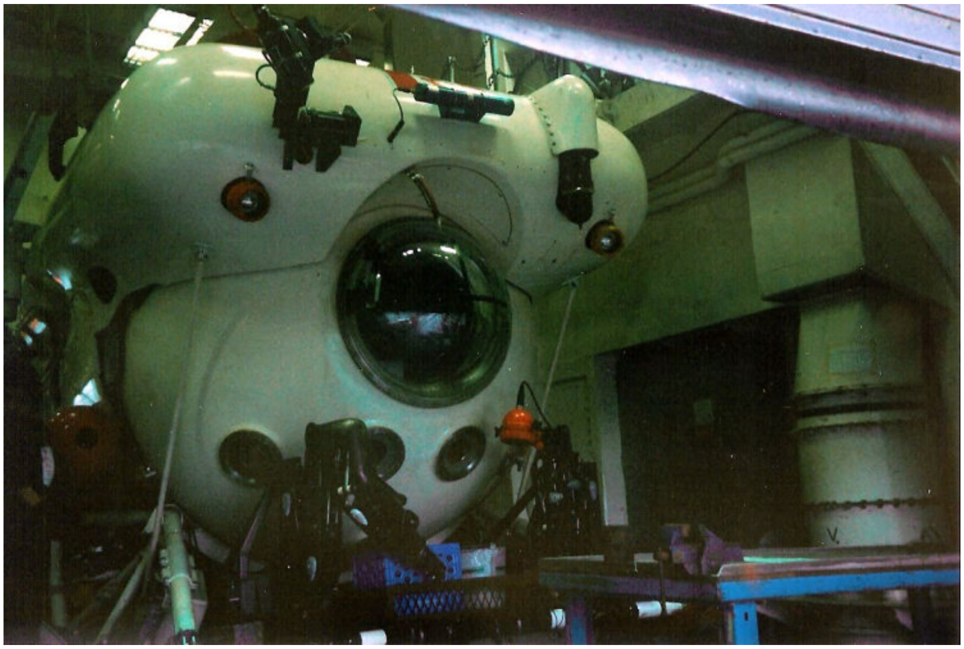


Figure 136: *HMCS CORMORANT's deep diving SDL1 submersible. Photo credit: Art Millett.*

CANADIAN FORCES
DEEP SUBMERSIBLE PROGRAM

Be it known to all Sailors of the Seven Seas that

A. MILLETT

descended in SDL-1 to a depth of 600' feet on this 16 day of SEPT., 19 86. In consequence of such meritorious submergence and initiation into the mysteries of the deep, he is hereby designated an

HONORARY DEEP DIVER

SDL-1 Co-Pilot
BAILLIE

SDL-1 Pilot
LATUS

Figure 137: *Some scientific crew members had the opportunity to go on a mission in the SDL1. A deep diving certificate was issued to those who went below 600 feet from the surface. Photo credit: Art Millett.*

12.5 Work in the High Arctic

In 1995 Garry Heard transferred from DREP to DREA and in 1998 was appointed the leader of the Surveillance Acoustics Group. That same year Heard participated in a DREP field trip on the Arctic Ocean north of CFS Alert. This was farther north than the DREA people had previously worked, and this time there were no ships involved. For Heard this was a training and familiarization exercise. DREP was in the process of closing, and Heard hoped to be able to continue the Arctic work that they had been doing.

When DREP closed and Project SPINNAKER (Section 8.2.5) had wrapped-up (1998), several of its Arctic personnel transferred to DREA on the east coast. A few individuals with Arctic experience and a few more without such experience became members of the new Surveillance Acoustics Group. Their first field trial, called “ICESHELF 1999,” was held the following year on the shore-fast ice near CFS Alert. It was the first DREA Arctic field trial that did not involve a ship. Figure 138 shows some of the crew. It also shows some personnel from DREO who became long-term collaborators with DREA in the Arctic.

Figure 138: *Some of the ICESHELF 1999 participants are shown enjoying a coffee break in the kitchen tent. From left: Ron Verrall, Mike Vinnins (DREO), Dan Wile, Michael Haggarty, Gordon Ebbeson, Lloyd Gallop (DREO), and Capt Richard Van der Pryt. Photo credit: Garry Heard.*

ICESHELF 1999 was primarily a learning experience, but it was also the beginning of two new lines of work. The first was the geobuoy work, described in Section 7.4, and the second was the use of hydrophone arrays made with a new and developing digital technology (Figure 139 on page 169). The digital array technology, now known as Rapidly Deployable Systems (RDS) was eventually to play a large role in DREA’s Arctic work.

Figure 139: *Don Richard and Mel MacKenzie are shown with an early version of an acoustic array built using the developing RDS digital array technology. They are in the process of deploying the array through a 6-inch diameter hole in the ice. Photo credit: Garry Heard.*

In addition to the underwater acoustics work, ICESHELF 1999 also collected bacteria from the bottom of sea ice to support a study by Dr. Francis Nano of the University of Victoria (BC) on bacteria that are able to survive sub-zero temperatures (for example [76]). DREA also provided assistance to Environment Canada personnel who were investigating the mercury content of freshly fallen snow in the Arctic.

In September 1999 a DREA crew again visited Alert. The project this time was to clean up an old warehouse that had been used by an earlier project. A major benefit was the experience of learning the ways of CFS Alert and of working in the Arctic during the summer. Figure 140 shows the wet and grey conditions encountered during much of the summer's melt.

Figure 140: *Clean-up work at CFS Alert in the cool, wet, and muddy conditions typical of summer's melt in the Arctic. Photo credit: Al Tremblay.*

DRDC Atlantic carried out more field trials at CFS Alert in 2000 and 2002. The 2002 expedition was a large experiment with participants from SPAWAR Systems Center, Benthos (now Teledyne Benthos), Environment Canada, DRDC – Ottawa Research Centre, and the Canadian Armed Forces (Figure 141, page 171). This trial was the first field experiment for the just-established Rapidly Deployable Systems (RDS) Technology Demonstration Project (TDP).

Of particular interest were experiments involving communications between underwater modems. Another experiment showed the possibility of determining the location of an underwater package by acoustic means.

The cost of DRDC – Atlantic Research Centre's Arctic research was high, even though costs were kept down by working close to the shore near Alert. Further research, to be operationally relevant, would have

Figure 141: *Iceshelf 2002 participants in front of the Camp Bearadise. The camp mascot is in front—a 1/2-m-tall plastic penguin that materialized on the site. The remote camp where a kytoon was used to drop geobuoys for Ottawa is visible as a red point in the distance. Front Row: (from left) B. Creber (SPAWAR), C. Fletcher (SPAWAR), P. Richer (DREO), D. Mosher, D. Richard, N. Collison, S. Dosso (UVIC/SEOS), F. Desharnais, A. Tremblay, D. Edwards (contract cook), K. Whalen. Middle Row: (from left) J. Lang (DREO), G. Heard, Lt G. White, J. MacInnis (MDA), Capt R. Van der Pryt (CF), D. Thomson, Pte S. Nantais (CF), B. Jovic (contractor), L. Gallop (DREO), I. Bond, M. Boyle (DREO), G. Ebbeson, D. Wile. Back Row: (from left) J. Rouleau, M. Vinnins (DREO), R. Apps (DREO), K. Amundsen (Benthos), M. Rowsome, V. Shepeta, M. Haggarty, R. Verrall, J. Milne, and MS B. Keeping (CF). Photo credit: Janice Lang, DRDC – Ottawa Research Centre.*

to be done farther out on the Arctic Ocean, and the cost of chartering the necessary aircraft was too high for the lab to bear. Without a stable source of funding, they had to put the Arctic work on hold. In 2003, DRDC – Atlantic Research Centre supported DRDC – Ottawa Research Centre in one final trial to complete the work on the directional geobuoy project and to test the GPS units that were candidates for the Defence Advanced GPS Receiver (DAGR) (Section 7.4).

