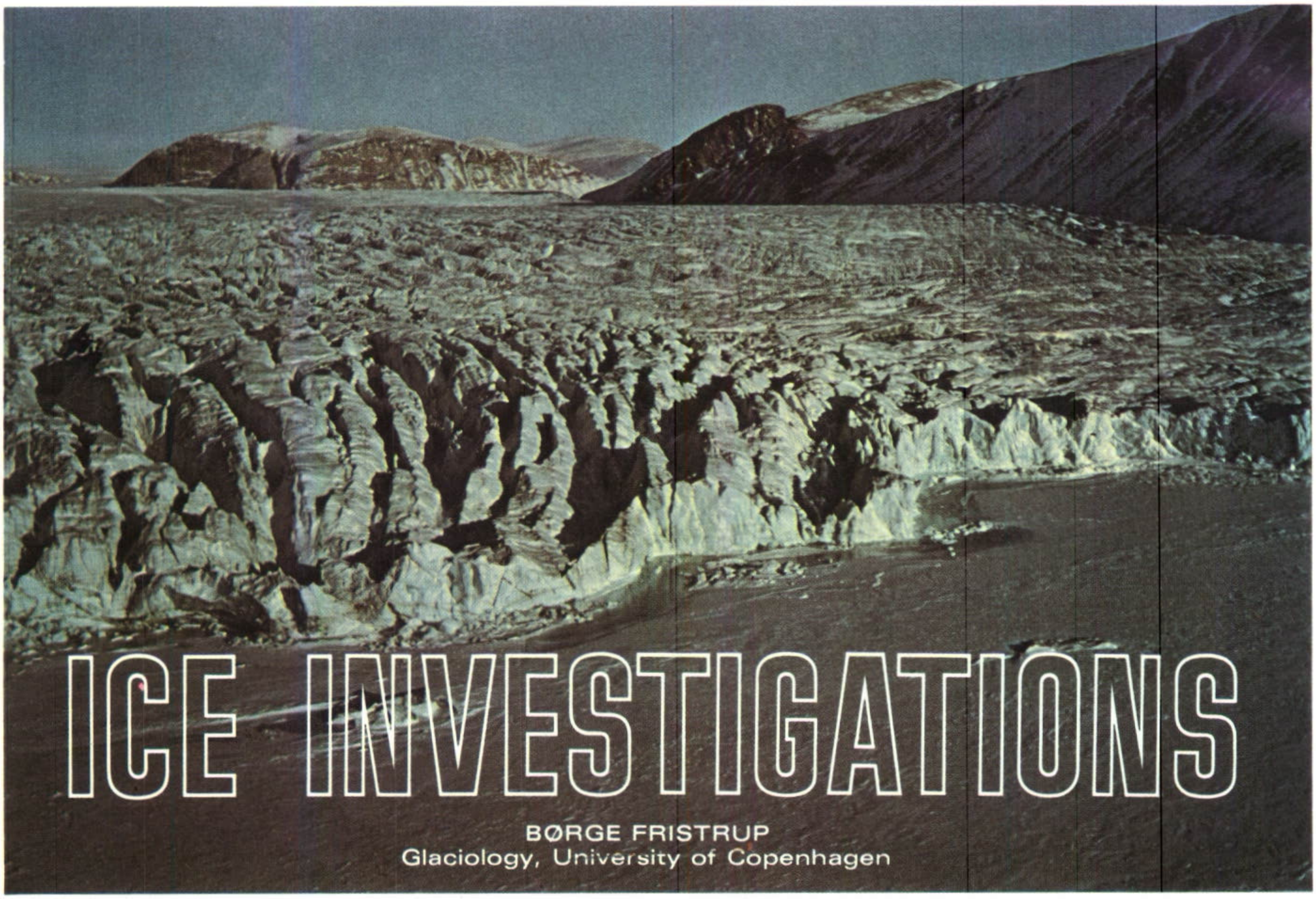


ICE INVESTIGATIONS

BØRGE FRISTRUP
Glaciology, University of Copenhagen

INTRODUCTION

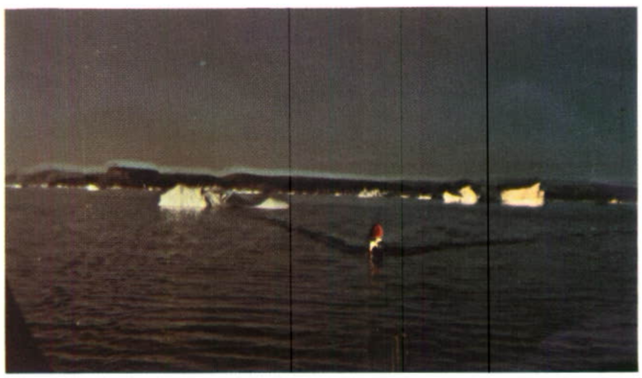
ON Sunday, 28 January, the Danish Atomic Energy Commission asked me to join the Danish Scientific Group at Thule Air Base. I left on Monday, 29 January, together with Dr P.M. Hansen, marine biologist, Dr C. Vibe, zoologist, and Dr F. Hermann, hydrographist. Weather conditions at Thule Air Base were poor, and just before we reached our destination the airport was closed because of a blizzard and we had to land at Søndre Strømfjord, an alternate airfield. From there the airplane returned to Copenhagen, and an American airplane took us to Thule Air Base on Tuesday, 30 January.

Although we represented different sciences, the members of our party had all worked in Greenland for several years and most of us had a thorough knowledge of the area around Thule.

During the days that followed we made observations in the crash area, and took part in discussions concerning what measures ought to be taken to protect the population.

NORMAL ICE CONDITIONS IN THE AREA

In Bylot Sound, where the accident happened, the ice cover is normally not very thick and rarely exceeds depth of 1 meter (39 inches), whereas much thicker ice can be found in North Star Bay and Wolstenholme Fjord.



Ice floe.

In the Thule area the formation of fjord ice usually begins at the end of September or the beginning of October. This early ice is often broken up by gales. Really solid ice is not formed until the end of the year. As the winter progresses, the ice gradually becomes thicker.

The rate of growth depends to a great extent on the temperature of the air and the snow covering. A thick layer of snow serves as insulation and the ice will grow slowly, whereas no snow or only a thin covering produces a faster rate of growth. At the beginning of May the ice will crack under the spring sun, and in the course of a few weeks pools of meltwater will gradually form on the surface of the ice. The melting begins and is most intensive in those places where the snow or ice has been soiled by sand or other material which has blown out from the shore. This is because the dark material absorbs the heat.

With increasing air temperature the ice cracks more and more, the pools of meltwater grow in size, and lanes of open water may be seen. The breaking up of the winter ice into drifting floes normally takes from 2 to 3 weeks. As the ice floes drift back and forth with the tides, they gradually tear apart, diminish and melt away. Towards the end of summer, only drifting icebergs are seen in the Thule district. They originate from the calving glaciers, particularly from Moltke Gletscher at the head of Wolstenholme Fjord and from Indlandsisen at the head of Inglefield Bredning.

When the ice in Bylot Sound has broken up, the current and the wind carry it out in Baffin Bay either north or south of Saunders Island, depending on the prevailing weather conditions. If the weather is relatively calm, the ice will usually go out south of Saunders Island, whereas a strong wind from the sea—the normal wind direction in this area—will carry the ice along the coast of Steensby Land and westward. The current may carry the drifting floes close inshore where they may be beached, but there are no particular places in this area where the ice is prone to pack.

ICE CONDITIONS IN THE WINTER OF 1967-68

A map showing the normal ice conditions in the Thule district is shown in Figure 1. In the autumn of 1967, the first freezing up was observed early in September, but a spell of mild weather caused the ice to break up again so that the genuine winter ice was not formed until the middle of October. During November there was a lot of snowfall, so it must be presumed that the winter ice was relatively thin and had not reached its maximum depth when the accident happened. The measurements taken during our investigations showed that the ice was still growing and that it must have been approximately 70 cm (27 inches) thick at the time of the accident.

