

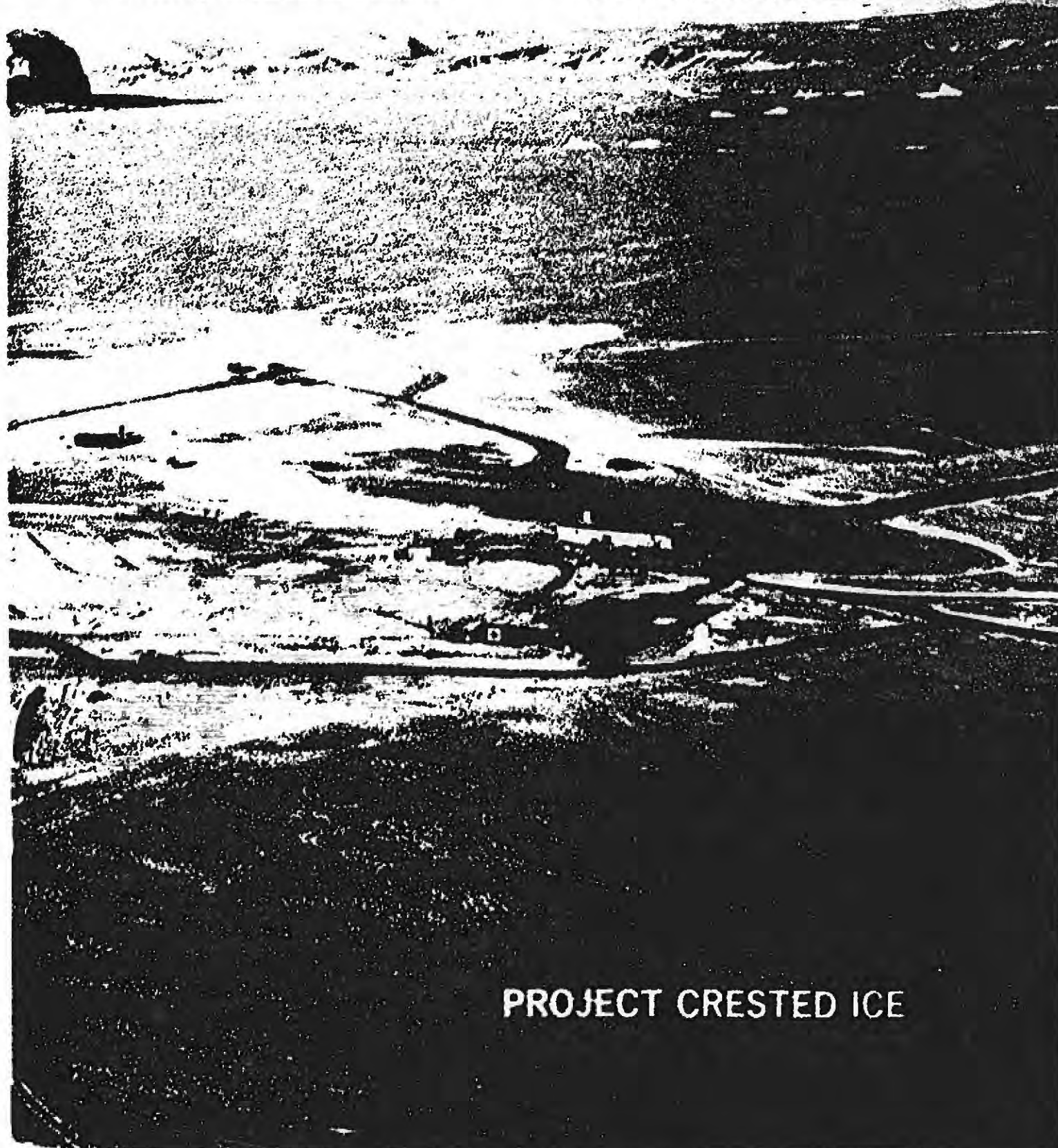


USAF Nuclear Safety

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VOLUME 65 (PART 2) SPECIAL EDITION



PROJECT CRESTED ICE

FOREWORD



GREAT technological accomplishment imposes great responsibility. Nowhere is this responsibility made more apparent than when an accident involving an advanced development poses a possible threat to people whose only involvement is that of proximity to the scene of the mishap. A potential catastrophe tests—as nothing else will—the desire to cooperate, to exert exceptional effort, and to devise new measures for averting disaster.

Our nuclear weapons can be activated only after a prescribed sequence of actions is followed. Because of their awesome destructive power, however, any accident involving them rightfully receives maximum attention. On January 21, 1968, a B-52 bomber carrying four nuclear weapons crashed on the sea ice off the shore of Thule, Greenland. Both the aircraft and the weapons disintegrated on impact. There was, of course, no nuclear explosion since the design of the weapons precluded any nuclear reaction. Nevertheless, limited contamination resulting from the dispersed radioactive material from the weapons had to be controlled and removed, as did the aircraft debris.

A major disaster was turned into a classic example of international cooperation at governmental, scientific, and local levels. During the ensuing months, the Danes and Americans at Thule provided a striking example of international teamwork. The seemingly insurmountable task of recovering and removing all traces of the accident proves again that truth may be stranger than fiction—and fully as exciting. This issue has been chosen to provide a condensed but complete summary of details of this true modern saga of international cooperation—by the people who were there.

MAJ GEN RICHARD O. HUNZIKER, USAF Retired



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VOLUME 65 (PART 2) SPECIAL EDITION

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HQ STRATEGIC AIR COMMAND
Offutt AFB, Nebraska

The Flight

SUDDEN AND UNEXPECTED DANGER

ON 21 January 1968, HOBO 28 took off on a 24-hour airborne alert mission. At the time of lift-off there was every indication that the mission would be completed successfully. All required maintenance and aircraft inspections had been performed. A later examination of all aircraft records and related documents revealed no signs of maintenance malpractices or system discrepancies that would bring on an accident. The crew of HOBO 28 was an integrated combat-ready crew; that is, its members had continually trained and flown together as a unit. An extra pilot was aboard to insure adequate rest for the principal crew.

Following take-off, the flight proceeded uneventfully. The first aerial refueling, accomplished approximately 4 hours into the mission, was routine. One hour later the aircraft commander instructed the crew assigned copilot to begin crew rest and ordered the spare pilot into the copilot's seat. At this moment in a most unobtrusive way started a series of events that led to the destruction of HOBO 28.

The cabin temperature became too cool for comfort at the flight-planned altitude. In accordance with approved procedure, the substitute copilot selected the emergency right-hand inboard position to provide cabin air and rotated the temperature rheostat to the position of maximum heat. This action provided a source of very hot air for cabin temperature control. After making the initial setting, the copilot began decreasing the rheostat setting as crew members on station reported they were getting too hot. Then, a few miles south of a northern air base, one crew member detected and reported the

odor of burning rubber. With fumes growing stronger in the cabin, the aircraft commander instructed the crew to go on oxygen and attempt to locate the source of danger. The copilot repositioned the air bleed selector back to the normal position.

IN-FLIGHT FIRE

The navigator searched the lower crew compartment once without finding where the smoke and fumes were coming from. Ordered to make a second search of the same area, he moved a metal box, and located the fire. Hurriedly he alerted the crew and started using a fire extinguisher on the flames.

The pilot notified the ground station of a fire in the cabin and requested authority for an immediate descent and for emergency landing at Thule Air Base. Two minutes later he began the descent. Downstairs, the



Crash path prior to impact on the ice.

mander and his staff, and close cooperation with Danish officials and scientists at all levels of government, who worked hand-in-hand with American counterparts in resolving the post-accident problems.

In mid-February, American and Danish scientists, government representatives, and Air Force officials reviewed the situation at meetings held in Copenhagen, and jointly planned the course of future actions. Since there was no evidence of any nuclear contribution from the destruction of the weapons involved in the accident, efforts were directed at removal of alpha-emitting particulates and aircraft fuels which could contaminate the Thule coastal areas after spring breakup of the ice.