During the following four or five years, many of the experienced personnel retired. These losses, plus the shortage of funding, did not bode well for a continuing Arctic Program. However, DRDC – Atlantic Research Centre still owned many physical resources in the Arctic, mainly at CFS Alert, and—to a lesser extent—in Resolute Bay (NU). At CFS Alert, for example, they had a large building, many tents, stoves, snowmobiles, generators and other equipment necessary to run an Arctic field camp.

Although there were no official DRDC – Atlantic Research Centre field trials in the Arctic during these lean years, their equipment was used to support other agencies (Canadian, American and European) with their Arctic research. This assistance was coordinated primarily by Jim Milne and Al Tremblay, both senior technologists at DRDC – Atlantic Research Centre. The lab charged a fee for this rental work, and the income was much appreciated by DRDC, which had a responsibility to generate as much of their own funding as possible.

The list of organizations and projects supported by DRDC personnel and equipment is long and quite impressive. It includes:

- Environment Canada's Polar Sunrise 2000 and Out On The Ice (OOTI) projects;
- Science Applications Internal Corporation's Arctic Climate Observation using Underwater Sound (ACOUS);
- University of Washington's Polar Science Center (UW-PSC) and their North Pole Environmental Observatory (NPEO);
- Long Term Observatory (LTO);
- Lamont Doherty Earth Observatory (LDEO) projects;
- International GreenIce, led by the Scottish Association for Marine Science, and the follow-on GreenArc projects;
- The Canadian Sea Ice Mass Balance Observatory (CASIMBO);
- Scripps Institution of Oceanography's Switchyard project;
- Department of Fisheries and Ocean's Canadian Archipelago Flow-Through (CAT) project;
- Canadian and Danish United Nations Convention on the Law Of the Sea (UNCLOS) projects; and
- The International PAM-ARCMIP (Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project) to ground-truth data from the CRYOVEX 2 satellite.

Thus, while DRDC Atlantic's own program did not directly include an Arctic-related component, their contact with other Arctic groups maintained an interest and a certain skill level, and—not insignificantly—it ensured that the northern equipment was maintained.

Beginning in 2007, DRDC again started to look to the Arctic with a real interest. Two large new projects became important both to DND and to the government as a whole. The first one, a DND undertaking, is the Northern Watch Technology Demonstration Project (abbreviated as NW TDP or just NW), and the second, which is a part of the Natural Resources Canada (NRCan) UNCLOS project, is called Project CORNERSTONE.

12.6 The Northern Watch Technology Demonstration Project

For the past several decades there has been ever-increasing evidence that the Arctic is warming and that the total amount of Arctic ice is lessening. In particular, the extent of the summer ice cover has been decreasing, and the multi-year polar ice is mostly gone from the Northwest Passage. A reasonable expectation, of course, is that the amount of ship traffic through the Passage will burgeon. According to a Library of Parliament Brief, the number of ships transiting the Northwest Passage has gone from seven in 2009 to 18 in 2010 and to 27 in 2011 [77].

The Canadian government has recognized the world's increasing interest in the Arctic and its own increasing responsibility for sovereignty and safety. Prime Minister Harper has made a number of statements emphasizing his government's concern for the Arctic, and this concern has manifested itself, in part, as support for the Northern Watch Technology Demonstration Project.[6]

The purpose of the Demonstration is to install a set of sensors that will automatically and autonomously detect ship traffic (both above water and below) passing through an Arctic Strait. Several DRDC laboratories are involved, with each one responsible for a different set of sensors. DRDC – Atlantic Research Centre is looking after underwater acoustic sensing. It is also responsible for general Arctic field operations, and it has taken the lead in system integration and project management. DRDC – Valcartier Research Centre is responsible for electro-optical sensors and meteorological measurements, DRDC – Ottawa Research Centre for radar and radio detection, and the Centre for Operational Research and Analysis (CORA) for evaluation and integration of the data into the military system.

The strait that they chose for this Demonstration was Barrow Strait, the main east-west passage through the Archipelago, and they used the old DREP camp at Gascoyne Inlet (NU) as their headquarters (Figures 87 and 88 around page 110, Section 8.2.3.2). The Project started in early 2007 with project definition and planning, and the first field trial got under way in the summer of 2008.

Somewhat later in the life of the project, the Communications Research Centre (CRC) Canada was included to help define the satellite communication requirements. Also, a partnership was developed with Jim Hamilton of the Bedford Institute of Oceanography (BIO) for collaboration in laying a cable to carry information from oceanographic instruments to shore. The result is DFO's Real-Time Arctic Ocean Observatory [78]. Another partnership is currently being developed with the Geological Survey of Canada (of NRCan). Seismic and atmospheric infrasound sensors may be installed at the Gascoyne camp, and, hopefully, interesting science will develop from comparing data from the infrasound, seismic, and underwater sensors. Figure 142 gives an indication how data is being collected from oceanographic sensors in Barrow Strait, cabled to Gascoyne Inlet, and sent south.

The first field trial, which was held in 2008, was particularly difficult. First of all, the weather was very bad, with almost continual fog preventing aircraft from flying and generally keeping everyone close to the immediate camp area. Secondly, the majority of the participants had no field experience in the Arctic. Finally, the buildings were in bad shape. The site had not been used for more than 20 years, and the shacks, which had never been intended as permanent structures, were definitely showing their age. One of the buildings had been inhabited by bears, and all of them had leaked and were riddled with mildew. The poor condition of the buildings meant that the accommodation was rather primitive, and no-one was particularly happy with that. Figure 143 shows the state of the camp at the beginning of the project. Since then, the camp has been rebuilt with a new kitchen and mess facilities, new sleeping and working areas, new wiring, and a new water supply and sanitary system.

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[6] Editor's note: Recall this book was completed in 2012.

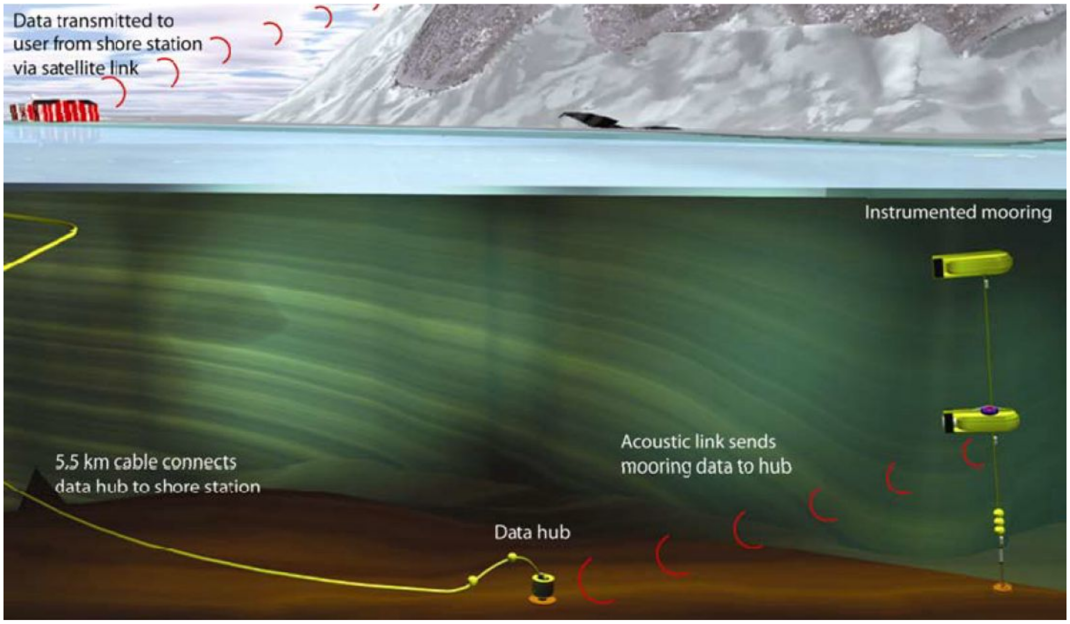

Figure 142: *The sketch shows how data from moored instruments in Barrow Strait is sent south and displayed on the Internet. Photo credit: Bedford Institute of Oceanography, Dartmouth, NS.*