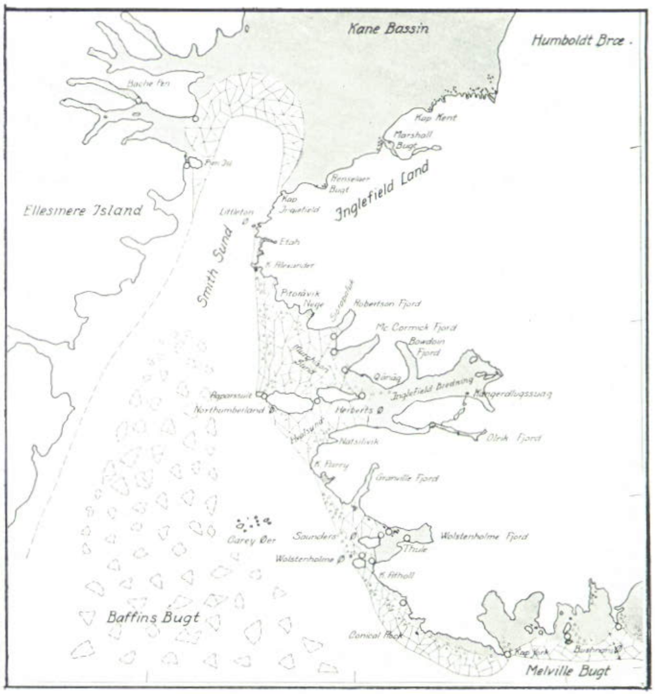
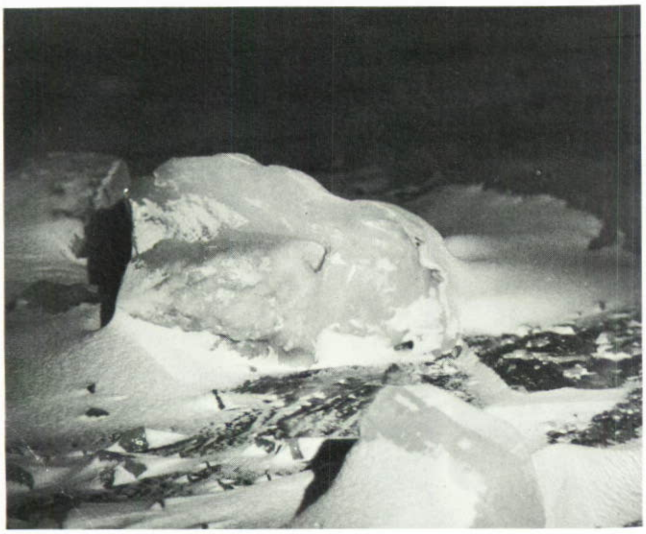


Figure 1. Ice conditions north of Baffins Bay. (Old Map)

- Usually unbroken winter ice from October-November to June-July.
- Extreme limit of winter ice, often broken during November-February, but usually unbroken from March to the middle of May.
- Occasional drift ice, formed by broken land ice, moving southwards.
- Banks with grounded icebergs.
- Open water owing to currents early in spring, also often at new and full moon throughout the winter.



Ice floe from the crushed spots.

OBSERVATIONS IN THE CRASH AREA

Observations at the point of impact of the B-52 showed that the sea ice had been broken up. Ice floes of from 2 to 5 meters (79 to 197 inches) in diameter had been tilted upwards. One ice floe had even been pushed right out of the water onto the surrounding ice, and in several places it was possible to see the underside of the floes. Between the floes, in many places one could see a mixture of crushed ice and new ice covered by a thin layer of snow. A few floes had not capsized but had been lifted up and lay higher than the surrounding ice, as can be observed when the sea ice is no longer coherent but is floating freely as floes in a lane. Pieces of ice were scattered around the point of impact, and it appeared from the texture of the snow that around the crushed ice there had been a zone where the snow had been drenched by sea spray or by a wave breaking in over the ice. The picture of the crushed ice and the piled up floes leaves no doubt that the ice had been broken and that at some moment there had been open water. The piled up floes were angular and there was no trace of any melting. The fractures were fresh and had no similarity to those of the old pack. What we saw was the result of the B-52 hitting the ice.

South of the crash area one could see the "black spot." This consisted of a 1-3 cm (0.5-1.5 inches) thick crust of snow that had been melted, and in a few spots the sea ice itself had melted. Under this crust, the snow was not deformed and there was no sign of any melting. Measurements showed that the crust was strongly contaminated, whereas the underlying snow was clean.

On the basis of these observations and the knowledge gained previously by this author, one obtains the following reconstruction of the events: When the airplane crashed, the ice was crushed and for a short time a lane had been formed filled with floes and bits of ice. One-fifth or one-third of this lane may have been open water. It is difficult to obtain an accurate estimate of the size of the lane since all the irregularities and floes had been covered by drift snow after the time of the accident, but a diameter of about 50 meters (approximately 165 feet) seems likely. It was evident that parts of the B-52 could have sunk to the bottom through this lane.

The "black spot" showed where the burning fuel had streamed from the airplane when it hit the ice. The heat from the fire had no doubt been considerable, but it is also well known that heat does not penetrate deeply into the snow. Within this area no traces were found of large pieces of debris hammered or melted down through the ice, and with an ice depth of 70 cm (27 inches) small objects could not have penetrated the ice either way.

A number of corings in the crushed ice area showed a layer of impurities large enough to be detected with the naked eye. Several of them looked like drops of oil. The measurements showed that this horizon fairly close to the underside of the ice was strongly contaminated. The layer of impurities corresponded to the underside of the ice at the moment of the crash. The impurities stemmed from the accident and had been swimming in the water immediately under the ice cover and were thereafter incorporated into the ice as it grew downwards. The records show that the ice grew at a rate of approximately ½ cm (0.2 inches) per day in the beginning of February.

A more detailed coring program with the collection of samples of the sea ice in the area of the accident was carried out by Dr G. Frankenstein.

CONDITIONS DURING ICE BREAK-UP

The Danish Scientific Group discussed the probable ice situation in the spring. It was obvious that the "black spot" would melt relatively quickly because of the effect of the sun on the dark colored snow and because the crust would melt more rapidly than normal snow anyway. A relatively large pool of meltwater would therefore be formed on the ice, and it was expected that an early formation of cracks and lanes in the ice would follow due to the compression of the snow caused by vehicles used during the clean-up operations. The biologists foresaw that these cracks and holes could attract seabirds, particularly the little auk.

The group also discussed what could be expected to happen to the drift ice once the ice had broken up. The possibility that the ice would go beyond the Thule district could be excluded, since it would melt before it had drifted that far. On the other hand, it was impossible to foresee with any certainty the direction of the ice drift, or whether some floes would drift ashore with their possible contents of contaminated debris. Furthermore, it could not be excluded that some material capable of floating might be carried ashore with the current once the ice had melted. Since the current generally flows northward, it seemed most likely that such objects would be washed up at Saunders Island or Steenby Land. However, since material from the garbage dump at Thule Air Base can float as far as to the head of Inglefield Bredning, the group recommended that a search be made in the summer of the coasts in the vicinity of the crash site.

It was generally agreed that any debris left on or in the ice after the clean-up operations should not be allowed to drift too far. So it was suggested that some dark material be spread over the ice to further the melting. In this way a hole could be melted in the ice and any debris left from the accident would sink before the ice broke up. Experiments with carbonized sand were later made by the Americans at the end of May.