A month later, a follow-up meeting was held between the two government groups, this time in Washington, and further refinements to cleanup and research guidance were promulgated and furnished the Air Force.

With SAC completing its search and recovery operations, further actions were directed by the Vice Chief of Staff, Air Force Logistics Command, under the Directorate of Special Weapons, planned and implemented their assigned task of removing all collected debris from Danish territory. The Aerospace Defense Command, as the operating command for Thule Air Base, provided security, radiological and crash scene monitoring, and performed a myriad of other support tasks required to meet agreement requirements between the United States and Denmark. Scientists and technicians from many Air Force units and other services assisted in accomplishing these tasks. All were directed, supported, and reported through the Broken Arrow Control Group acting as the agent for the Chief of Staff.

The list of individuals, offices, agencies, and departments who worked together as a team would fill the pages of a sizeable book. Countless unsung participants, many of whom performed in a prodigious manner with little or no recognition, can rightfully take pride in the

fact that they rose to the occasion and met the challenge with professionalism.

SAC's dynamic forces were brought to bear and consequently have reaped the praise and respect of the free world for the professional and thorough manner in which they performed search and recovery operations.

The Aerospace Defense Command and its 4683rd Air Base Group took charge upon SAC's departure from Thule in March and served as a holding force, coordinating and supporting further cleanup, removal, and technical study operations. As host to many hundreds of people—technicians, scientists, foreign diplomats and the world's press—the Aerospace Defense Command presented a most creditable image of the Air Force to the world.

The Directorate of Special Weapons of the Air Force Logistics Command was tasked with the monumental job of safely removing all crash debris for disposition in the United States. The work was accomplished with dispatch and technical precision.

The Atomic Energy Commission's experts in the field of handling and disposing of radioactive waste materials closed out the episode when they completed the debris processing.

From the viewpoint of the Headquarters United States Air Force Broken Arrow Control Group, on which I was privileged to serve, it was clearly evident that the disaster preparedness plans of the Department of the Air Force and Government were dynamic, workable, and manageable. Valid and valuable lessons were learned.

Under the added pressure of international public interest, Project Crested Ice was a meticulous effort that severely tested the Air Force's ability to cope with a complex and costly situation.

In the final analysis the record will show—"Mission completed in an outstanding manner."



Personnel of the Materiel Section in action.



Mr. Zinglarsen briefing General Hunziker and staff.

EVALUATION OF POSSIBLE HAZARDS

THE DANISH THULE COMMITTEE

Considerations by the Danish authorities regarding the evaluation of possible hazards to the population in the Thule district and the precautions to be taken.

THE essence of the information received by the Danish authorities in Copenhagen after the B-52 airplane crash near Thule on 21 January 1968, was that an American military bomber carrying nuclear weapons had crashed on Danish territory. Reliable information concerning what had happened to the aircraft and to its cargo of nuclear weapons was not available at that time, but it was known that within a certain area near the site of the crash, small amounts of radioactivity had been detected.

In order to evaluate possible hazards to the population in the Thule district and the precautions to be taken, a close coordination was established between the National Health Service, the Atomic Energy Commission (both having certain administrative responsibilities for problems which might arise in connection with the use of atomic energy and radiation), and—of course—the Ministry for Greenland.

The initial considerations as to what the Danish authorities should do towards establishing and dealing with possible risks in connection with the accident, took place in the Ministry for Foreign Affairs on 22 and 23 January. During these discussions, the Ministry of Defense, in addition to the above mentioned authorities, was also represented.

As early as 22 January, in the course of these discussions, it was decided that a Danish Scientific Group should be sent to Thule immediately. As representatives of the Danish Government and in connection with operations initiated by the United States, this group was to establish and evaluate possible immediate and long-range effects of the accident on the local population and then take the necessary measures. The composition of the Danish Scientific Group, both during the first few days and after 29 January when the group was expanded with more Danish experts, as well as its objects and activities, are described in detail in the contribution by the leader of the Danish Scientific Group, Professor Dr Jørgen Koch, "Danish Scientific Group Investigations," and the following Danish contributions.

Before the departure of the group, which was delayed by 1 day because of landing difficulties in

Thule, the Honorable Dr Carl Walske, Assistant to the U.S. Secretary of Defense (Atomic Energy), arrived in Copenhagen to brief the Danish authorities on the information available on the accident.

On 25 January, Dr Walske met with the team of Danish scientists and other officials from the Danish authorities involved, in order to pass on technical information on the accident which might be useful for the group's investigations in the Thule area. During this meeting, the first Danish-American discussions took place concerning the extent of and type of risks which might be connected with the spreading of radioactivity in the area. The discussions were based on the supposition that the plutonium contamination, which had been demonstrated, could have been the result of the explosion of the conventional high explosive surrounding the nuclear material in the unexploded bombs in one or more of the bombs during the crash, thereby producing the spread of fissionable material. At the same time, it was clear that nuclear reaction could not have been brought about by the crash.

The Danish Scientific Group left for Thule on the afternoon of 25 January. During the time following their arrival, they carried out a series of investigations and operations in Thule parallel to and as a supplement to the American work. As will be evident, there was close coordination in the steps taken by the Danish and American authorities. On the basis of the information sent out from Thule, the Danish authorities in Copenhagen were able to continue to follow and evaluate developments accurately. Immediately after the crash preparations were started at Risø to enable Danish measuring operations to take place. As more information became available these preparations were expanded and intensified.

Some 2 weeks later, when the initial Danish investigations and measurements in Thule had been completed, and when the type and extent of the work which had been begun by the American group had been ascertained, nearly all of the Danish scientists returned to Copenhagen. Replacements were sent out, however, and during the following months there was always at least one Risø staff member in Thule.

Thus, when the Danish as well as the American initial investigations had been carried out at and around the crash area, meetings were set for 15 and 16 February to be held in Copenhagen between Danish officials and an American delegation under the leadership of Dr

Walske, together with a group of experts, both Danish and American, who had participated in the investigations in Thule. Previous to the Danish-American meetings, Danish officials and scientists had met to evaluate the investigations and evidence in connection with the accident, and to discuss measures required with regard to further investigations, clean-up of the area, etc.

At the meetings on 15 and 16 February, the information gathered by both sides was reviewed and discussed, both in meetings between all participants as well as in smaller working parties appointed to deal with particular aspects. Aside from an exchange of views and increased knowledge concerning the extent and nature of the accident, the meetings resulted in detailed agreements as to what measures should be undertaken with regard to cleaning up the area where plutonium contamination had occurred.

Agreements were also reached concerning further measurements and investigations on the land areas surrounding the crash site, as well as continued surveillance of possible ecological consequences. It was a basic premise for the agreements reached at the meeting that further talks should take place concerning modifications or extensions of the operations agreed upon if new information or evaluations should prove such operations desirable. Furthermore, it was also agreed that in the course of the continued work, close contact should be maintained between the parties. The joint press release of 16 February, issued after the meetings, follows:

"Scientists from Denmark and the United States have been meeting for the past 2 days for discussions of the technical questions arising from the B-52 crash at Thule, Greenland. The meetings continued the close cooperation which has existed since the time of the crash. Scientists of both nations have worked together at the scene of the crash and participated in the gathering of scientific evidence. The scientists reviewed the considerable progress which has been made at the site in collecting aircraft and weapons parts. Contaminated material will be removed from Greenland. They also assessed the extent to which radioactivity was released.

"It was agreed that under present conditions the radioactivity spread in the area is not a hazard to people or biological species, nor is any hazard foreseen for the future. Nevertheless, an effort will be made to remove the main part of the radioactivity which is on the ice. The conclusions of the scientists regarding the absence of hazards to the biosphere will continue to be examined in detail. Further supporting evidence will be accumulated through an extensive program of data gathering."