Figure 143: *The Gascoyne Inlet camp had been left unused for many years and was in need of considerable repair. Photo credit: Jacques Rouleau.*

Living conditions have improved immensely. A bear-alarm fence has been built around the whole complex in order to give warnings of bear intrusions. The fence does not actually keep the bears out; rather, it immediately announces their presence as the bear stumbles through a trip-wire. Figure 144 shows the rebuilt camp as it existed in the summer of 2012.

Figure 144: *The Gascoyne Inlet camp photographed from an unmanned aerial vehicle in summer 2012. Photo credit: Paul Pace.*

None of the underwater sensors were deployed in 2008. However, some of the light-weight underwater cables and repeaters were laid. The problems of this deployment provided valuable experience, and this made the 2009 operation much easier. The cables and repeaters were left on the sea floor, and when they were examined the following year they were found to be fully functional.

The 2009 field trip was much more successful. The weather was much better, even though the summertime fog did occasionally show its presence. The lessons of 2008 had been taken to heart, and new equipment for the deployment and recovery of cable had been built. Figure 145 shows the very successful new cable-recovery system.

Before they were recovered, the telemetry cables laid the previous year were tested and found to be fully functional, which was very reassuring to the system designers. However, once the cables were recovered, the designers found that the junction cables (known as "pigtails") had been nibbled by some kind of animal life (sea urchins are suspected). In just one year the nibblers had stripped some of the copper wires bare. A tentative fix was to wrap the edible cable with a double layer of vinyl tape in hopes that this would repel whatever was feeding on the insulation.

Figure 145: *A Coast Guard unpowered barge (known as a "dumb barge") carrying a large powered reel is used to recover the telemetry cable. The barge is propelled by a motorized shore-patrol barge. Photo credit: Dan Hutt, DRDC – Atlantic Research Centre.*

A suite of underwater sensors was deployed during the 2009 field trip. Figure 146 shows one of the two arrays spread out on the deck of the unpowered barge just before it was lowered.

Unfortunately, both arrays failed after several weeks due to material incompatibilities. Nevertheless, the arrays provided the necessary proof of concept. Their ability to "detect" was quite adequate.

Although the arrays failed while the field trial was still ongoing, they were left in place in order to give the telemetry cables and the repeater units a long immersion test. They were left on the bottom until 2011 (a two-year duration), at which time the cables and the repeaters were found to be fully functional. The vinyl tape, however, had not been a success: the "sea life" had eaten through it in order to get at the pigtail jackets.

A second-generation array was tested in Barrow Strait at the Gascoyne site during the summer of 2012 (Figures 147 on page 178 and 148 on page 179). Many changes were made, the major ones pertaining to the packaging of the components. For example, no dissimilar metals were used anywhere. Breakouts were moulded in the same plastic used in the array cable jacket, which resulted in a single unbroken skin, and

Figure 146: *A first generation Northern Watch array is shown laid out on the deck of the barge. The cable reels hold the telemetry cable that transmits the array data to shore. Photo credit: Dan Hutt.*

materials were chosen that are particularly unattractive to marine life. The cost of this new array was approximately double that of the first array, but the designers say that it was still very cost-effective. The cost of the entire underwater system was less than the cost of deploying it!

The 2012 field trial saw the installation of a number of sensor systems. Besides the underwater acoustic arrays, there were temporary installations of radar, electro-optical, radio detection, an automatic identification system (AIS) and automatic dependent surveillance-broadcast (ADS-B) receivers. CFAV QUEST participated in this trial. One of its main duties was to serve as a cooperative target for the sensors.

Another field trial is planned for summer 2014. If all goes well, the final version of the underwater sensors will be installed and tested during this trial. These arrays will remain in place and will be operated for the duration of the project. Other sensors will be installed and tested, and all sensors will be integrated into an overall system and operated for the duration of the project.

By the summer of 2014 all system sensors will have been installed, and the Gascoyne camp will be occupied by a small scientific team for a six-month period in 2015. They will conduct tests, starting when Barrow Strait is still covered with ice and continuing on through the summer. In 2016, final tests will be

Figure 147: *A second generation Northern Watch hydrophone assembly. The orange cable breakout is the same material as the black cable covering. The blending of colours at the interface points shows how the materials mix to create a continuous covering. Photo credit: Don Glencross.*

conducted, and the system will be removed. The final report of the Northern Watch project is expected by March 2016.

The Northern Watch surveillance system is a demonstration project and it is not intended to become operational. These types of projects are intended to provide the background for the development of operational systems if and when they are required by the CAF.[7]

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[7] Editor's note: The Northern Watch TDP did not play out as planned in 2012. The final trial was conducted in summer 2015 and the underwater arrays were deployed at that time. The project completed in early 2016. The underwater arrays were not removed as originally planned. They remained in the water and were tested in 2017 and 2019. Both arrays remained fully functional for four years. When the Coronavirus pandemic struck, field trials were not possible, and the next array test was not conducted until summer 2022; after the arrays had been in the water for seven years. Only one of the arrays remained functional for this test. The array will be removed in the future and examined. Overall, the project was a success, but not all the original goals were pursued. A technical summary can be found in Reference [79].

Figure 148: *A prototype second generation Northern Watch array ready for testing and calibration at the DRDC Atlantic Calibration Barge Facility. Photo credit: Derek Clark.*

12.7 Project CORNERSTONE

The United Nations Convention on the Law of the Sea (UNCLOS) defines the rights and responsibilities of nations in their use of the world's oceans. Article 76, the "Definition of the Continental Shelf," is the Article that is relevant to this work. It says that if a country wishes to claim an "extended" continental shelf that lies beyond the 200-nautical mile Exclusive Economic Zone (EEZ), it must submit scientific, technical, and legal details about the underwater territory in question to a United Nations Commission. It must show that it has a good knowledge of the water depths and of the nature of the bottom. This submission must be presented to the United Nations within 10 years of the nation's signing on to the Convention, and, since Canada signed the Convention in 2003, its submission must be made by 2013.

Canada's continental shelf beyond the EEZ is an area of approximately 1.5 million square kilometres (roughly the size of Quebec) split between the Atlantic and Arctic coasts. There is evidence of oil and other minerals in these regions, and it behoves Canada to make the appropriate studies. The Arctic work began in earnest in 2006 with a sub-bottom seismic investigation of the Lomonosov Ridge (in the Arctic Ocean). This study, and the subsequent work on the Alpha Ridge (also in the Arctic Ocean) in 2008, was done by the Geological Survey of Canada (GSC), which is part of the department of Natural Resources Canada (NRCan).