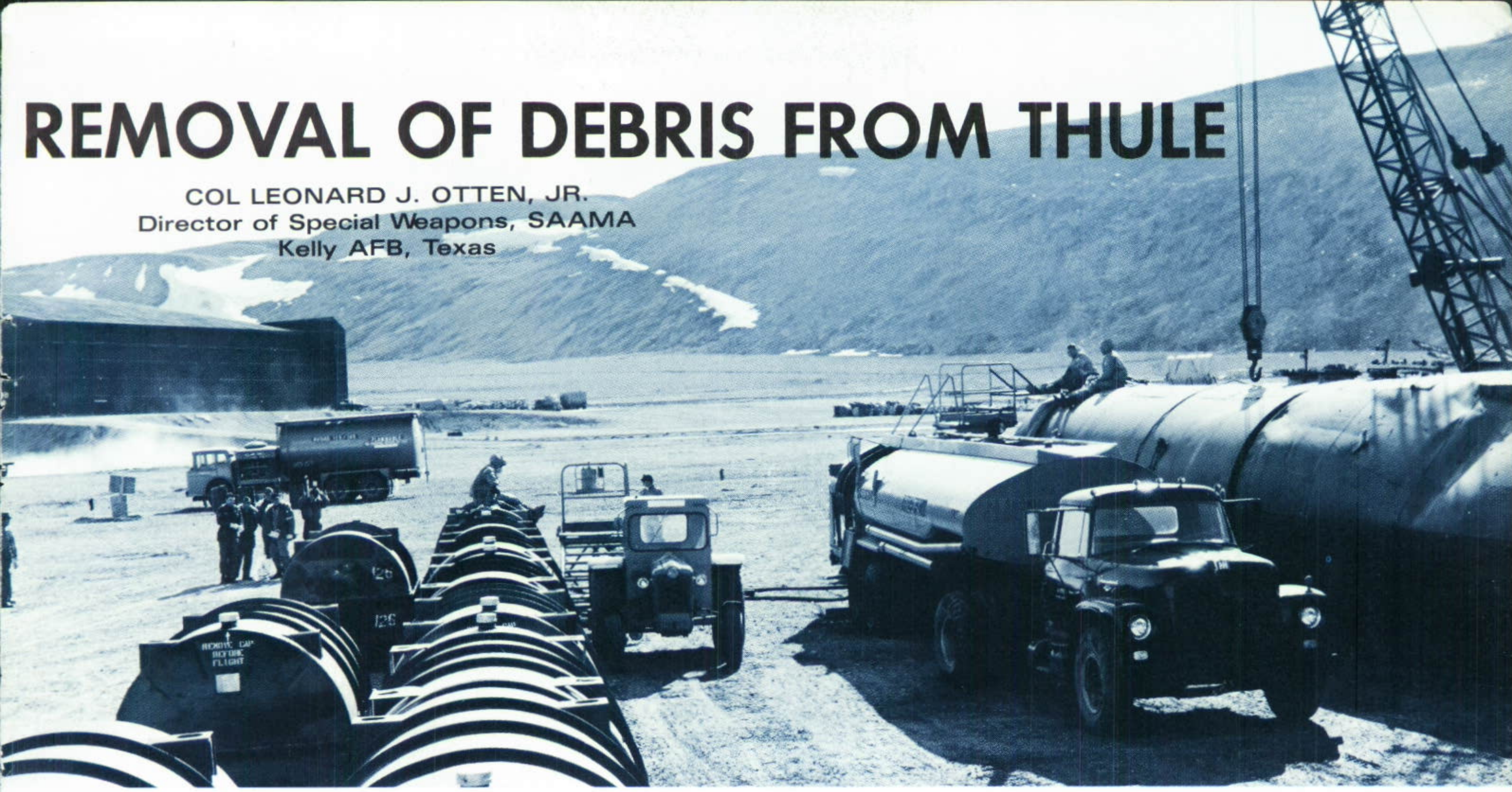
On 29 May, I was again in the Thule area and had the opportunity to follow these experiments. From a helicopter, it could be seen that the carbonized sand had had some effect, but since snow had fallen and covered the sand after it had been sprayed on the ice, the total effect was not too impressive. Time did not allow me to follow the experiments any further.

As has been mentioned in other articles in this magazine, it appeared that most of the contamination was contained in the "black area" and so it was decided to remove this localized contaminated layer of snow.

Without going further into the physical properties of snow and ice, it is clear that the fact that the accident occured on snow-covered sea ice limited the extent of the contamination. There was no contamination of the sea ice in general, and the sea ice from the site of the accident did not go far before it melted away.

REMOVAL OF DEBRIS FROM THULE

COL LEONARD J. OTTEN, JR.
Director of Special Weapons, SAAMA
Kelly AFB, Texas



WITH the completion of on-site evaluation and recovery operations by the Strategic Air Command (SAC), effort was directed toward the problem of dealing with the contaminated waste. During recovery operations, 217 various sized containers of aircraft residue and sixty-seven 25,000-gallon tanks of contaminated snow and ice from the site were collected. In addition, there were four 25,000-gallon containers filled with such items as tires, clothing, tools, plywood, and parachutes.

Transportation requirements for a removal operation of this size created a problem of great magnitude. It was decided to turn the job over to the Air Force Logistics Command (AFLC). Within the command the task was assigned to the Directorate of Special Weapons located at the San Antonio Air Materiel Area (hereafter referred to as SAAMA), Kelly AFB, Texas. Lt Col Vernon E. Carkin, Chief of the Production Management and Technical Services Division, served as Project Officer.

To gather all necessary information, a meeting was held at SAC Headquarters on 8 April with personnel who had recently returned from Thule Air Base following recovery operations. The main questions concerned the amount of waste requiring disposal and its degree of contamination. These questions were directed to the civil engineers and health physicists.

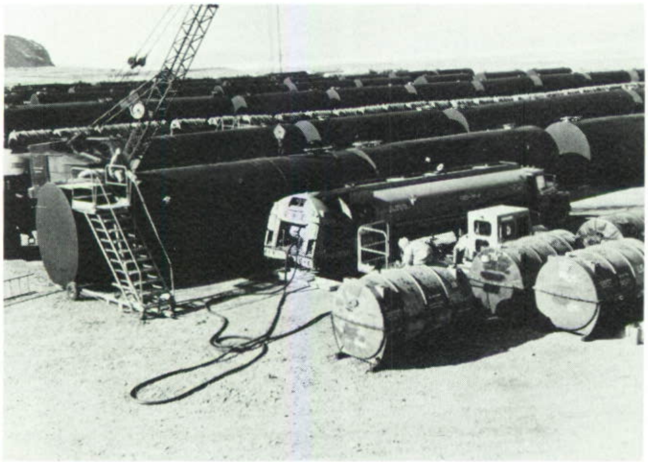
The SAC Civil Engineers estimated that the 67 petroleum, oil and lubricant (POL) tanks were 85% full, with approximately 4,500 gallons of melted snow and ice in each tank. They recommended a filtration process be used to decontaminate the liquids. This would allow the effluent to be discharged into the bay and would eliminate the necessity of transporting the liquids to the United States for disposal. However, the health physicists did not fully agree with this concept due to the high degree of purification required to meet international drinking water standards.

Returning to SAAMA, another meeting was called with personnel from the Atomic Energy Commission, Aerospace Defense Command, and AFLC, who had been at the site. Many ideas and suggestions concerning the handling, storage, and transportation of the radioactive materials resulted from the conference. To insure thorough evaluation and consideration of each suggested plan, a formal staff study was prepared. Many aspects including international opinion, feasibility, climatic and geographic conditions were considered in the study.

Three alternatives were proposed. A brief summary of the plans follows:

One plan was to ship all of the 25,000-gallon tanks and smaller containers, filled with contaminated waste, to the United States for disposal. However, the disadvantages of this plan were far greater than the advantages, with such problems as the requirement for extensive cradling supports from the tank farm to the ship, and also aboard ship. Another hazard was the tilted entry of partially filled tanks into the ship. These procedures could prove to be extremely dangerous.

The second plan provided for handling the radioactive waste by filtration and dilution. The frozen waste was to be melted in the POL tanks. The "clear" liquid between the scum and sludge layers would be pumped through a five-micron filter, followed by three one-micron filters placed parallel and leading to a holding tank. Again, the disadvantages proved too great. The



TANK FARM. Pump-transfer crews prepared to pump melted snow water from the large 25,000-gallon tank to small containers to facilitate shipping the residue to the U.S.

Decontamination personnel unloaded forklift inside designated bunker.

problem was that an adequate filtration system, with necessary operating procedures, had not yet been designed, fabricated, and service tested.

The third plan provided for transfer of radioactive waste into smaller transportable tanks for return to the United States for disposal. Radioactive residue in the POL tanks would be melted and the liquid pumped into smaller tanks made from modified engine containers of 1,800-gallon capacity which were excess to the Air Force needs. The tanks would then be transported from the shoreline storage area to the ship docking area for loading aboard cargo ships. The tanks would be shipped to the United States and transferred to railroad cars for shipment to Atomic Energy Commission designated disposal areas. Empty POL tanks, which originally held the material, would be sent to designated disposal areas as well.

This alternate was approved by the Air Force Logistics Command, Aerospace Defense Command, the USAF Directorate of Nuclear Safety, HQ USAF, Department of Defense, Department of Transportation, Department of State, and the Atomic Energy Commission. After this process, the plan was coordinated with and approved by the Danish Government.