During the first phases of the Thule case, the organization and carrying out of the Danish investigations and operations as well as the coordination between the

Danish authorities involved, had taken place to some extent in an improvised way. After the Danish-American meetings in February, it was agreed that as a continuation of the cooperation which had existed between the National Health Service, the Atomic Energy Commission, and the Ministry for Greenland, it would be useful to establish a restricted committee to maintain continued contact with the American authorities and to follow the execution of the measures and investigations which had been agreed upon. In close contact with government, this committee was furthermore to make additional agreements on any measures or investigations which might be deemed necessary for further clarification of any other factors connected with the accident, and take any additional measures for the protection of the population of Greenland against possible effects of the accident. On 8 March 1968, the Minister of Education (the Nuclear Installations Act which includes rules on the safety of such installations is administered under the Minister of Education), on behalf of the Government, approved the establishment of this committee. The following members were appointed:

H. H. Koch, Permanent Under-Secretary of State, and Chairman, Executive Committee, Danish Atomic Energy Commission.

E. Juel Henningsen, M.D., Deputy Director General, National Health Service.

Jørgen Koch, Professor, University of Copenhagen, and Consultant to the National Health Service.

H. Lassen, Head of Division, Ministry for Greenland.

Dr. C. F. Jacobsen, Assistant Director, Risø.

H. L. Gjedrup, M.Sc., Head of Health Physics Department, Risø.

Mr. G. Vigh, Head of Section, Danish Atomic Energy Commission, was appointed as secretary of the Committee. The Committee maintained close contact with the Ministry of Foreign Affairs throughout.

Mr. Vigh was appointed as secretary of the Committee. The Committee maintained close contact with the Ministry for Foreign Affairs throughout.

During the period following the meetings in Copenhagen on 15 and 16 February 1968, in accordance with the agreements reached, investigations and clean-up operations were carried out in the Thule area. However, on the basis of the negotiations between the American and Danish technicians and scientists working in Thule, and as a result of the contact between the American authorities in Washington and the above mentioned Danish Thule Committee, the measures taken were continuously adapted and in certain respects changed as further clarity of the circumstances of the accident was established.

As the above mentioned work progressed, it became evident that another meeting would be necessary for establishing a new overall evaluation of the case. What was needed was a comparison of the extensive Danish



Press people and team of Danish radiation experts are informed by U.S. General Hunziker, Feb. 27, in Thule, Greenland, about recovery progress of radioactive bomb fragments from the B-52 bomber which crashed near Thule Air Base Sunday, Jan. 21. In front of the General photo shows from left: Engineer H. L. Gjerup, Hans Jensen from Ministry for Greenland, Professor O. M. Kofoed-Hansen, Professor Jørgen Koch and Master of Science Per Grande. Copyright: Nordfoto 29.1.68/OL Photo: LAD

and American measurements and investigation results, on the basis of which a revision and extension of the agreements reached in Copenhagen could be drawn up. For this purpose, a meeting was arranged in Washington for 18 and 19 March between the Danish and American authorities.

At the meetings, the progress of the work was discussed, including the nearly completed task of removing the contaminated snow from the crash area and the likewise nearly completed collection of airplane debris and fragments of the nuclear weapons. In addition, the scientific evidence collected by both countries confirmed that, as hitherto assumed, there were no risks involved for human beings, animal and plant life as a consequence of the crash. New agreements were reached as to the completion of the cleaning up of the area, the removal of aircraft debris and of contaminated snow and ice, as well as the completion during the coming summer of control measures, including a radioecological investigation program. The joint press release of 19 March follows:

"Danish and American scientists and officials met on Monday and Tuesday to review the status of operations at the site of the B-52 crash in January near Thule Air Base, Greenland. These meetings continued the cooperative approach to technical matters associated with the incident. Previous exchanges

have taken place at Thule on a continuing basis and in meetings at Copenhagen.

"The participants discussed the program for removing contaminated snow. This had been jointly agreed earlier as a housekeeping measure, even in the absence of concern regarding biological hazards. Removal of contaminated snow is now nearly completed. This snow is presently contained safely in storage tanks and the contamination will be removed from Greenland.

"The group noted that removal of contaminated aircraft debris from the ice is nearly complete, except for small pieces which are still being recovered. The recovered aircraft debris is being stored safely in metal containers at Thule AB and will be sent to the U.S. for disposal.

"In addition to reviewing the housekeeping operations and agreeing that they are nearly complete, the scientists jointly examined the extensive data gathered from the ice at the crash point, as well as from outlying areas. These measurements have confirmed the earlier views that there is no risk for human beings, nor for marine, animal or plant life. Joint surveillance will, however, continue."

In the course of the spring and summer of 1968, the clean-up work of the area around the crash and the removal of the aircraft debris and contaminated snow

and ice were completed. The Danish health physicists from Risø followed the work (for further details, see article "Danish Health Physicists' Activities", by O. Walmod et al.).

Already at the time of the February meetings in Copenhagen, the Danish authorities had emphasized that they wanted to ensure complete safety with regard to the risk of possible consequences for human beings and animal and plant life, also of possible long-run consequences. At the March meetings in Washington, this position resulted in agreements concerning the implementation of a Danish radio-ecological investigation program to be carried out during the latter part of the summer of 1968. The purpose of the investigation was to obtain further confirmation of the scientific evidence previously collected by both countries. A more detailed description of the program and its operation in August 1968 can be found in the article, "Ecological Survey" by F. Hermann and Christian Vibe. In support of the radio-ecological program, the United States furnished an oceanographic research submersible, the STAR III, for



The Danish Motor Ship, AGLANTHA.

the investigation of the sea bottom at the crash area. Reference is made to the following joint press release as of 9 August 1968:

"The Department of Defense and the Danish Atomic Energy Commission announced today the beginning of two wrap-up actions related to the B-52 crash last January in Thule, Greenland.

"First, Danish scientists will lead a joint two-part ecological survey. Second, approximately 600 containers of melted ice, snow and other residue, collected at the crash site, will be shipped to the United States for disposal.

"The joint Danish/United States ecological survey will begin at Thule in early August. It is part of a joint Danish/United States follow-up effort agreed upon at the last meeting of Danish and American scientists early this year. The survey party will again evaluate the environment in the crash area. Previous joint scientific findings established that there was no risk in the area for human beings, nor for marine, animal, or plant life as a result of the B-52 crash last January.

"This re-evaluation is in keeping with the conservative scientific approach followed throughout the recovery operation.

"The Danes will conduct the main phase on the surface where samples of plant and animal life will be collected and evaluated. Their party, operating from the 54-foot Danish motor ship, AGLANTHA, will consist of five Danish scientists, specializing in the fields of biology, ecology, hydrography, and health physics. One American scientist will also accompany this team. Their 1-month surface survey will also provide an opportunity to acquire new knowledge of the region's normal ecology.

"In support of the joint program, the United States is furnishing an oceanographic research submersible—the STAR III—which will survey the area below the crash site. Underwater survey operations are expected to be completed in August.

"In addition to the joint survey, the United States will remove previously collected ice, snow and aircraft debris from the Thule crash site. This low-level, radioactive residue will be sealed in containers and tanks and transported in three Military Sea Transportation Service (MSTS) ships during August and September to the United States for disposal.

"The ships will unload the material at the United States Army Port at Charleston, South Carolina. It will then be moved by rail for final burial at the Atomic Energy Commission (AEC) Savannah River plant near Aiken, South Carolina.

"As required, the shipment will be monitored during the entire operation to assure compliance with all existing safety regulations.

"Weapons debris was previously airlifted to the Atomic Energy Commission Pantex plant at Amarillo, Texas."

The material procured during the ecological investigation program was exposed to further radio-ecological investigations at Risø in the same way that previously collected material had been examined and measured.