One of the important data sets to be presented to the United Nations is that of water depth (bathymetry). In the southern oceans, where ships have few restrictions to their travel, the acquisition of bathymetric data does not pose a problem. In the Arctic, however, the heavy ice creates an entirely different situation. Ships can get access to only part of the ocean and, even then, only part of the time. At locations that are inaccessible by ship, nearly all existing information has been measured with the aid of a helicopter. The depths are measured one point at a time, with the helicopter landing at a (hopefully) suitable spot on the ice, and an operator endeavouring to "see" the bottom with an acoustic bottom-sounder. If the ice is honeycombed with air pockets, an acoustic measurement is not possible, and the helicopter has to move on. Even more frustrating are the many days that the helicopter cannot fly at all because of bad weather.

In 2008 DRDC – Atlantic Research Centre became involved with a new and more efficient approach to gathering depth information. The idea is to send an autonomous underwater vehicle (AUV) out several hundred kilometres from an ice camp and have it make depth measurements along its route. Since the AUV can make a measurement every few seconds, it can generate a very detailed track. The data, which is recorded on the AUV, is downloaded from the vehicle when it returns to its launch site.

The project, known as "Project CORNERSTONE," was a joint effort involving National Resources Canada (NRCan) and DRDC. DRDC was responsible for the development of the AUVs and the necessary support systems.

Project CORNERSTONE was led by David Hopkin of DRDC – Atlantic Research Centre. Erin MacNeil and Michelle Renner alternated as the Project Manager for CORNERSTONE and Richard Pederson was the Project Engineer. DRDC personnel were seconded from several sections: Maritime Asset Protection, Underwater Sensing, Technology Demonstration, and Technical Services. The project team also included people from Memorial University and from International Submarine Engineering (ISE) of Port Coquitlam (BC).

In November 2008 a contract was given to ISE to build two long-endurance AUVs that would be capable of withstanding the water pressure at a depth of 5000 m. The vehicles, known as ISE Explorers, were ready by August 2009, and acceptance-testing was carried out from August through October. Testing at sea continued until February, 2010, and the vehicles were taken to the Arctic in March 2010. Figure 149 shows the two vessels at DRDC Atlantic.

The Arctic work had begun in the spring of the previous year (2009) when an Explorer AUV was borrowed from Memorial University and taken to CFS Alert. The purpose of this exercise was to familiarize the team with the logistics of handling the vehicle in the cold and on the ice. The team developed procedures for launching and recovering the vehicle, for aligning the navigational system, for handling the vehicle "tender," a small remotely operated vehicle (ROV), and for the many other tasks inherent in such a complicated operation.

One important requirement is for navigational aids. When the AUV gets to within several tens of kilometers from a recovery hole or a maintenance hole, it needs assistance in navigating the rest of the way to the freely drifting recovery location. At Alert the team tested two new acoustic systems. The first, which was called the long-range acoustic bearing (LRAB) homing system, gave directions to the vehicle when it was a long way from the recovery hole. The second, called the short-range localization (SRL), was a more accurate (but shorter range) navigational aid that directed the vehicle the last few kilometers to the hole. Both systems were developed by the Networked Autonomous Littoral Surveillance (NetALS) group at DRDC – Atlantic Research Centre.

The LRAB has proven itself to be a very effective system capable of bringing an AUV home from distances as great as 100 km. It has now been used repeatedly from fixed and drifting ice camps as well as from an icebreaker. The LRAB has become a key component of the AUV operations.

The short-range (SRL) system is quite high-tech and provides the AUV with accurate absolute location estimates. Generally, this system is not required for normal AUV operations. It was intended to be used to reset the AUV inertial navigation system after a period of operation without a Doppler "lock" on either the sea surface or the sea floor. Fortunately, the LRAB system worked so well, it has not been necessary to go to the effort of deploying the constellation of six Benthos underwater acoustic modems used by SRL.

If SRL must be used, then six modems are placed around the camp on a circle having a radius of approximately 1 km. A seventh modem is lowered down the AUV recovery hole. Each of the outer six modems is lowered through a small hole drilled in the ice. Each is equipped with a data radio for communicating with the camp, and each is provided with a GPS receiver so that its position is known at all times (this is particularly useful when the ice is rotating or when the modems are placed on disconnected ice sheets and are moving relative to each other). When the AUV is in acoustic range, it uses its own modem to query the modems in the constellation and determines its distance from as many modems as possible. Once all the available distances are known, the AUV is able to calculate its location relative to the recovery hole in the ice. The calculations are quite complex because there are factors such as moving modems, long suspension systems where the GPS only gives an approximate location for the modem, and intermittent communication links where noise and interference prevents range estimates to all modems being made every time.

12.7.1 Operation of the AUV from an Ice Camp

Borden Island (NT) is in the northwest section of the Canadian Archipelago (Figure 150). Access to that general area is difficult because it is a long way from either Resolute Bay or Eureka, the two closest places with long landing strips. The ice north of Borden Island is generally under compression, and this makes ice-breaker operations difficult. Helicopter surveys are hindered by frequent fogs, which prevent

Figure 149: *The two modified ISE Explorer AUVs are shown being tested in the Heavy Engine Laboratory at DRDC Atlantic. Various compartments are open, and the modular nature of the AUVs is apparent. Each Explorer breaks down into seven sections to facilitate transport in small boats or aircraft. Photo credit: Don Glencross.*

helicopters from flying. The net result is that there is a shortage of depth information north of Borden Island, and it is an area where such data are badly needed. This, then, was the area chosen for the first Explorer survey.