An adequate number of the smaller, modified tanks were available at SAAMA, as well as F-6 aviation gas refueling units which were used as on-site portable pumping equipment. Prior to approval for use, the modified cans were subjected to a severe testing program for leaks, stability, and durability.

To determine the conditions at the site, what equipment was available, and what problems would be encountered during the actual removal and disposal operation, a team of highly specialized personnel visited Thule Air Base.

Upon the team's return from Thule, the SAAMA Military Personnel Office selected the personnel who would make up the on-site task group.

On the morning of 25 June, the hand-picked on-site team assembled at the Directorate of Special Weapons conference room to learn of their assignment. The team consisted of 24 personnel—one officer, 18 airmen, two civilians from SAAMA, two airmen from the Tactical Air Command, and one from SAC.

Faint murmurs ran through the group. What is this all about? What is Project Crested Ice? How long will this thing last? And, of course, why me?

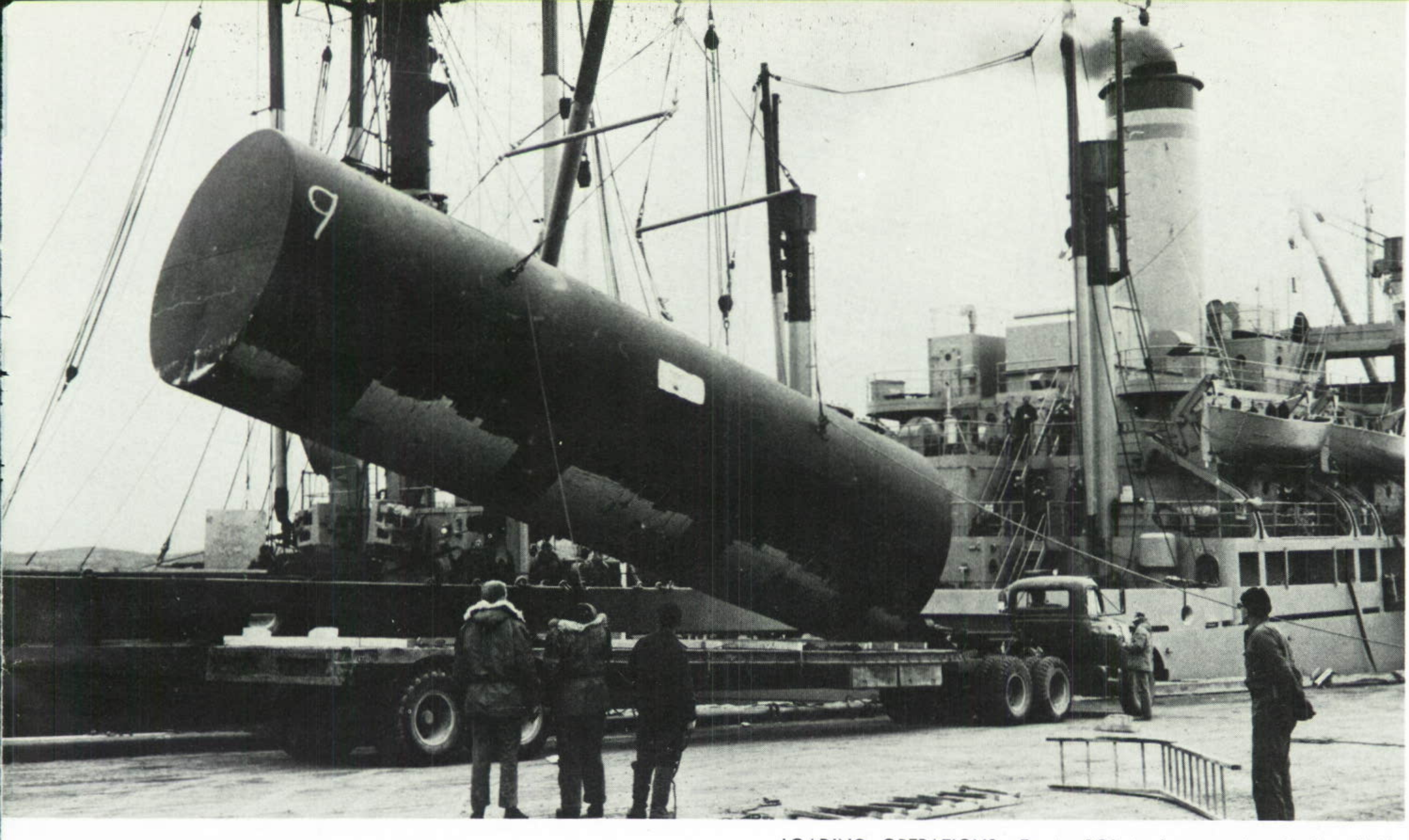
These and all other questions were answered during a comprehensive briefing concerning the mission, constraints and time schedules, international interests and relationships. Individual crew assignments were made in the major areas of effort: melting, pump transfer, radiological monitoring, packaging and transportation, and finally, administrative and control functions.

Training the task group began on the 26th of June at Kelly Air Force Base. The training was unusual; the circumstances were unusual. Some learned to heat ice filled tanks rather than aircraft engines, others to pump-transfer radioactively contaminated liquids without spillage instead of pumping aviation fuels, while still others learned to palletize and label drums of radioactively contaminated aircraft debris rather than oil drums.

The personnel who were given secondary or augmenting assignments were cross-trained. Those not currently qualified to operate related equipment received intensive training and were licensed by Kelly authorities. On 11 July, the team left Kelly Air Force Base on a C-118 which became affectionately known as "Thule Commuter's Special."

Upon arrival at Thule the following day, the group was briefed by the SAAMA Advance Liaison Officer. The briefing included a tour of the local area.

On 16 July the USNS TOWLE, of the Military Sea Transport Service, docked at Thule's DeLong Pier and immediately began unloading the Crested Ice equip-



LOADING OPERATIONS. Empty POL tanks are placed aboard the USNS TOWLE for shipment to Charleston, South Carolina.

Fuel tank being lifted onto flatbed by crane.

ment, including 232 modified engine containers and two F-6 refueling units.

To protect against spillage, additional equipment was manufactured at Thule Air Base. Sheet metal pans were made to place under the F-6 units and collars were fabricated to encircle the R-4360 filler caps and POL tanks to soak up contaminated liquid from suction or discharge nozzles.

Other innovations were made such as the adaption of a POL system filter unit to fit around the suction nozzle to screen out debris from the POL tanks.

All preparatory efforts of the pump-transfer operations were completed by 22 July.

The igloo area operations began 17 July with the manufacture of barrier bags to completely contain and seal the drums and cans of residue for shipment.

During the operation, it was discovered that one of the modified cans and one POL tank had leakage due to punctures. However, it was determined that the liquid was not "hot" and the containers were repaired with an epoxy compound.

Additional safety briefings were held by the On-Site Health Physicist, Capt William Moyer. He reviewed the hazards and demonstrated the use of available protective clothing and gear.

Full pump-transfer operations began 22 July, with two crews, each with a radiological monitor, operating 10 hours a day. Competition immediately sprang up between the crews to see which could pump the greater amount each day.

Thanks in part to the prevalence of good weather, 49 of the 67 POL tanks of contaminated liquid waste were emptied and two hundred and thirty-one R-4360 containers filled by 29 July. One-hundred gallons were left in each POL tank as a dampener to lessen the danger of sparking effects of debris. The 232d container was sent to the Danish Construction Corporation, a Thule Air Base contractor, to serve as a model for modification and test of the eighty R-4360 cans arriving on the USNS TOWLE's second trip to Thule.

Since the USNS TOWLE was not due to return to Thule until 26 August, the members of the task group returned to their home stations. The Thule operations were secured and left in the custody of two task group members. Their tasks included housekeeping, maintaining daily surveillance over filled containers, and to note any pressure build-up.

The on-site team reassembled and returned to Thule Air Base on 19 August. Upon arrival, additional modification of the previously filled cans was necessary.

A .0625-inch hole was drilled in the filler caps with a rubber surge chamber inserted to eliminate any possible air/gas pressure build-up inside containers as they were transported from a 30-40 degree environment to the possible 90-100 degree temperature of the Southern United States.

When the USNS TOWLE arrived on 21 August, its cargo of an additional 80 unmodified R-4360 cans was taken to Hangar 1 for modification. The last container was completed on 31 August.