The results of the radio-ecological investigations are described in the article by Asker Aarkrog. The investigations led to the following conclusions, as stated in this article:

The radio-ecological investigations have shown that the plutonium levels in the collected samples in no instances were such that they can be considered harmful to man or to higher animals in the Thule district or in any part of Greenland. Nevertheless the B-52 accident measurably raised the plutonium level in the marine environment as far out as approximately 20 kilometers from the point of impact. The highest concentrations were found in bottom sediment, bivalves and *Crustacea*. The higher animals such as birds, seals, and walrus showed plutonium levels hardly significantly different from the fallout background.



MAJ GEN R. G. HUNZIKER
SAC On-Scene Commander

THE COMMANDER'S POINT OF VIEW

WHETHER in war or in peace, adequate military response is based upon expecting the unexpected and being prepared to cope with any contingency. Aircraft are designed to fly; not to crash. Weapons are designed to destroy a target; not to have their parts spread over a peaceful countryside. Yet when these unplanned events occur, immediate action must be taken to determine the extent of the problem created, to contain and control the effects, and eventually to restore the affected area to a clean and safe condition.

This is the report of the search and recovery portion of one such effort, designated "Crested Ice," which was carried out under my command dur-

ing the 70 days between the 21st of January and the 30th of March 1968. It is not a technical summary; there are specialists who can provide that. It is, rather, an overview of the problems faced, management decisions made, and the unique—at times unorthodox—approaches which had to be taken to meet contingencies as they arose.

The 21st was much like any other winter Sunday in Omaha—until about 3 o'clock in the afternoon. I had just finished lunch when I was alerted by the Strategic Air Command (SAC) Headquarters Command Post that a B-52 had crashed somewhere on the ice close to Thule Air Base at 4:39 p.m. Greenland time. The first reports were scanty,

but enough to indicate that a recovery effort be initiated immediately. It was known only that one of our B-52s was down, and that it carried four atomic weapons which must be accounted for. Neither the cause of the crash, the fate of the crew, nor the exact location and condition of the aircraft and weapons wreckage had then been determined.

While such events are not planned, planning for them has taken place. I immediately called the command post and started the sequence of events which follows a "Broken Arrow," the code designation for an accident involving a nuclear weapon. The response was immediate and extensive. Specialists from a wide range of areas—disaster control,

radiation monitoring, explosive ordnance disposal, medical and others—were alerted, and followed the carefully prepared plans which it had been hoped would never have to be implemented. By 7:25 that same evening, my group and I were aboard a KC-135 headed for Thule. Among us was Col Chester Hockett who was invaluable as my chief of staff during the entire project. We arrived at 2:52 on the morning of the 22nd of January. My Disaster Control Team was met by Col Paul D. Copher, the Deputy Base Commander, and given a status briefing at the Base Service Club which had been converted into an office building for the team.

The initial response had been made by the Deputy Base Commander. He had informed the SAC Command Post of the loss, and had dispatched Mr Jens Zinglersen, a Danish National, to alert the Greenlanders to the danger and to warn them to stay away from the crash site. Mr Zinglersen, who had heard the explosion and seen the fire subsequent to the crash, volunteered to be of any assistance possible. During the coming days, he was an indispensable link with the Green-

land population as he spoke both Danish and the native Greenland dialects.

After traveling to the village on the mainland to warn the Greenlanders in the locality, he and five other dog team drivers assisted in locating the aircrew survivors. At the time of my arrival, six crew members had been located, five within approximately 3 hours. The sixth, the only fatality, had been found a short time previously. The seventh and last crew member eventually was recovered some 20 hours after the crash.

The crash site was approximately 8 miles west of Thule on the open sea ice of North Star Bay between the mainland and Saunders Island. The aircraft had crashed on an

almost due south heading. Initial helicopter reconnaissance reported only a blackened area approximately 500 x 2100 feet, with no large pieces of aircraft debris in sight except the engines. The weather was extremely cold — approximately -24°F. A 7-knot wind produced a chill factor which lowered this to the equivalent of a -53°F reading. January is the depth of the Polar darkness, which engulfs the northern region during part of every year. The sun would not be seen at all until the 14th of February, yet within 2 weeks of that time its glare would be so intense that sun glasses would be required to prevent discomfort and eye damage.

There were many unknowns . . . whether the aircraft had gone



Dogsleds with their Greenland driver.



Aerial photograph of the crash site.

through the ice, as appearances would suggest; whether the ice was strong enough to support the weight of recovery vehicles; where and what there was to recover were only a few of the many unanswered questions. Preliminary survey by some base personnel had indicated light alpha contamination. While this did not present an immediate danger, it necessitated full documentation of both amount and extent, and the development of immediate measures for its control and removal.

The first problem which had to be met was that of visiting the crash location. Since neither the thickness of the ice nor its ability to support vehicles were known, the first survey

contemplation. There were pressing and serious problems which had to be met immediately and effectively. As was the case throughout the entire project, necessity and expediency dictated methodology.

Because of the possibility of contamination, the village where the drivers lived was monitored for radiation on the 25th of January and periodically thereafter. None was found except small amounts on clothing. Aside from the requirement temporarily imposed that they refrain from seal and walrus hunting in the area of the crash until permitted to do so again, the lives of these Greenlanders, except for those actively engaged in the recovery

determined immediately if the problems inherent in the crash were to be kept under control.

These weather conditions also demonstrated the need for adequate shelters against the rigors of the storm. The Greenlanders, who served so long and well during the entire project, were pressed into building a small colony of igloos, capable of holding up to 100 people, which could be used in case of emergency. While these would serve well for survival, it was obvious they would not be adequate for an on-site base operations, which was essential. It was necessary, therefore, to develop an on-site camp from which operations could be directed. Early



Thule weather forecast.



Igloos built at crash site for emergency use during severe arctic storms.

of the areas as well as much of the activity during the next several days was directly dependent upon dogsleds with their Greenland driver. Later, of course, more advanced methods of transportation were developed.

For one given to philosophical contemplation, the contrast between a sophisticated nuclear age and the basic survival methods of the Greenlanders gave pause for thought. It was ironic that one of man's most technically complex endeavors had gone astray and that recovery from its effects must depend upon the most primitive of methods. There was, however, little time for idle

effort, remained unaffected.

Weather proved to be a merciless enemy during those early days. Storms repeatedly swept the area. Three days after the crash a surface wind of about 25 knots with gusts of 45 knots persisted for 12 hours. Three days later a comparable storm lasted for almost 24 hours. The equivalent temperature at times dropped below -100°F. The blowing wind, in addition to raising chill factors to an unbearable degree, created problems of visibility and aggravated the possibility of spreading the radiation in the loose, blowing surface snow. The extent, level and type of contamination had to be

reports on the strength of the ice indicated that it was from 2- to 4-feet thick and in the process of thickening. This was heartening because it meant buildings could be constructed and roadways could be built to alleviate the transportation problem.

A few years ago in the missile development era, the term "concurrency" came into common use. Nowhere could it be more appropriately applied than to Project Crested Ice. It would have been desirable to construct the roads, then the camp, then engage in the search activities, and eventually to launch follow-up programs. Stark reality indicated the

infeasibility of this systematic approach. It was necessary to establish concurrently the on-site headquarters, determine the scope of the radiation problem, recover the weapon components and aircraft debris, protect personnel on the ice from hazards inherent in both the accident and in the environment, and begin procedures to control and reduce radiation hazards. In order to do all of these things simultaneously, a heterogeneous work force had to be mobilized and a firm and skilled guidance maintained to assure that concurrent actions were carried out rapidly and efficiently.

This mobilization involved personnel from Danish authorities and

and food had to be provided. The difficulties of integrating this diversified group into an efficient working force dictated a management decision which was important to the success of the operation.

It was decided at the start that available individuals would be used without regard for their normal chain of command. I resolved that this must be an organization of workers, not observers. Another pressing reason for deviation from normal chain-of-command procedures was that the time for solution of this grave situation was of undetermined but limited length. With the coming of warmer weather, the ice would break up and melt, and

on friendly territory. It was only natural that the world was interested in the import of the event and its possible ramifications. Because of its relative inaccessibility, it was difficult for newsmen to visit the scene. After consultation with Col A. J. Lynn, Chief of Information, Hq SAC, I decided that everything possible would be done to facilitate their transportation, provide accommodations, and assist in providing accurate information about the occurrence. "Credibility" was a watchword from the beginning to the end of the project. When information could be made available, it was given freely. Where security dictated secrecy, newsmen were so informed



General Hunziker with Jens Ziglensen and unidentified dogsled driver.