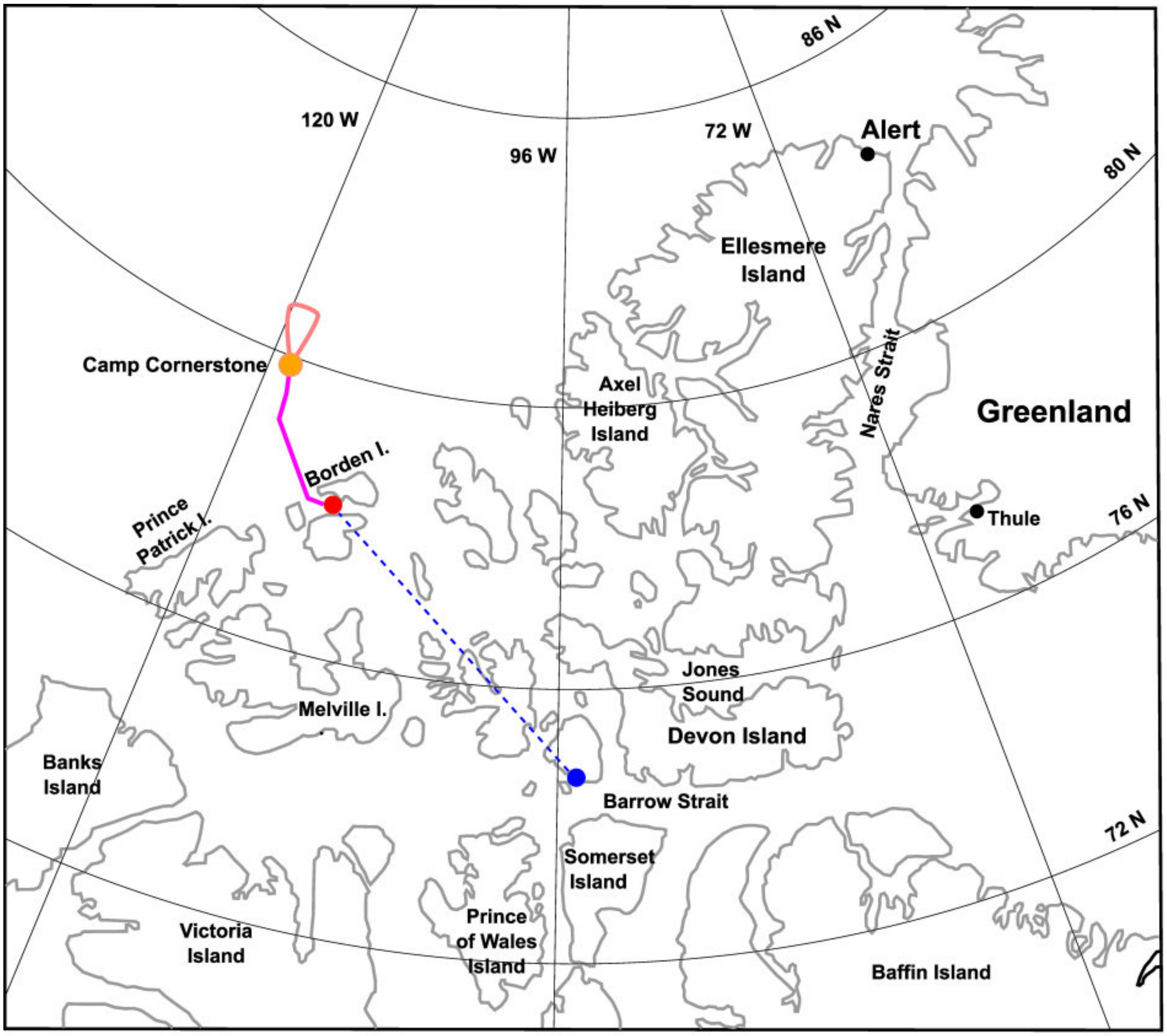

Figure 150: *This map shows the location of Camp Borden (red), the aircraft route from Resolute (dashed blue line), and the approximate AUV track (violet line and a looped pink line to/from Camp Cornerstone) to Camp Cornerstone (orange).*

In the spring of 2010, a base camp, called "Camp Borden," was established (78°13.5'N, 112°38.9'W) just south of Borden Island in the shore-fast ice trapped between Borden and Mackenzie King Islands.

Camp Borden grew into an extremely large ice camp housing many scientists with a great diversity of interests. As well as the AUV team, there were hydrographers measuring depths with acoustic sounders and scientists measuring gravity. And, as well as these "full time" people, visiting scientists could usually be seen going about their tasks. The camp routinely housed 40 to 50 people. Each morning the camp sounded like a major airport as four helicopters, two DC3s, an occasional Buffalo, and a varying number of Twin Otters took off. There were two runways as well as a helicopter parking area on the ice. Figure 151 shows the camp when it was nearly complete.

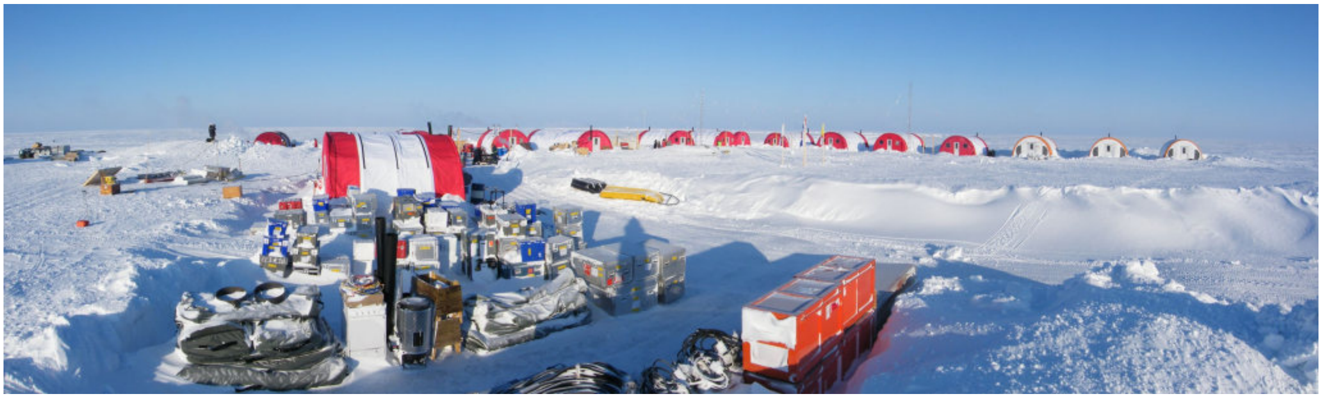

Figure 151: *A stitched composite photograph of Camp Borden under construction. Several more tents were added after this picture was taken making it a very large field camp. Photo credit: Garry Heard.*

The AUV team cut an 8 m by 3 m access hole for the AUV through ice that was 2 to 3 m thick (Figure 152). Figures 153 and 154 show the AUV Explorer in its "support" tent. Meanwhile the DRDC – Atlantic Research Centre crew installed a suite of underwater modems and all the other equipment necessary for the two navigational aids (Figure 155, page 187).

A second camp, known as "Camp Cornerstone," was established some 320 km to the northwest of Camp Borden. This was in the region where depths were to be measured. Here, a smaller ice hole (1.3 m by 2 m) was cut. This was too small for the recovery of the vehicle, but it was large enough for the ROV tender. The small ice hole also gave adequate access to the Explorer for recharging its batteries and downloading its data. Unfortunately, by the time the camp was completed, the ice drift had taken the camp too far from Camp Borden, and the whole camp had to be torn down and re-established at a more suitable spot. Figure 156 (page 187) shows the camp in its second incarnation.

After several test dives at Camp Borden, the Explorer was sent off to Camp Cornerstone on its first long under-ice mission. One can imagine the apprehension and concern as they gave the command to "Go." However, to everyone's relief, Explorer arrived safely several days later at the smaller camp (Figure 157 on page 188). The vessel autonomously homed to the ice hole where it was secured with the help of the small ROV. Explorer was recharged and stripped of its bathymetry data, and then it was sent further north to survey a ridge known as the Sever Spur (79°N, 115°W). Again it returned safely to Camp Cornerstone where the pit crew once again recharged it, took its data, and sent it back to Camp Borden.

Roughly two and a half days later, the AUV was detected signalling the Camp Borden control station, and the long worry was over. Recovery was relatively easy in the shallow water near the main camp. Before long the camp was in tear-down mode.

The achievements of the AUV Explorer were impressive. It had spent 10 days under the ice between launch and recovery. It had travelled nearly 1000 km making bathymetric measurements the whole way. It had reached depths of 3160 m (a pressure of 31 MPa or 4500 psi) travelling at an altitude of roughly 130 m above the seabed. Its average speed was 1.5 m/s (3 knots).

Figure 152: *A large hole is cut through the ice at Camp Borden. Photo credit: Garry Heard.*

The number of missions run during this field trial was fewer than what had been planned, but the results that were obtained were very useful. In particular, the entire scheme had been shown to be both possible and valuable. The missions had given the team experience, skill and confidence, and that boded well for the success of future operations.

A number of informal newsletters were created and distributed during the 2010 deployment of the AUV. These informal updates, which contain many more pictures and details than have been presented here, are available on the Internet [80].