The loading of the USNS TOWLE began with eight POL tanks, 50 pallets of 192 drums and 268 filled R-4360 cans during the period 26 August to 1 September.

Departing Thule's DeLong Pier on 2 September, the USNS TOWLE headed for the Army Pier at Charleston, South Carolina, with a due date of 11 September.

When the USNS TOWLE arrived at the South Carolina pier, railroad cars were waiting to take the contaminated debris to its final resting place. Sixty-six cars were needed to carry the load which was moved at a speed of not more than 30 miles per hour.

The second ship, the USNS MARINE FIDDLER, arrived at Thule on 3 September and began loading Crested Ice retrograde cargo. It departed on 17 September with forty-seven R-4360 cans and five 25,000-gallon POL tanks, 67 empty 25,000-gallon POL tanks and eleven 3,000- to 10,000-gallon POL tanks of residue and the two F-6 refueling units. The MARINE FIDDLER arrived in Charleston on 28 September with its cargo. It was necessary to use 81 railcars to transport the containers. To keep the material from sloshing to any great degree and because of the close clearances, the train moved no faster than 20 miles per hour to its destination.

FILL 'ER UP. Airmen at Thule fill engine container with melted snow water pumped from the larger POL tank.

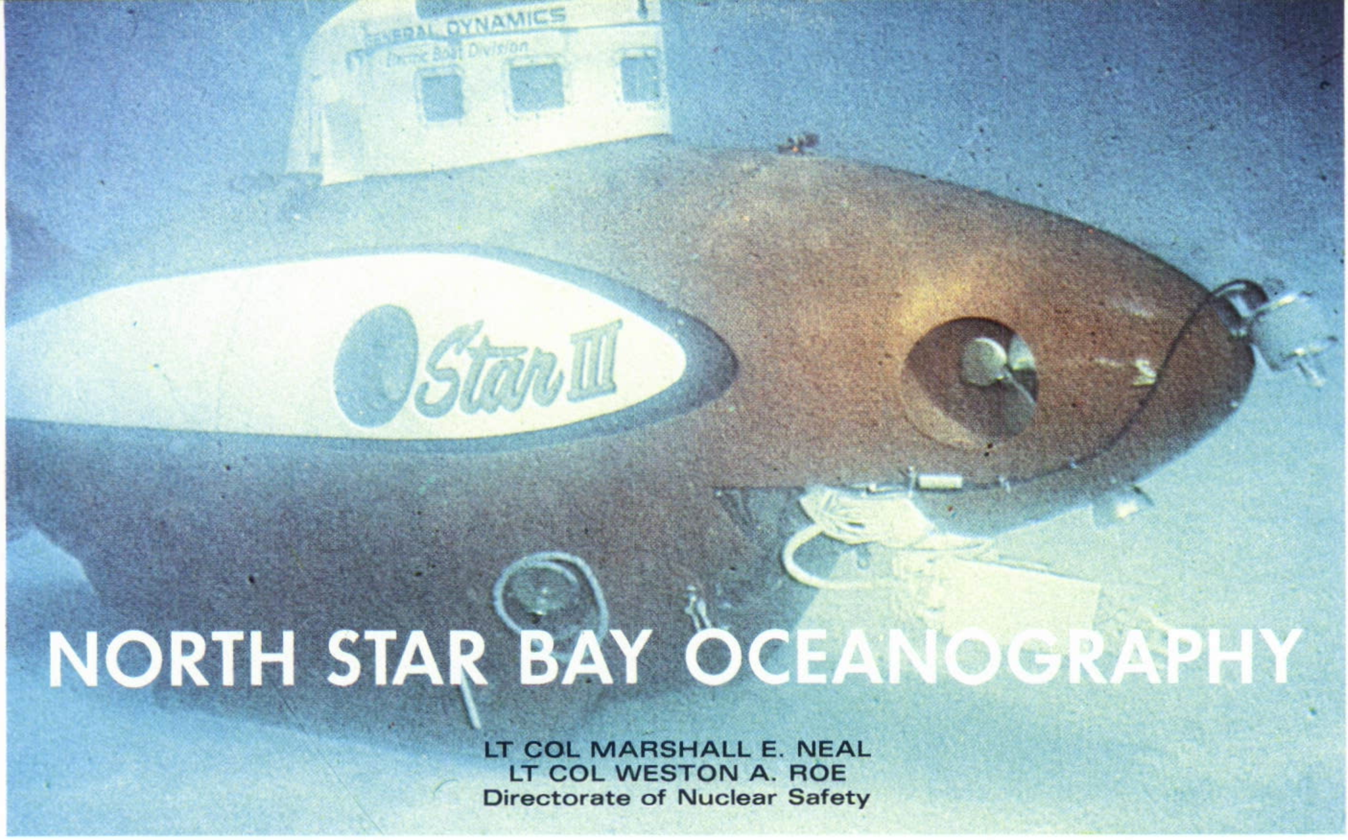
FINAL CHECK. A radiological monitor checks for contamination of alpha particles on the clothing of a pump transfer operator by using PAC-1S scintillator detector.

With Thule Air Base secured, the task group departed on 6 September, after assuring that the former tank farm area was left clear and monitored to a zero contamination level. The AFLC/SAAMA project close-out responsibilities were completed.

SUMMARY

We would be remiss if we did not acknowledge the contributions made by the Danish Nationals assigned to Thule Air Base. They were, without exception, professionals in their jobs and their cooperative and constructive attitudes were outstanding. The SAAMA team will long remember these fine people, both for their proficiency and for the warm personal relationships that developed.

Our only regret is that we could not have met with the Danes under happier circumstances.



NORTH STAR BAY OCEANOGRAPHY

LT COL MARSHALL E. NEAL
LT COL WESTON A. ROE
Directorate of Nuclear Safety

Photo used by permission of General Dynamics

IN separate articles, our Danish colleagues have reported on the extensive radioactivity measurements in the biosphere which they conducted at North Star Bay and in its surroundings. This article adds to that picture the details of two supporting American programs. One of these provided measurements of North Star Bay currents, the other surveyed conditions on the ocean floor.

The ocean current measurement program was conceived in the early days of the operation, before it was known what procedures would be required to preclude any danger to plant or animal life. The currents were needed in order to estimate how the ice might drift, following the spring breakup. Although it was eventually decided that the ice at the crash site should be cleaned up, so that the original purpose of the current measurements disappeared, the program did present an interesting operational problem at the time. To measure the currents it was necessary to drill holes in the ice through which current meters could be lowered. At the same time it was possible to lower a camera with lights to the ocean floor in order to obtain the first data on the general nature of the bottom.

Later, when the Bay cleared of ice in the summer, Air Force, Navy, and their contractor personnel joined with the Danes in an ecological survey of the Bay area. The U.S. contribution to this effort was to survey the bay bottom directly beneath the crash site. This part of the joint survey, besides contributing to the general scientific knowledge of environmental conditions, was designed to verify that any contaminated aircraft debris which might have broken through the ice was stably situated on the bottom. It was carried out with the use of a small research submersible, the STAR III (Submarine Test and Research Vehicle).*

These activities, and their results, are described in the following paragraphs:

HYDROGRAPHIC SURVEY OPERATIONS

A team of four personnel from the U.S. Naval Oceanographic Office (NAVOCEANO) arrived at Thule Air Base on 25 March 1968 to measure the flow of currents in the Bay.** Figure 1 shows the general area of their operation.

North Star Bay has two main channels. The deepest water is in a channel from Kap Atholl on the southwestern end to Wolstenholme Fjord on the northeast. Another relatively deep channel extends westward from Wolstenholme Fjord between Saunder Island and the mainland. The channel between Saunder and Wolstenholme Islands is shoal water. Maximum water depth in the general area of the crash site is approximately 135 fathoms (247 meters).

The geography of the area indicates four possible paths through which water might flow out of the area of the crash site:

• Between the northern tip of Saunder Island and Kap Abernathy on the mainland;

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*The STAR III is a small two-man oceanographic research submersible equipped with lights and cameras. It was leased by the Navy from General Dynamics/Electric Boat Division.