Camp Hunziker.

over 70 U.S. agencies, including elements of the Department of Defense, Atomic Energy Commission, State Department, and others—in all, over 700 people during the course of the operation. The maximum number of people in place at one time—565—was reached on 14 February. The sheer numbers of people and the fact that many had no experience in arctic operation presented difficult problems. They had to be outfitted with suitable clothing and equipment, briefed on the hazards of arctic operation, and watched to assure that required safety procedures were followed. Accommodations, transportation,

the crash site would disappear into the sea. Whatever was to be done had to be done before that time, and as rapidly as the unpredictable storms would permit. The available personnel, therefore, were divided into teams. Leaders were selected because of their experience and competence and regardless of current assignment or organization. Concurrent operations were conducted to the maximum extent possible.

Another major management decision had to be made within hours after my arrival. The teletype services of the world had flashed the news that a U.S. bomber had crashed

—frankly, without equivocation and without apology.

In all, 51 newsmen visited Thule. Twenty-five were from the United States and 26 from other countries, the greatest number from Denmark. At the press conference on the 25th, 10 countries were represented. I personally conducted four press conferences, one each day between the 25th and 28th of January. There were many questions, but those most frequently asked related to the extent of the explosion and the degree of the radiation hazard. In keeping with avowed policy, the press was informed without equivocation that there had been an explo-

sion of the conventional materials in at least some of the nuclear weapons, that some radiation was present, and that there had been no nuclear yield.

Not only were there attempts to keep the world informed, but special emphasis was placed upon close coordination and cooperation with the local authorities, both military and civilian. It was considered essential that the local community be aware of the hazards presented and of the measures being taken for their control. On the 29th of January, a meeting was held with Mr Klaus Borneman, the Acting Governor of Greenland, and members of his party. This same close cooperation was maintained throughout the project.

tional, the arduous task of erecting the camp began. The local Danish workmen, who were responsible for the upkeep at Thule, assisted tremendously in this task. Prefabricated huts were built at the base, transferred to the crash site, and erected on the ice. The first such building was completed on the 24th of January—less than 2 days after the arrival of the Disaster Control Team.

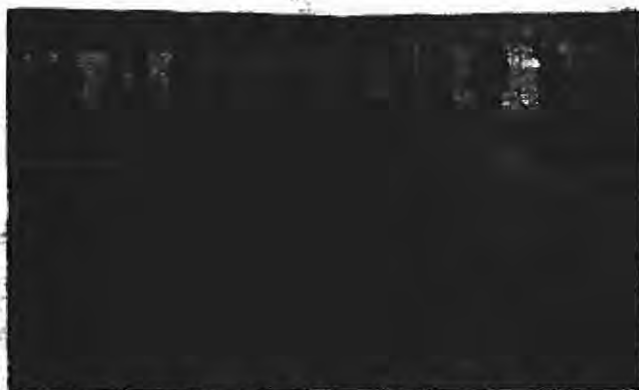
The second building was ready on the 25th. The completion of the buildings was only the first step toward a functioning facility. Generators for lighting, heaters, telephone, and teletype lines all had to be installed and maintained.

The use of ground vehicles was

of the press of circumstances, it had originally been planned that the work of recovery and decontamination would be carried out on a 24-hour basis. It soon became apparent that this was not possible. The intense cold took its toll, not so much of men but of equipment. Flashlight batteries would last only 10 minutes. Equipment designed for use in milder climates broke with unpleasant regularity. Engines had to be kept running. If one stopped, it could not be started again. Batteries on the radiation monitoring equipment failed. An on-site fix greatly alleviated this particular problem. Batteries were carried inside the outer clothing while the monitor-



Equipment failure—road grader with broken front axle.



In intense cold and darkness, workers searched the blackened area.

The first step in the development of an on-site camp was the establishment of a heliport which, in addition to permitting quick access for search personnel, would permit supplies and materials to be flown in. Helicopters could not land on the ice because the rotor wash created a snow cloud which reduced visibility to zero. This problem was solved by airlifting sheets of plywood to serve as a heliport. When laid on the ice, the rotor also raised these in the air so that it was necessary to devise some method of fastening them down. This was solved by using water to freeze them to the ice surface. Once the heliport was func-

authorized following a survey of the ice which indicated that it could hold vehicular traffic as long as there was adequate spacing so that too much weight was not placed on any one segment. Two roads were built—one for incoming traffic, and one for its return. In order that one of these roads might "rest," a third road was also built so that only two were in operation at any one time. With the completion of the roads, the immediate logistic problem of the on-site camp (designated "Camp Hunziker" by Colonel Lynn) was essentially solved.

The problem of maintenance, however, had only begun. Because

ing instrument was held in the hand. Gasoline lanterns were ordered from the U.S., and eventually floodlighting was installed. The extensive maintenance problems, however, made it necessary to divert at least one shift out of each 24 hours to repair and maintenance if the primary task was to be accomplished.

By contrast, the breakdown of the men was minimal. In spite of the intense cold, darkness, bulky clothing, poor visibility, contamination, and generally austere working conditions, the men assigned to the task worked long hours without illness or accident. It is also noteworthy that there were no vehicular acci-

dents during the entire operation.

The first searchers in the area had observed the blackened crash site and the fact that alpha radiation from the dispersed plutonium from the weapons was present. In order to define the limits of radiation, monitoring of the area was done so that by the 25th of January a zero line was established. This comprised a rectangular area which was physically enclosed by ropes strung between reflectorized stakes. The term "zero line" signified the point at which radiation was at a zero reading.

Accurate determination of the levels of radiation depended upon radiological monitoring, utilizing

From the start, decontamination procedures for personnel, equipment, and dogs had been in effect. Monitoring the first parties to visit the crash site showed contaminated clothing, particularly footwear. Nothing higher than a reading of zero was considered satisfactory for any except American personnel. For our own people, normal Department of Defense standards were accepted. At the on-site camp, a decontamination station was set up at the zero line. Personnel who had been at the crash site entered on the "hot" side, underwent gross decontamination, and exited on the "cool" side. Final decontamination was then completed at an on-base facility. In order to

part of the expense of the recovery procedures. These skins were purchased to replace Greenlander pants which routine decontamination did not reduce to a zero reading. In addition to routine cleansing, nasal swabs were taken on all personnel and urine tests were taken if it was considered desirable. In keeping with the concept of using experience regardless of organization, CAPT R. E. McElwee, USN, of the Defense Atomic Support Agency, was given direct command of radiation control. The actual decontamination procedures were carried out primarily by members of the SAC Disaster Control Team.

Although a minimal direct health



Zero line.

grid methods to obtain readings at systematically defined points. Doing this was complicated, as were all other activities, by the low temperatures and instrument failures. Eventually the task was completed and a contour map indicating the areas of various concentrations could be developed. As had been anticipated, by far the greatest percent of all radioactive material was in the blackened area which resulted from the explosion and fuel fire that followed the impact. It was apparent that removal of the black snow crust from the top of the sea ice would result in elimination of essentially all the plutonium contamination.

reduce the load on the decontamination personnel, every effort was made to restrict entrance into the contaminated areas. Vehicles from the Air Base not directly utilized in the search effort stayed outside the zero line.