12.7.2 Deployment of the AUV from an Icebreaker

The spring 2010 deployment of the Explorer AUV at Borden Island had been a great success, and much good data had been collected. However, the people preparing for the UNCLOS presentation in 2013 wanted as much data as possible—both bathymetric and seismic. Consequently, the Explorer went north again in 2011.

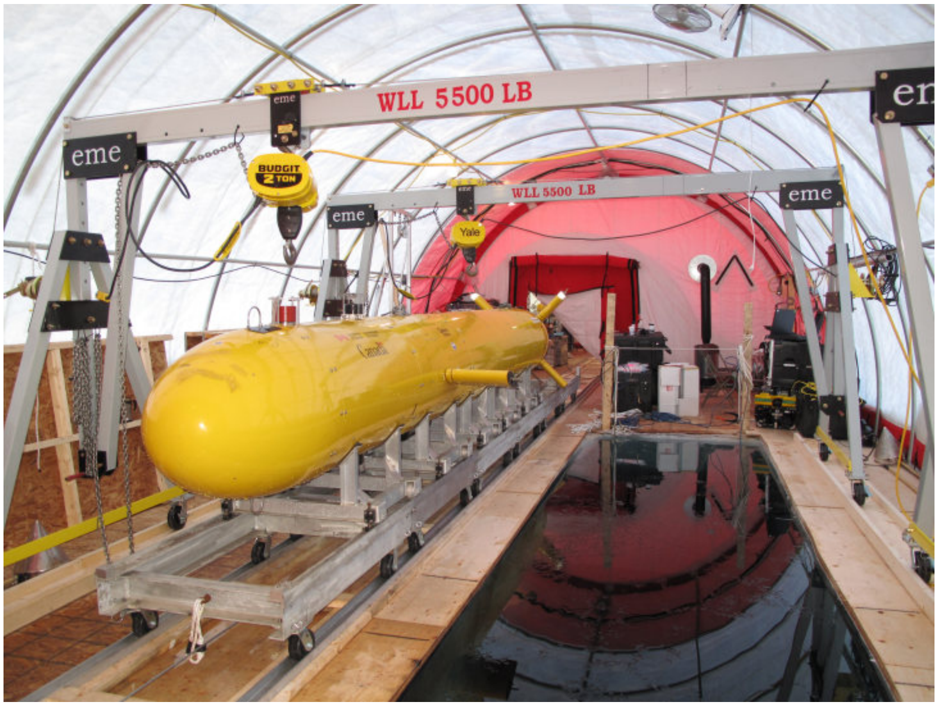

Figure 153: *An Explorer AUV is assembled and ready for launch in the support tent. Photo credit: David Hopkin.*

Figure 154: *This is the smaller rear portion of the support tent shown in the previous figure. It was used as a control station and workshop. Photo credit: Garry Heard.*

Figure 155: *Nicos Pelavas (left) and Val Shepeta (right) install a remote modem station on the moving ice. Photo credit: Garry Heard.*

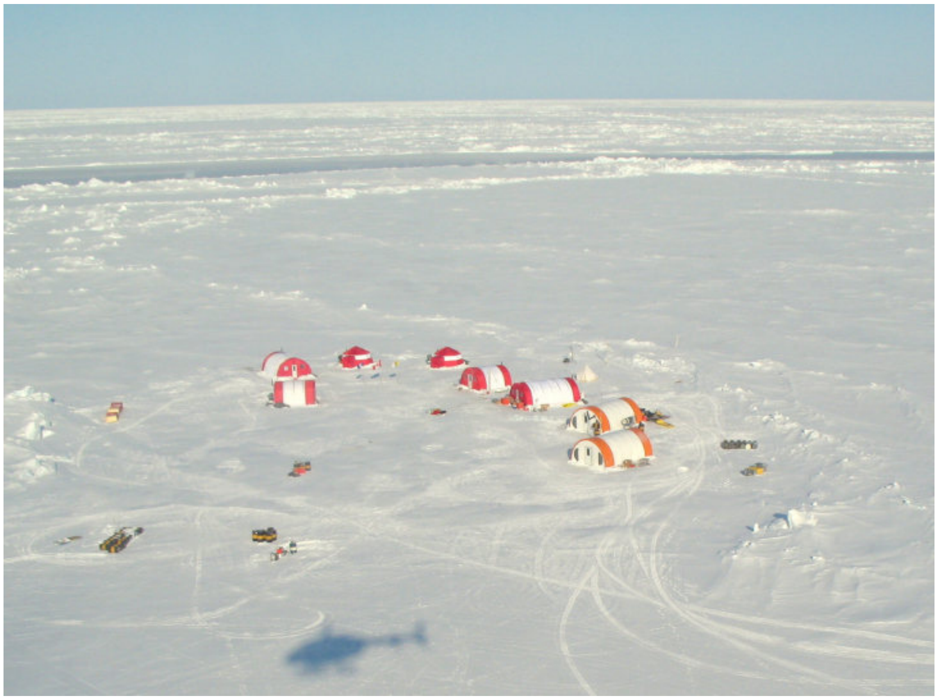

Figure 156: *A view of Camp Cornerstone and the new lead near the camp. Photo credit: Garry Heard.*

Figure 157: *Alex Forrest (contractor to ISE) works the AUV control station during a mission at Camp Cornerstone. Photo credit: Garry Heard.*

This time, however, the mode of operation had changed. Instead of going north in the spring and being deploying from an ice camp, the AUV went to the Arctic on an icebreaker in the summer when the ice was relatively thin and broken. The main reason for this different approach was that the area to be surveyed was out of reasonable aircraft range from any central Arctic location. Also, seismic measurements were to be made from the icebreaker. Thus, the icebreaker had to go anyway, and efficiency dictated the combining of the projects.

The changes involved in the technique of deploying and recovering the AUV gave rise to many new problems and headaches for the AUV team. A major problem was the noise produced by the icebreakers. There were to be two ships, the CCGS LOUIS S. ST. LAURENT and USCGS HEALY, which would work together (Figure 158). The homing equipment used by the Explorer was acoustic in nature, and any background noise would make this homing more difficult. Since icebreakers make a lot of noise there was great concern that the Explorer would never find its way back to the acoustic beacons. This problem could have been eliminated if the ship had dropped off the AUV and its crew on a large floating pan of ice and then gone off a decent distance—sixteen kilometers, say. However, safety concerns would not allow a crew to be “abandoned” on the ice. Therefore, the AUV had to be lowered into the water from the icebreaker. This introduces the second major problem. The region of interest tends to be filled with ice that is under pressure, so that when the icebreaker makes an ice-free pool beside or behind the ship, the pool does not stay open very long; it refills with ice almost immediately. How does one get a large AUV into the water when an ice hole will not stay open? Needless to say, there was a lot of discussion, planning and worrying.

Figure 158: *The CCGS LOUIS S. ST. LAURENT (foreground) and the USCGS HEALY (background) in the Arctic Ocean during summer 2011. Photo credit: Don Glencross.*

On the positive side, there are some benefits to having the support of an icebreaker. The ship can move about to help locate the AUV, and it can also move to change the modem locations and thereby assist with communication problems that arise from sea floor reflections.

Preparations began in the fall of 2010. DRDC and ISE personnel overhauled both AUVs, and they checked, evaluated, and often improved all its components. The DRDC – Atlantic Research Centre people improved the Long-Range Acoustic Bearing homing system by giving it—among other things—the ability to send simple commands to the AUV at long ranges. They hoped that this one-way command capability would provide a back-up in the event of noise interfering with the normally-used modem control link. They also checked the modems and determined that reflected signals did, indeed, occasionally disrupt communications. Unfortunately, there was no simple fix for this problem. The best option was to be aware of the issue and avoid it through mission planning.