**The discussion of NAVOCEANO operations is the contribution of Mr L. J. Fisher and Dr L. R. Breslau.

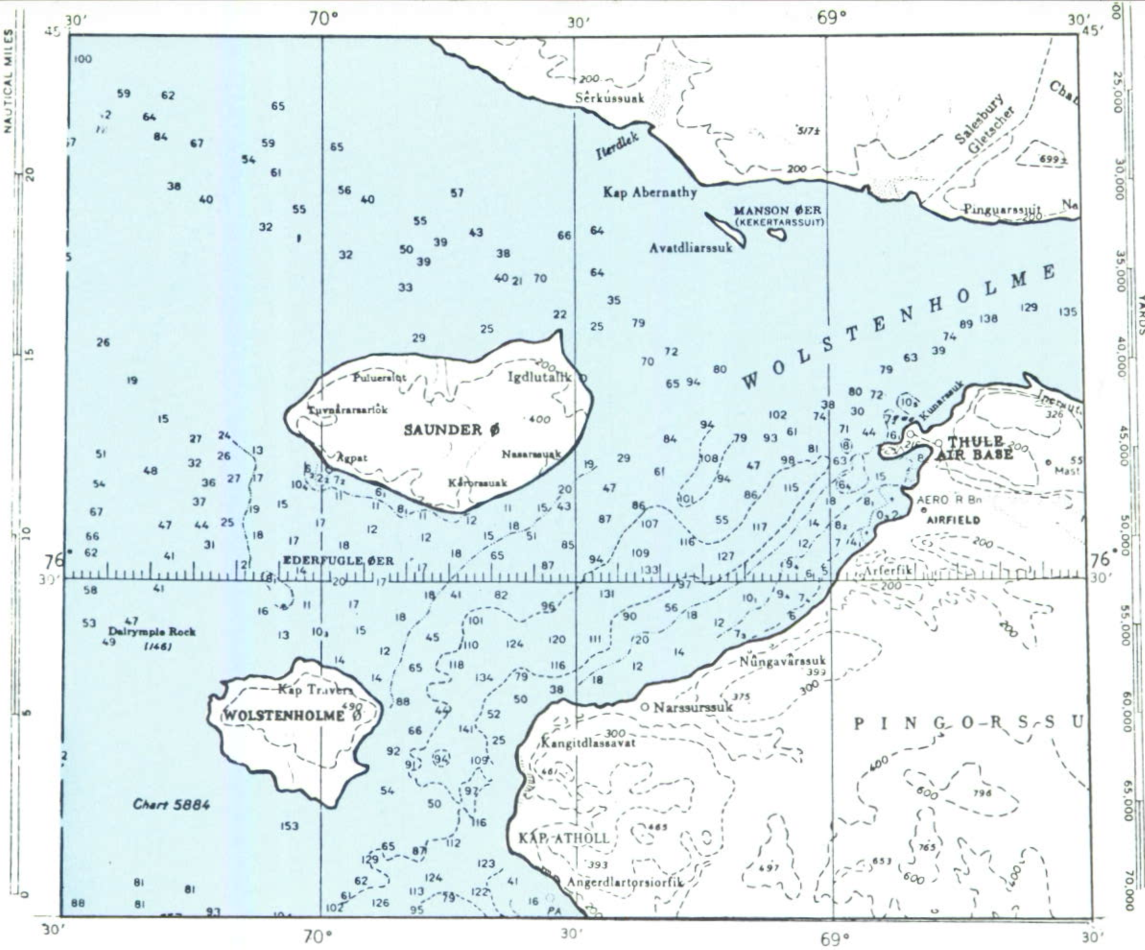


Figure 1. General Operational Locale.

- Between Saunder and Wolstenholme Islands;
- Between Wolstenholme Island and Kap Atholl on the mainland;
- Into Wolstenholme Fjord.

Midchannel current measurements were planned in each of the four passages to determine the direction and speed of the current through these passages. In addition, current measurements were to be made at each of three stations extending across the general area of the crash site on a line from Nasarssuak on Saunder Island to Nungavarssuk on the mainland. The planned current measurement sites (Figure 2) were precisely located by a USAF geodetic survey team before the NAVOCEANO field operations began.

Original plans specified 24-hour surface and bottom current measurement at each of the seven sites. A string of five current meters was to be installed at Site 1 at the beginning of the operation for continual data recording until retrieval of the meters at the completion of the operation. Bottom photographs also were to be taken at Sties 1 and 2 upon completion of the current measurements. The current meters and camera were to be lowered and raised with a winch mounted in a specially constructed mobile laboratory. Since rapid deterioration of the ice prevented moving the heavy mobile laboratory and camera lowering equipment to Sites 3, 4, 5, 6, and 7, operations there were conducted lowering and raising the current meters by hand.

The current data were obtained with two types of meters—the Hydroproducts Model 501B and the Geodyne Model A-101. The Hydroproducts meter is a system with an integral recorder capable of unattended recording of current speed, direction, and temperature for periods up to 30 days. The record is a permanent analog plot that can be analyzed immediately after recovery of the meter. These meters were used to obtain a 24-hour current record at each site. The records were analyzed as soon as possible to provide the on-site Strategic Air Command (SAC) Disaster Control Team with immediate information on the surface currents in the vicinity of the crash site. The Geodyne meter is a system capable of recording up to 200 days of current speed and direction data. The data are recorded as a digital coded dot matrix on photographic film. These meters were used to obtain a 7-day record from five different depths at Site 1. These data were not processed until the field team returned to NAVOCEANO where the necessary processing facilities were available.

The current meters were lowered through 2-foot diameter holes drilled in the ice with the ice auger. The thickness of the ice in t e area ranged from a minimum of 20 inches to a maximum of 48 inches. The data collected indicate that the currents in the area are pre-