Decontamination procedures were standard. Most of the contamination was removed by simply brushing the snow from garments and vehicles. Thorough cleansing eliminated most of the rest. In those few instances where contamination had impregnated the materials, the clothing was replaced. This latter decision accounts for the bill for three polar bear skins which became



Men taking a coffee break on the sea ice.

hazard, the radiation contamination presented an inconvenience to on-site search personnel as it was not possible for them to eat in the contaminated area. Because of the difficulty and time consumed in transportation, they were kept at the site for full 8-hour periods. Here, only liquids could be consumed. Soup, hot chocolate, and coffee were used by the gallon. Keeping these in a liquid state until they could be swallowed was not always a simple procedure. Not uncommonly, coffee froze in the cup if conversation was carried on too long. In order to accommodate these workers at the end of their shift, a dining hall on

the base was maintained on a 24-hour basis.

A Weapons Division was established on 23 January with Col Robert S. Marcum as its chief. Its primary function was the recovery of weapon and aircraft parts. The initial search teams were instructed not to move any of the wreckage components. Understanding the dynamics of the occurrence could best be achieved if the parts in their relation to each other were clearly identified. This early survey located portions of all four of the nuclear weapons. The fact that all four had been accounted for was announced publicly on the 29th of January. The explosion which had occurred had completely

magnetic pole, compasses were nearly useless. It was almost impossible because of darkness and the lack of reference points to obtain an accurate heading which could be used to develop parallel grid lines. It was common for searchers who had been in the same areas and seen the same pieces of debris to vary widely in their descriptions of its location. It was decided, therefore, to pick up all pieces as they were located. This decision was further supported by high winds that scattered the small light weight aluminum parts, thus aggravating the radiation and the recovery problems. Because of this, as the pieces were accumulated they were

placed in barrels, cans, and drums. This phase was completed on the 20th of February. The nuclear weapons parts were returned to the U.S. and the aircraft wreckage stored for future disposition.

From the beginning, plans were made to support the operation with the best scientific talent available. The American scientific group was established on 25 January with the arrival from the Los Alamos Scientific Laboratory of Dr Wright Langham to serve as my Chief Scientific Consultant. Dr Langham is one of the world's leading authorities on the biological behavior of plutonium. With Dr Langham were Dr H. D. Bruner and Dr John Wolfe of the



Workers picking up debris.



Aircraft debris piled up on the sea ice.

disintegrated the aircraft. This relatively complete disintegration resulted in literally thousands of small pieces and accounted for the fact that early searchers found relatively few large aircraft parts. There was speculation at the time that portions of the aircraft might have plunged through the ice. There was, however, no practical method of evaluating this possibility, although later developments proved it to be correct.

It soon became apparent that while it was desirable, time would not permit the developing of an accurate wreckage grid. Because of the relative position of the north

stacked into piles and covered with chicken wire until packaged for storage. In the final analysis, the search resorted not to scientific findings, but to use of mass manpower. It was conducted using airmen shoulder-to-shoulder systematically sweeping the area many times. The lines were maintained by noncommissioned officers (NCOs) whose primary function was to insure that the formations were kept intact. Although sensitive radiological and metal detecting equipment was available, the best mechanism for detection proved to be the human eye. Eventually, however, the weapons and aircraft parts on the surface were recovered and

Atomic Energy Commission, and Dr Nathan Benedict and Dr Joseph Tinney of the Lawrence Radiation Laboratory. This scientific advisory group continued to grow until in all, 23 U.S. scientists were involved. They came and went as their duties dictated. The primary function of the group was to give me support on technical and scientific matters. A second and extremely important function was to serve as a liaison with the Danish scientific group, to work with them on a daily basis, and to assure mutual compatibility of goals and procedures. With the departure of Dr Langham on February 3rd, the control of this group

passed to Col Jack Fitzpatrick, Field Command Surgeon of the Defense Atomic Support Agency, who had arrived on the 31st of January.

The first group of Danish scientists also arrived on 25 January. This group consisted of Professor Jorgen Koch, an eminent physicist from the University of Copenhagen, and 11 select Danish specialists from a variety of fields. As soon after the arrival as possible, I met with the group, extended a welcome to them, and offered to assist in their survey in any way possible. They, in turn, expressed their desires for full cooperation and mutual assistance in the task at hand. After this initial briefing, the Danish members partic-

The 3-inch cores were obtained by hand, drilling through the ice and by preserving the cores intact for subsequent photographic and radiological inch-by-inch monitoring. In all, over 180 cores were collated and processed in this fashion. Analysis of these cores revealed traces of tritium.

Systematic evaluation of the sea ice indicated an area approximately 100 meters in diameter which had been disrupted by the crash. In the central portion of this area, sea water and large blocks of ice had risen to the surface and been refrozen. Cores from this area were contaminated. Cores from other than the impact area were clean.

The Danish scientists were partic-

been reached on the extent of these studies, it was anticipated that they would be continued and that the U.S. scientists would cooperate in every way possible. Obtaining sea bottom samples was a particularly arduous task. The same effort used to obtain ice core samples had to be expended in breaking an even larger hole in the ice through which grappling equipment with over 600 feet of attached line could be lowered.

On the 25th of January, the first information meeting was held in Copenhagen between Dr Walske, Assistant to the Secretary of Defense (Atomic Energy), and Mr Hans Koch of the Danish Atomic Energy Commission. At Thule, there were many



Barrels filled with aircraft debris, stored outside the zero line and awaiting movement to the base.



Road grader and men windrowing the contaminated snow and ice

ipated in the press conference with representatives of the Danish and U.S. press. The Danish team was given headquarters adjacent to command headquarters. Colonel Fitzpatrick, Dr Langham, and Dr Bruner were designated as the technical contacts for this group.

These scientific advisory groups were particularly useful in determining the radiation levels which ultimately resulted in systematic profiles of the entire area. In addition to surface radiological surveys and snow samples, it was apparent very early that many ice cores would have to be taken. This laborious task was begun on the 5th of February.

ularly interested in the long-term ecological effects which might be involved. In addition to routine radiation monitoring of the crash site, they were interested in obtaining samples of the sea bottom, the sea water, the snow, and the surrounding area. They were also concerned with the long-term effects on the flora, fauna, and human inhabitants in the area. Their ecological interests were influenced by the habits of the local and nomadic Greenlanders, with particular respect to food sources. They were interested in evaluation of wildlife, both surface and underwater. Although a firm decision had not

informal meetings between the Danish and American scientists during the first few days on site. Two formal meetings were held on the 4th and 6th of February to consider problems of mutual interest. These concerned radiation monitoring, sample development of ecological studies, and discussions of the decisions which had to be made regarding the disposition of the wreckage and radioactive material. Another meeting was held in Washington on the 5th of February involving U.S. scientists and still another joint meeting in Copenhagen with Danish and American scientists and authorities on 15 and 16 February. It was

mutually agreed that the radiation hazard was minimal and that if all of the radioactive material in all of the weapons was allowed to sink into the bay, the plutonium oxide would be diffused in the sea water and produce such diluted concentrations that no hazard would exist. It had originally been estimated that 1 cubic kilometer of water would be more than sufficient to dilute all of the plutonium oxide from all of the weapons to drinking water standards. Later calculations showed that only 1/500 of a cubic kilometer would have been required. In fact, North Star Bay contains approximately 50 cubic kilometers of water.

It was agreed that, while no

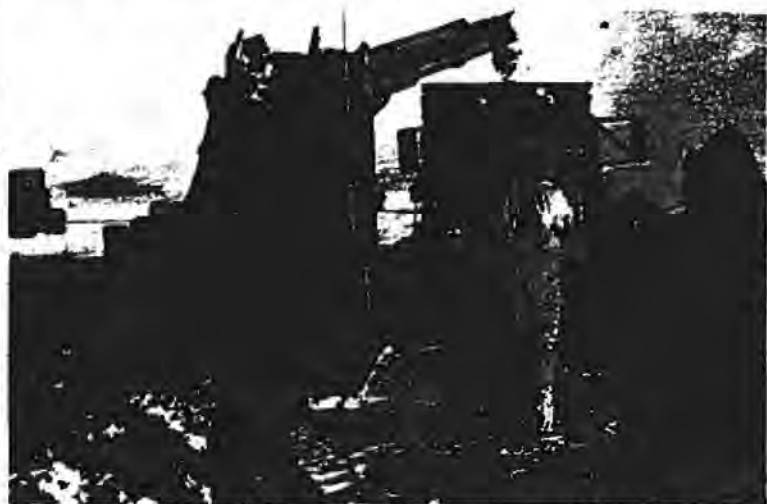
aspects of moving masses of material, were requested.