The AUV crew did an enormous amount of work to prepare the LOUIS for the Explorer and for the operation as a whole. They worked on AUV storage, deployment, and recovery, and they immersed themselves in the planning for all other aspects of the trial. The time available was short, however, and not all the desired enhancements could be included. After calling a halt to the “improvements,” they organized two test runs. The first was on the LOUIS to practise procedures and to measure acoustic interference due to ship noise. The second was held on the DRDC barge in Bedford Basin (NS) to test the final integration of the new and rebuilt components.

After the tests were completed, the LOUIS S. ST. LAURENT went north with Explorer, with the Arctic exercise taking place during August and September, 2011. During this cruise there were two AUV deployments. The first was situated not too far from the geographic North Pole and the second was conducted over the Sever Spur (mentioned before).

During the time at sea the AUV team used the LOUIS' helicopter hangar as their workshop and laboratory space (Figure 159). From this location the AUV was easily wheeled out onto the helicopter deck where the ship's crane was able to pick it up and swing it over the side of the ship.

Figure 159: *The helicopter hangar housed the Explorer. It also served as a workshop and laboratory space for the AUV crew. Photo credit: Don Glencross.*

The ship was never able to stop moving during deployment and recovery. The procedure was to smash the ice and create a temporary pool of open water into which the AUV was lowered. Once the procedure was started, only a few minutes were available before the ice closed in. Certain checks had to be made with the AUV in the water, and, because the open pool rapidly filled with ice, these checks had to be done quickly. The relaxed procedures of the previous spring were now a distant memory. Figure 160 shows how the cables to the AUV were attached and disconnected. It also indicates the difficulty of maintaining an open patch of water.

An associated difficulty was that of protecting the acoustic monitoring gear, which had to be submerged. A successful technique was to attach this equipment to the underside of a massive sled and tow it from the stern of the ship. The sled was so heavy that it stayed below the ice that eddied in the wake of the ship (Figure 161 on page 193).

Both missions (one near the North Pole and the other at the Sever Spur) were successful, and the data will be used in the Canadian submission to the UNCLOS.[8] Moreover, a wealth of experience in ship-borne deployment was acquired. Figure 162 (on page 194) is a group photo showing many of the ship and scientific crew members.

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[8] Editor's note: DRDC's Project Cornerstone continued through 2011 and ended in 2012. Canada made a partial submission to the United Nations in December 2013. A second partial submission was made in May 2019. Both submissions included data from the AUV deployments described here. The second submission is available online: `https://www.un.org/depts/los/clcs_new/submissions_files/can1_84_2019/CDA_ARC_ES_EN_secured.pdf` and includes a picture of the AUV and Arctic camp [81]. Both AUVs are in use in on-going projects and have been deployed often in the past decade.

Figure 160: *Men in a basket were lowered by the crane in order to release and attach the AUV support lines. Note all the ice in this supposedly open pool. Photo credit: Don Glencross.*

Figure 161: *All of the deployed equipment had to be mounted on a very heavy sled that was towed at the stern of the LOUIS. Photo credit: Don Glencross.*

Figure 162: *Some of the Louis crew and scientific crew in a group photo. Front Row: (left to right) S. Netcheva (EC), S. Nichio (ISE), G. Millar (ISE), C. Kaminski (ISE), A. Tuck, S. Wheeler, L. Hann, W. Austin, J. Dalley, B. Molyneaux, H. Martin, R. Lockyre, O. Shuttleworth (DRDC), S. Spears (DRDC), D. Mosher (DRDC). Back Row: (left to right) C. Morency, V. Demers, B. Salisbury, E. Jones, M. Goodwin, M. Rowsome (DRDC), N. Jollymore, V. Shepeta (DRDC), B. Pickrill (DRDC), A. Barnett, S. Lloyd, Capt M. Rothwell, H. Boggild, D. Walsch, R. Pederson (DRDC), C. Brannan (DRDC). Photo credit: Don Glencross.*

13 Conclusions

The Defence Research Board was officially created on 1 April, 1947, and it—or one of its successors—has been actively pursuing defence-related science and technology ever since. DRB began with a strong interest in the Arctic, and northern research started in the early 1950s. Since then, interest in Arctic matters has waxed and waned. It was very high when there was a perceived threat from the Soviets. It fell to a low ebb in the 1990s and early 2000s after relations between Russia and the West improved. More recently, Arctic warming, easier access to natural resources, intense world interest, and sovereignty concerns have brought the Arctic back into the limelight. DRDC projects such as Northern Watch and Cornerstone (Chapter 12) have indicated a resurgence of interest. Doubtless, such research projects will continue to grow, both in number and in size.

Finally, it should be noted that DRB, in its Arctic research, was never timid. It has always accepted great risk—in some cases almost to the point of foolhardiness. However, the people involved were intelligent, quick-to-learn, brave, tough, and—at times—lucky, with the result that the success rate was virtually 100 percent. Hattersley-Smith and three companions explored the north coast of Ellesmere Island for several months with almost no contact with the outside world. They had no serious trouble, and they came home with good data. Allen Milne took a group having almost no cold-weather experience up onto the sea ice of the Arctic. Not only did they cope very well, but they returned with a series of important new discoveries in underwater acoustics. The DRTE scientists and technicians who built the ALOUETTE satellite were experts at electronics, but they knew nothing about rockets or the problems of getting equipment to work in a vacuum. The fact that they took on such a project was looked on by some as utter folly. The Americans, for example, were so sure that it would not work that they made no provision for analyzing the data from the satellite. In the end the satellite was still working ten years later! Project SPINAKER, which involved the use of an autonomous underwater vessel to lay an underwater fibre-optic cable out to a large hydrophone array 180 km offshore, required solutions to many new problems, any one of which could have written an end to the project. The installation was quite successful, and, sixteen years later, the underwater vehicle, THESEUS, still holds many records for size, length of cable deployed under ice, etc.[9] Project CORNERSTONE involved sending an autonomous underwater vehicle out several hundred kilometres under the ice to collect bathymetry data. This project was very risky, particularly with regard to its underwater navigation, but all turned out well, and the vehicle (an ISE Explorer) returned safely and with much good data. It, too, set many records—such as longest continuous underwater mission, both in distance and in time.

These successes pay testament to the quality of the scientists and technologists who worked on them. They are also a tribute to the managers who were willing to trust their people on projects that looked extremely risky. No wonder one can occasionally hear, “Man, we have all this fun, and they pay us, too.”

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[9] Editor’s note: In the past 10 years, interest in AUVs has continued to grow around the world. Theseus is no longer the largest AUV. Others in development have exceeded Theseus’ displacement. Similarly, new propulsion, energy sources, and fuels have provided increased the range capabilities of AUVs.