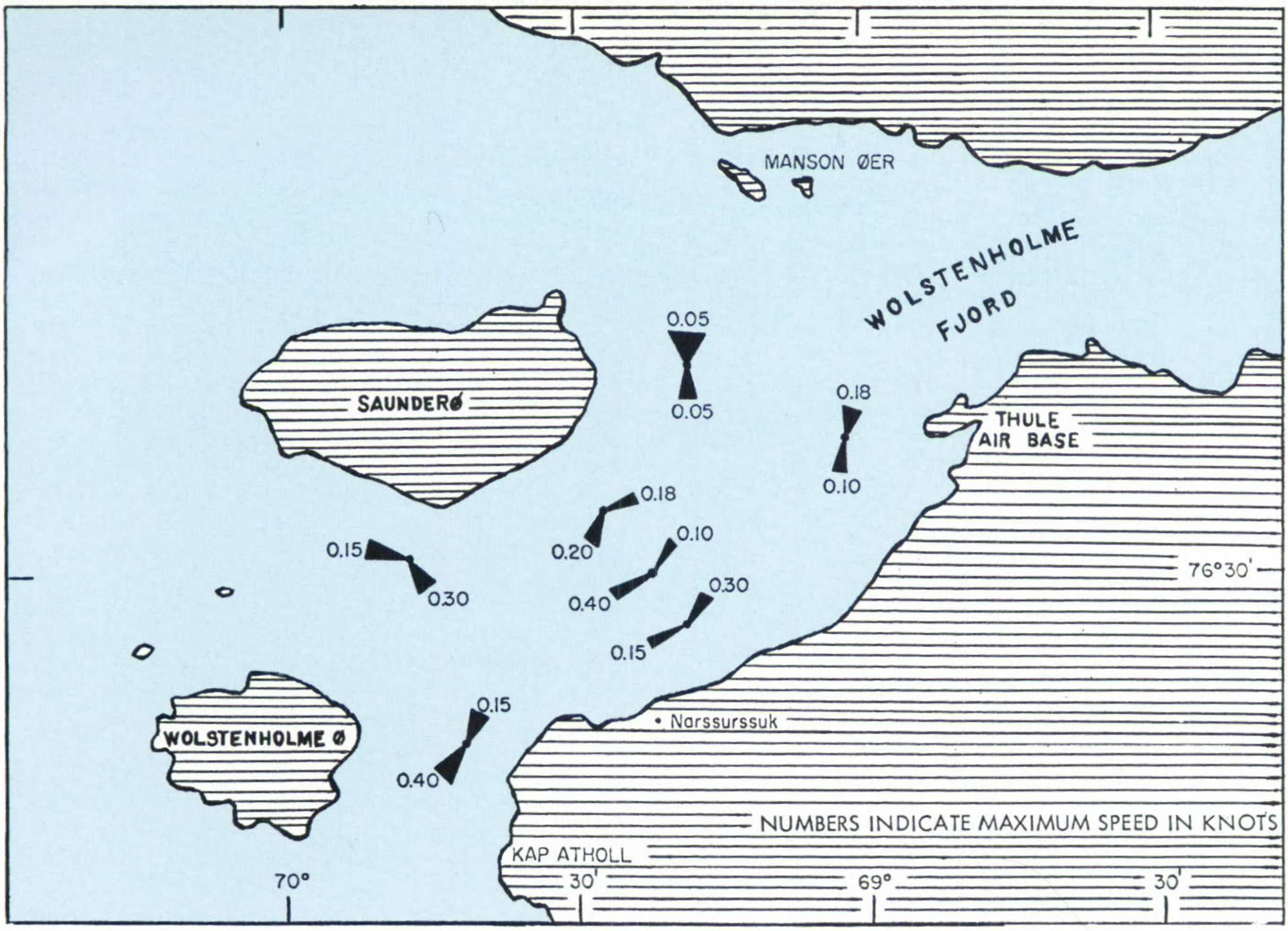
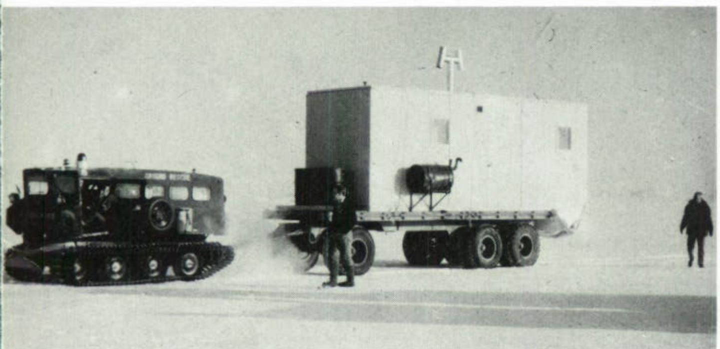
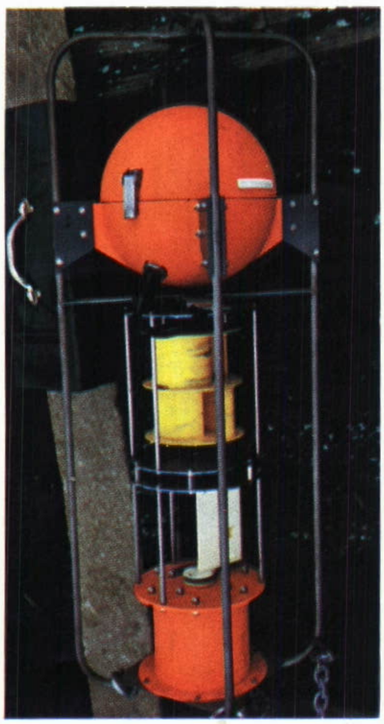


Figure 2. Summary of current data.

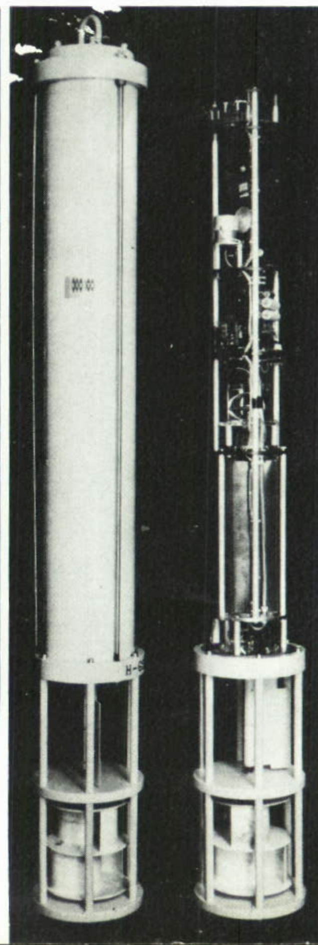


Mobile oceanographic laboratory.

Measuring the currents of North Star Bay.



Hydroproducts Current Meter



Geodyne Current Meter.

dominately tidal.

Figure 2 is a summary of all the current data.† The cones extending from the site locations indicate the most frequently observed current directions at each site. The numerals indicate the maximum current speed in knots recorded for each range of directions. The final analysis of the data indicated that the currents measured during this operation were not strong enough to have any significant effect on the breakup of the ice. Movement of the ice was thus dependent upon the wind direction and speed.

The Air Force requested that bottom photographs be taken to determine the nature of the bottom in the general vicinity of the crash site. Photographs taken at Site 1 at a depth of 240 meters indicated very little marine life and a soft bottom typical of an area of fine sediment deposition. Photographs taken at Site 2 at a depth of 135 meters indicated an abundance of marine life and a rocky bottom typical of the sea bottom of the coastal waters and of an area scoured by bottom currents.

RESEARCH SUBMERSIBLE OPERATION

During August 1968, three Air Force observers from the Directorate of Nuclear Safety and three submarine pilots from General Dynamics/Electric Boat Division, performed deep submergence operations in STAR III during the final phase of Crested Ice response. These were the northernmost research submersible diving operations ever undertaken by the United States.

The U.S. Air Force received excellent support for the ocean bottom survey from the U.S. Navy, the U.S. Coast Guard, numerous contractors and subcontractors, and the Danish Construction Corporation. The Navy Supervisor of Salvage, contracted with Ocean Systems, Inc., of Arlington, Virginia, to place the Air Force observers on the bottom of the Bay at the point of impact. Various tasks of the effort were subcontracted. The Electric Boat Division of General Dynamics, Groton, Connecticut provided the submarine, the necessary submarine support equipment, photographic and video tape recording equipment, and boat operations personnel. John E. Chance and Associates of Baton Rouge, Louisiana, provided the surface navigation support to place submarine operations accurately in the survey area.

The U.S. Coast Guard Cutter WESTWIND was operating out of the port at Thule Air Base when plans for the ocean bottom survey were approved. The commander at Thule Air Base, who was the on-scene commander for this survey, and his Military Sea Transport Service representative were successful in securing Coast Guard boats and crews from the WESTWIND who rendered invaluable assistance. An arctic survey craft about 50 feet long performed the tow operations to get STAR III to and from the survey area. An LCVP (landing craft, vehicle, and personnel) positioned reference lines on the bottom and buoys in the water and transferred essential materials and people during surface operations. The submarine pilots, assisted by Coast Guard divers, braved 37° water in either wet-suits or dry-suits, to disconnect or reconnect the towbar each time the submarine was towed to or from the survey site.

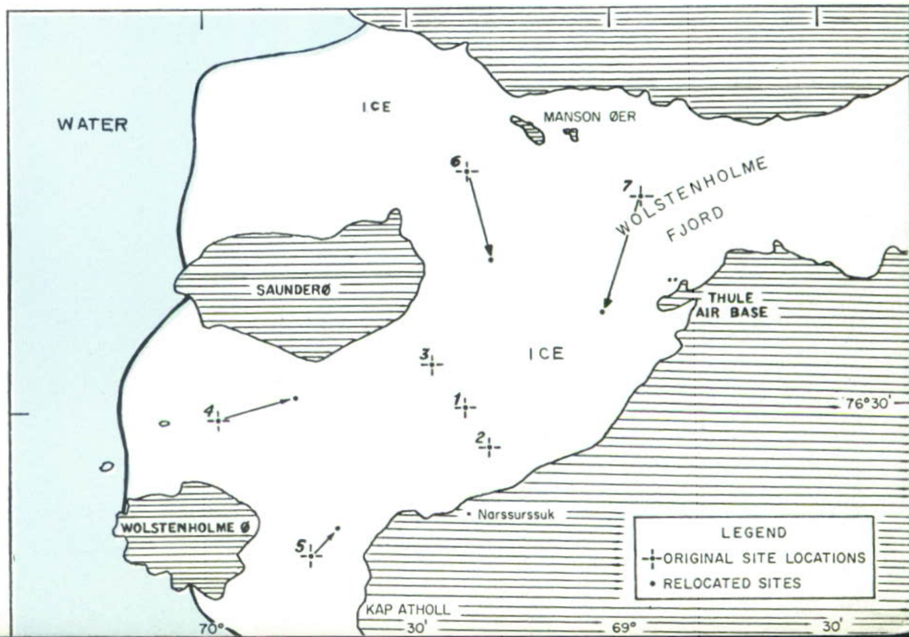
Communications, weather, helicopter crash/rescue operations, heavy equipment and its operation, space and facilities, protective clothing for arctic operations, administrative and other logistic support for the survey were provided regularly and promptly throughout the effort. The Thule Photography Laboratory worked throughout the diving operations to develop and print the still photographs taken of the Bay bottom.