A number of proposals had been advanced as to how the contaminated snow and ice were to be collected. This was solved by scraping the ice surface and piling the material into windrows. "Hot" spots not scraped were monitored and removed by shoveling. The next major decision was how to store or dispose of the material. Suggestions for storage included the use of two-million-plus-gallon, above-ground storage tanks, the use of permanent underground storage tanks, the setting up of an on-site filtration plant, and, last, the use of a number of 25,000-gallon tanks that were at Thule Air Base.

in the tops of the tanks, through which the contaminated snow and ice could be dumped. The next problem involved removing the contaminated ice and snow from the crash site to the storage area. Plywood boxes 10-feet long were especially constructed for this purpose. The boxes were filled by continuous belt loaders and front-end loaders, and were transported to the base on flatbed trailers. On-base cranes lifted and dumped the contents of the boxes into the 25,000-gallon tanks. As the tanks were filled, the covers were welded back in place. In all, 67 tanks were filled with contaminated snow and aircraft debris, and an additional four tanks with general contami-



Men and machinery working on the sea ice.



Continuous belt loader filling boxes with contaminated snow and ice.

serious radiation hazard existed, good housekeeping demanded that the area be cleaned up and the radioactive waste as well as metal debris be disposed of properly. This presented me with the second major series of problems to be faced in this operation.

It was first necessary to review manpower requirements and skills involved. It was readily apparent that the shift in emphasis required a shift in manpower and operations techniques. As this first phase was closed, large numbers of personnel were returned to the United States, and others, primarily those concerned with the civil engineering

The last alternative was the one that was eventually selected. It was decided that the contaminated snow and ice would be placed in steel containers for storage pending final disposition.

The Danish Construction Company was engaged to assist in the preparation of the tanks. This was an excellent choice. The cheerful patience of this group of dedicated workmen, their hours of productive effort, and their willingness to serve, were major factors in solving the many problems yet to be faced. The tanks had to be removed from their installation, cleaned, and all openings welded shut. Holes were then cut

nated debris such as tires and lumber. Over 237,000 cubic feet of material were involved. Venting systems were installed to relieve any internal gas pressure which might develop when the snow and ice melted. Evaluations indicated that no problem of critical masses that could lead to a nuclear reaction was involved, so provision did not have to be made for this.

By the 15th of March the total area had been cleared. A radiation survey completed on that date and compared to one on the 27th of February indicated that the radiation hazard had been reduced to negligible proportions.

On the 18th and 19th of March, a U.S./Danish meeting was held in Washington to examine progress on the project. On the basis of the material presented, it was decided that the removal measures to date had adequately fulfilled expectations. At this meeting it was decided that the sun would be exploited to the maximum. To precipitate melting in the impact area, it was agreed that 25,000 square meters would be treated with black carbon sand. During the cleanup operations, it had been necessary to preserve good housekeeping habits since items thrown onto the snow produced faster melting, which in turn developed holes into which

the decontamination of roads, vehicles, and loading areas. The Danish Atomic Energy Commission personnel also indicated that they would continue with their ecological studies.

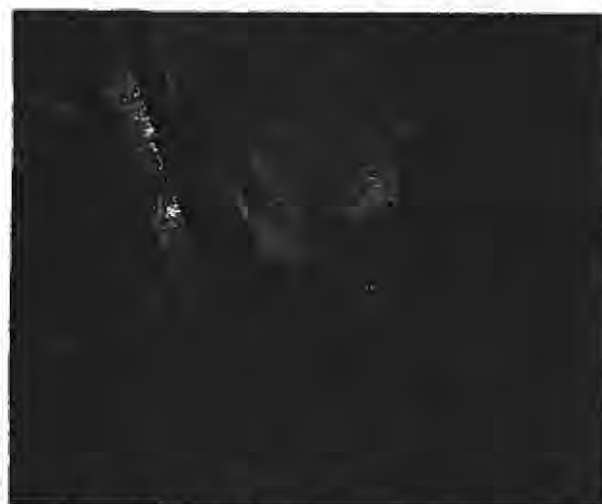
In the final effort to assure that all aircraft and weapons had been collected, the area in and around the crash site was systematically ploughed and again inspected by long lines of airmen. Areas which were unsafe for such procedure were surveyed by use of helicopter, using radiation detection equipment suspended from a cable. In all, approximately 30 square miles were subjected to these treatments.

This work was completed at 6:00

Project when the American Ambassador to Denmark, Mrs Katharine E. White, visited Thule on the 24th and 25th of February. With her was the Honorable Erik Hesselbjerg, Permanent Undersecretary for the Danish Ministry for Greenland, and the Honorable Mr Hans Koch of the Danish Atomic Energy Commission, as well as other distinguished dignitaries. It was my pleasure to brief them and members of their entourage on the progress of the project to that time. It was also my pleasure to see Ambassador White present to Mr Zinglensen, the well-deserved USAF Exceptional Service Award for his outstanding contributions to the Crested Ice effort. This effort was a



Flatbed trailer loaded with boxes filled with contaminated ice and snow.



Crane at work on the sea ice.

items as large as a trailer could be lost. It was anticipated that the heat absorbed by the black sand would act in the same way to accelerate melting. This would then accelerate the dilution of the residual radioactive material by permitting it to mix with the water in North Star Bay. Its initial use over a test area proved disappointing; however, with the longer summer days, melting was increased so the project was not pursued. It was also agreed at the meeting that the crash site would be fenced and posted. This project was completed on the 20th of March. By mutual concurrence, normal good health practices were to be followed in

p.m. on the 30th of March, at which time the evaluation and recovery portion of Crested Ice was officially terminated. Final storage, sealing and decontamination procedures continued until 10 April, when the last member of the Disaster Control Team departed Greenland. This was none too soon, for estimates had been given which indicated that approximately 1 May would be the last time that ice operations could have been continued safely.

Every experience, in retrospect, has highlights which make it memorable. No matter how grim, there are always pleasant interludes. One of these occurred in the Crested Ice

reflection of the full cooperation and tireless effort of all of the Danish and Greenlanders who became involved in the project.

Every project also has its amusing side. Because the Greenlanders were unable to hunt food for their dogs during the time that they were so ably assisting the early efforts of the Disaster Control Team, each dog had to be supplied 3.9 pounds of veal or horsemeat for each day it was worked. The Thule Commissary probably became the veal center of the Air Force and certainly the only one that stocked fresh horsemeat.

On the serious side, there were lessons learned that should improve



Loading aircraft debris into engine containers.



Workers scraping contaminated snow from the sea ice.



Sealing a tank containing aircraft debris.

Air Force reaction to this kind of emergency. These lessons centered around good pre-planning, flexibility, adequate support, and priorities in handling requirements. There is always a conflict of interest between immediate accomplishment and appropriate documentation. The Crested Ice Project reemphasized the value of a carefully prepared program and adequate documentation to indicate progress as well as areas which required reconsideration. In the long run, comprehensive documentation is the keynote to the saving of time and money.