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List of Abbreviations

Abbreviation	Meaning
AB	Alberta, Canada
ACOUS	Arctic Climate Observation using Underwater Sound
ADM(Mat)	Assistant Deputy Minister (Materiel)
ADS-B	automatic dependent surveillance-broadcast
ADSA	All Domain Situational Awareness
AFCRC	Air Force Cambridge Research Centre
AIS	automatic identification system
AK	Alaska, United States of America
AMSAT	Amateur Satellite
APC	armoured personnel carrier
APL	Applied Physics Lab
ASG	active shaft grounding
AssocADM(Mat)	Associate Assistant Deputy Minister (Materiel)
AUV	autonomous underwater vehicle
AWPPA	Arctic Waters Pollution Prevention Act
BC	British Columbia, Canada
BIO	Bedford Institute of Oceanography
BMD	ballistic missile defence
BMEWS	Ballistic Missile Early Warning System
CAF	Canadian Armed Forces
CARDE	Canadian Armament Research and Development Est.
CASIMBO	Canadian Sea Ice Mass Balance Observatory
CAT	Canadian Archipelago Flow-Through
CAUSE	Canadian Arctic Underwater Sentinel Experimentation
CCGS	Canadian Coast Guard Ship
CESAR	Canadian Experiment to Study the Alpha Ridge
CFAV	Canadian Forces auxiliary vessel
CFIEM	Canadian Forces Institute of Environmental Medicine
CFS	Canadian Forces Station
CHS	Canadian Hydrographic Service
CIU	Clinical Investigation Unit
CO	commanding officer
CORA	Centre for Operational Research and Analysis
CRAD	Chief of Research and Development
CRC	Communications Research Centre
CRWPC	Canadian Radio Wave Propagation Committee
CSS	Canadian Science Ship
CW	continuous wave
CWL	Chemical Warfare Laboratories
DAGR	Defence Advanced GPS Receiver
DCBRE	Defence Chemical Biological and Radiation Est.
DCBRL	Defence Chemical, Biological, Radiation Laboratories
DCIEM	Defence and Civil Institute of Environmental Medicine
DK	Denmark
DMCS	Director of Maritime Combat Systems

Abbreviation	**Meaning**
DMEWS	Ballistic Missile Early Warning System
DND	Department of National Defence
DOC	Department of Communications
DOT	Department of Transport
DRB	Defence Research Board
DRCL	Defence Research Chemical Laboratories
DRDC	Defence Research and Development Canada
DREA	Defence Research Establishment Atlantic
DREL	Defence Research Electronics Laboratory
DREO	Defence Research Establishment Ottawa
DREP	Defence Research Establishment Pacific
DRES	Defence Research Establishment Suffield
DRET	Defence Research Establishment Toronto
DREV	Defence Research Establishment Valcartier
DRTC	Defence Research Telecommunication Laboratory
DRTE	Defence Research and Telecommunications Establishment
DRML	Defence Research Medical Laboratory
DRNL	Defence Research Northern Laboratory
EDRD	Esquimalt Defence Research Detachment
EEZ	Exclusive Economic Zone
ELF	extremely low frequency
ELT	emergency locator transmitter
EM	electromagnetic
ERS	European remote sensing
FM	frequency modulated
GPS	global positioning system
GSC	Geological Survey of Canada
HADCS	High Arctic Data Communications System
HF	high-frequency
HFDF	high-frequency direction-finding
HMCS	Her/His Majesty's Canadian Ship
ICBM	intercontinental ballistic missiles
IEEE	Institute of Electrical and Electronic Engineers
IGY	International Geophysical Year
ISE	International Submarine Engineering
ISIS	International Satellites for Ionospheric Studies
ISS	International Space Station
JAWS	Joint Arctic Weather Stations
LDEO	Lamont Doherty Earth Observatory
LNG	liquid natural gas
LORAN	long range navigation
LRAB	long-range acoustic bearing
LTO	Long Term Observatory
MAD	magnetic anomaly detection
MB	Manitoba, Canada
MDA	MacDonal Dettwiler and Associates
MHz	megahertz

Abbreviation	**Meaning**
MIT	Massachusetts Institute of Technology
MLSI	multi-year landfast sea ice
MOU	memorandum of understanding
MPA	Maritime Patrol Aircraft
MPEU	Maritime Proving and Evaluation Unit
NASA	National Aeronautics and Space Association
NATO	North Atlantic Treaty Organization
NB	New Brunswick, Canada
NetALS	Networked Autonomous Littoral Surveillance
NL	Newfoundland and Labrador, Canada
NPEO	North Pole Environmental Observatory
NRaD	Naval Research and Development Cente
NRCan	Natural Resources Canada
NRC	National Research Council
NRE	Naval Research Establishment
NOAA	National Oceanic and Atmospheric Administration
NO	Norway
NRE	Naval Research Establishment
NS	Nova Scotia, Canada
NT	Northwest Territories, Canada
NU	Nunavut, Canada
NW TDP	Northern Watch Technology Demonstration Project
ON	Ontario, Canada
OOTI	Out On The Ice
OSCAR	Orbiting Satellite Carrying Amateur Radio
OTHR	over-the-horizon radar
PAM-ARCMIP	Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project
PARL	Prince Albert Radar Laboratory
PCSP	Polar Continental Shelf Project
PE	Prince Edward Island, Canada
PLGR	Precision Lightweight GPS Receiver
PNL	Pacific Naval Laboratory
QC	Québec, Canada
R&D	research and development
RCAF	Royal Canadian Air force
RCMP	Royal Canadian Mounted Police
RDDC	Recherche et développement pour la défense Canada
RDS	Rapidly Deployable Systems
RF	radio frequency
RIP	recording instrument packages
ROV	remotely operated vehicle
RPL	Radio Propagation/Physics Laboratory
SAR	synthetic aperture radar
SARSAT	Search and Rescue Satellite
SIGINT	signals intelligence
SIPRE	Snow, Ice, and Permafrost Research Establishment

Abbreviation	Meaning
SK	Saskatchewan, Canada
SLAR	side-looking airborne radar
SOSUS	Sound Surveillance System
SRL	short-range localization
STEM	Storable Tubular Extendible Member
TB	tuberculosis
TDP	Technology Demonstration Project
UNCLOS	United Nations Convention on the Law of the Sea
USAAF	United States Army Air Force
USAF	United States Air Force
USCGC	United States Coast Guard Cutter
USSR	Union of Soviet Socialist Republics
UVic	University of Victoria
UW-PSC	University of Washington's Polar Science Center
VHF	very high frequency
WCI	wind-chill index
WCT	wind-chill temperature
YK	Yukon, Canada

Index

In the period between 1947 and 2012, Defence Research and Development Canada (DRDC) and its predecessors conducted a wide variety of research activities in the Canadian Arctic. This book attempts to summarize the Arctic work done by nine separate Establishments in that time period, as well as by some early expeditions run by Defence Research Board (DRB) Headquarters. This history has been written in an attempt to provide general information to new employees who are preparing for their first Arctic experiences and to give background material to managers and Canadian Armed Forces personnel with an interest in Arctic activities. Hopefully it will also inform the general public of DRDC's valuable contributions to a better understanding of our Arctic regions and to our claims of sovereignty.

De 1947 à 2012, Recherche et développement pour la défense Canada (RDDC) et ses prédécesseurs ont mené une vaste gamme d'activités de recherche dans l'Arctique canadien. Le présent livre renferme le résumé des travaux réalisés au cours de cette période dans l'Arctique par neuf établissements distincts et par les membres des premières expéditions dirigées par le Bureau chef du Conseil de recherches pour la défense. Cette histoire a été écrite dans le but de donner des renseignements généraux aux nouveaux employés qui se préparent à vivre leurs premières expériences dans l'Arctique et de fournir de la documentation aux gestionnaires et au personnel des Forces armées canadiennes qui participent aux activités liées à l'Arctique. Nous espérons qu'elle permettra également de sensibiliser le grand public au rôle important que joue RDDC pour mieux faire connaître nos régions arctiques et nos revendications en matière de souveraineté.

Ronald I. Verrall

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