Most diving operations during Crested Ice were con-

† When submerged operations began in August, tidal condition approximated those measured during this effort. Tides were a little stronger on one occasion.

Drilling a hole in the ice.

Site Locations.



ducted to depths of 100 fathoms (600 feet) or more. The marine life on the ocean bottom in North Star Bay consisted of shrimp, various types of starfish, bivalves, shellfish, and barnacles. Jellyfish and shrimp were iridescent as they scurried before the quartziodide lamps rigged on STAR III.

When the crew had sealed the diving sphere, and were cleared for operations, the STAR III began to descend slowly, inching the conning tower below the surface as negative buoyancy built up. As soon as the boat was below the surface, communications switched from radio to underwater telephone. Boat lights were required for visibility below about 100 feet. The water temperature also decreased as STAR III descended but was measured at a constant 32°F at and below about 200 feet throughout more than 2 weeks of diving. The temperature inside the sealed sphere was comfortable, although the steel sphere was cold to touch and condensed moisture profusely. The crew described the sphere, heated by the motors and equipment, as "the warmest spot in Greenland." The oxygen supply and life support system required periodic checks for crew safety but worked quite satisfactorily. The checks consisted of measuring the percentage of oxygen and detecting any carbon dioxide in the diving sphere. The life support system provided a continuous flow of oxygen from a regulator on a pressurized supply bottle. Carbon dioxide was filtered out by recirculation through a chemical pack; spare filters were carried inside the boat.

Water conditions and light intensity permitted the observers to see clearly out to 20 feet—sometimes beyond 25 feet. The best visibility for the purposes of this operation was achieved by moving the boat forward slowly 6 to 18 inches off the bottom. Most of the survey area revealed no evidence of the crash nor of years of human activity on the waves and ice above. There was a wide variety of debris in some places on the bottom: juice cans, milk cartons, candy bar wrappers, and wreckage. One item observed was an "A" frame. It was found 90 feet from the datum point on the first dive. This "A" frame was used during the crash recovery and cleanup effort and left on the ice. When the ice melted, it sank to the ocean floor and thus became a marker of sorts, helping to verify the datum point. Another indication of the accuracy of the datum point was the presence of a crowbar standing in the silt. Early in the accident investigation effort, the crowbar had been dropped through a hole in the broken ice. There were areas of concentrated wreckage, but usually the concentration was light, the pieces widely scattered, and small; often only a few square inches of surface area or a long slender piece of debris. There were small pieces of crumpled sheet metal, stringers, dynamotors, and pieces of wiring, tubing, and tires. As expected, the aircraft debris was stable and well fixed. Over much of the survey area, no wreckage existed.

The abundance of coelenterate life on the sea floor contrasted sharply with the barren surroundings near Thule. Starfish, brightly colored mollusks, and marine animal-flowers called anthozoans were plentiful. In some ways, the ocean bottom seemed an environment less hostile to man than the surface, until the extent of support needed for human survival was recalled.

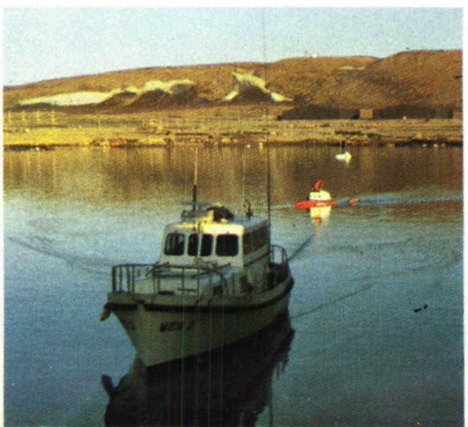
Four and three-quarter hours was the maximum submerged time for underwater arctic operations with the STAR III submersible. This allowed an average of 3 hours of productive survey time per dive. Except for switching off and stowing any equipment not required for surfacing the boat, the ascent sequence closely resembled descent.

A relief pilot rode the STAR III as it was towed back to port, which gave the dive crew a chance to relax. The trip between the datum point and shore took about 2½ hours. On one occasion the fog started to move in past Kap Atholl and Saunder Island. Tension mounted for the team until the arctic cruiser had towed STAR III beyond the bigger icebergs. Some difficulty plagued every dive. In spite of some foul weather, limits on time, camera failures, and icebergs, STAR III and its support team performed the required submerged boat operations very well. The surface navigation system repeatedly placed the team positively on their reference point during 11 diving operations.

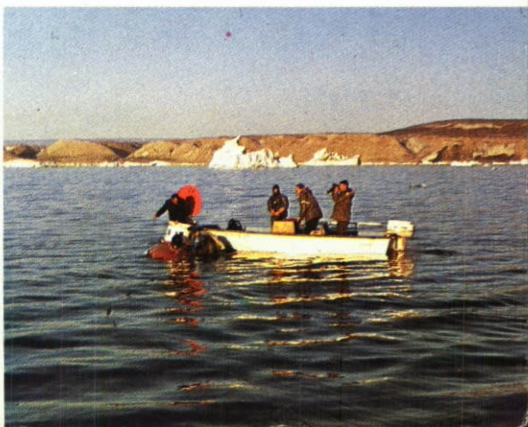
The successful underwater survey helped to confirm previous joint scientific findings that there was no radiological hazard from the limited aircraft debris on the ocean floor below the point of the crash.

Macoma Calcarea shells and Ophiuroids on the bottom of North Star Bay.

Arctic cruiser with STAR III in tow.



William A. DeCourt of General Dynamics enters STAR III to begin a dive.



EPILOGUE

From the Danish Point of View:

THE Thule District, in the northwestern part of Greenland, is one of the most inhospitable places man has ever inhabited, and except for the American air base near Thule, hundreds of miles separate the isolated Thule Greenlander hunters from other permanent settlements. Yet the Thule District is part of Denmark, and it was evident that when suddenly faced with an unprecedented and possibly dangerous situation, the people there would first turn to Danish authorities for guidance and protection.

No danger to man or animal and plant life was created by the Thule accident—that is now a well established fact. Within a week after the accident, this was the preliminary view of American and Danish scientists applying usual scientific methods and working side by side, although quite independently. Through swift action, and with the American and the Danish press as ever present witnesses, a situation, which obviously involved many problems, was brought under control, and unnecessary alarm avoided.

Although no one in Denmark had foreseen exactly this type of emergency, it turned out that resources and, most important, willingness to put them into action were in fact available. The record, which has been given here, is a tribute to the men of good will, Americans and Danes, who without regard to the rigours and discomforts gave their wholehearted support towards the solution of the problems at hand.

HANS HENRIK KOCH
Permanent Under-Secretary of State
Chairman, Executive Committee
Danish Atomic Energy Commission

EPILOGUE

From the American Point of View:

THE Thule accident was a shock to us all. We were saddened by the death of one of the crew and concerned with the harsh realities which would face our accident control team's efforts. The threat that the unforgiving arctic climate could exact a further toll made the outlook ominous. The situation seemed grim.

And yet, from such a harsh beginning, the days that followed saw a monumental performance by the team at Thule charged with surveying the accident scene and taking remedial housekeeping actions. Under the leadership of General Hunziker, Air Force personnel, with the assistance of their colleagues from other services and of Danish and American scientists, the cleanup moved forward rapidly in the most extreme climatic conditions. Within a few months this team brought Project Crested Ice to a successful conclusion without further loss of life. By September the contaminated debris and snow which was collected from the crash scene had all been removed from Greenland. Furthermore, an extensive ecological survey, led by Danish scientists, had reconfirmed that no hazard remained for animal or plant life.

This conclusion was due to the skill and devotion of all those involved. It attested to the dedication of each participant. We owe much to all those who participated on the American-Danish team. Once again the record reveals that the combined efforts of men, well-led, can triumph over the greatest adversities.

CARL WALSKE
Assistant to the Secretary of Defense (Atomic Energy)

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