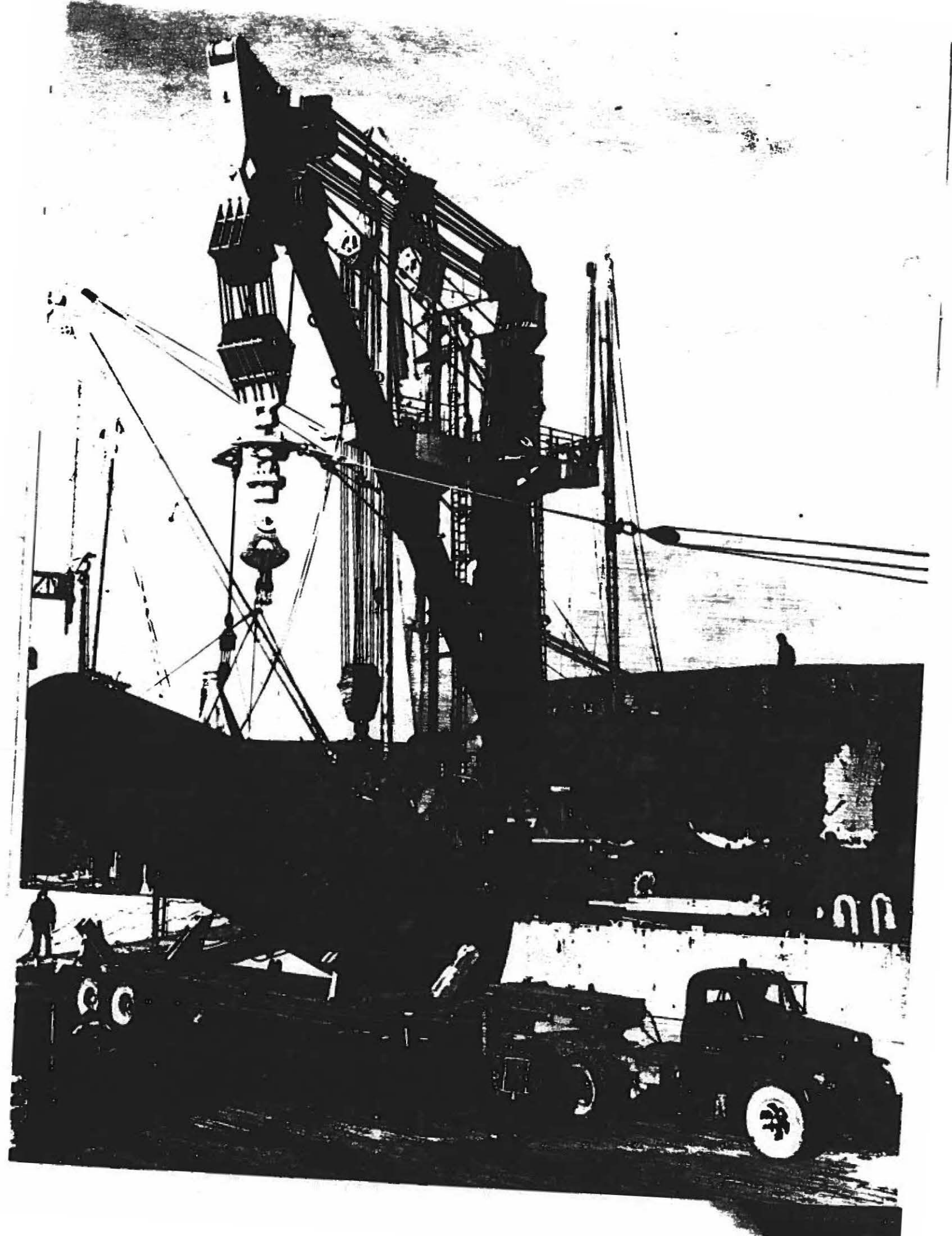
Crane lowering a chute onto 25,000-gallon tank preparatory to loading it with contaminated snow and ice.

Hopefully, there will be no more Crested Ice or comparable problems. If, however, the project demonstrated anything, it was the almost limitless adaptability of well-trained, disciplined and motivated people. Their intelligence, ingenuity, and determination in solving a problem without precedent—in the most inhospitable of environments—was a source of great pride to me. To men like these, nothing is impossible. Their saga will be a continuing inspiration to all of us.

JAN/FEB/MAR 1970



**The crash path
of HOB0 28
prior to impact
on the ice.**



HOST BASE SUPPORT

COL G. S. DRESSER
Commander
Thule AFB, Greenland

TO many people Friday the 13th signifies a day of ill omen. But to U.S. Air Force and Danish officials at Thule Air Base, Greenland, Friday, 13 September 1968 was a day of elation.

The last of 600 containers of low-level radioactive residue from Project Crested Ice were loaded aboard a U.S. Navy cargo ship for transport to the United States.

Air Force and Danish officials watched as a giant 150-ton crane hoisted the last 25,000-gallon container of debris, melted snow, and ice from the pier to the deck of the U.S. Navy Ship **MARINE FIDDLER**. Danish stevedores guided the tank to its resting place on deck and secured it with cables.

For the personnel at Thule this final act completed a difficult, painstaking task which had begun many months earlier when a B-52 bomber caught fire and plummeted to the frozen surface of Wholstenholme Fjord, 8 miles from Thule.

Except for the base air traffic controllers and a limited number of staff members, personnel at Thule were completely unaware of the drama taking place in the pitch-black sky overhead. The impact shattered the arctic stillness of that Sunday afternoon, rocking the base's

concrete weighted buildings perched on pilings above the permafrost. Then someone spotted flames out on the bay ice toward Saunders Island. The Base Command Post flashed a message to Headquarters, United States Air Force, of an accident near the Aerospace Defense Command (ADC) installation at the top of the world. At one of Thule's mammoth black hangars, a stranger walked in and asked to use a telephone; he was Maj Alfred J. DeMario, a member of the bomber's crew. Major DeMario called the Command Post and reported to Col Paul D. Copher, acting base commander, that the bomber was carrying a crew of seven, at least six of them had ejected over the base area and that the huge stratofortress was carrying four unarmed nuclear weapons.

Within 10 minutes of Major DeMario's phone call, Capt John M. Haug, a pilot on the B-52, called in from another hangar. This confirmed Major DeMario's statement that the crew had ejected over the base. The Command Post dispatched an ambulance to pick up both men and take them to the dispensary where they were treated for bruises, abrasions, and chills.

The Command Post had been activated at 4:50 p.m. when it was notified of the plane crash, but until Major DeMario called no one had any idea if the crew had bailed out, where they had bailed out, or if they had gone down with the plane. Now the Command Post staff had a point of reference. All off-duty security police were recalled over the base-wide public address system and also over Radio 1425, Thule's Armed Forces radio and television affiliate station. Twenty-one security policemen split into seven teams and began searching the base and the roads leading to the various military sites in the hills above the main installation. All tenant units at sites in the 20-mile radius of the installation sent out patrols to search for the remaining members of the bomber's crew.

All personnel were instructed to report the sighting of strange lights or signals to the Base Command Post. It was imperative to find any survivor quickly. The temperature was a -23°F, the wind was blowing at 9 knots with a chill factor of 5. Exposed human flesh would freeze in 2 minutes.

Telephones in the Command Post were ringing constantly now. Someone reported sighting lights on South Mountain. More flashing lights were seen on the ice toward the wreck. Ground rescue personnel, driving trackmasters and two HH-43 helicopters assigned to Detachment 18, Eastern Air Rescue and Recovery Center, Military Airlift Command, investigated each report. Snow removal called to report that they had picked up another survivor near the base dump. He was SSgt Calvin Snapp, a gunner aboard the downed aircraft. An hour and 15 minutes had gone by since the plane crashed into the frozen bay.

Colonel Copher, on advice from Aerospace Defense Command Post at Ent Air Force Base, Colorado, dispatched four security policemen to the crash scene with ground rescue personnel. They were instructed

to stay 2,000 feet from the wreck. A helicopter hovered overhead at 1,900 feet and reported the impact had broken the ice. In spite of the heat of the burning wreckage the 3-foot thick ice had refrozen within minutes after the impact. The equivalent temperature was -50°.

Helicopter pilots (in Pedro II) spotted two parachutes and two ejection seats on the ice 3 miles out in the bay and began following the footprints leading away from them. A radiological monitoring team checked the shorelines from the base dump to the foot of Mount Dundas for radiation, but obtained negative readings. A security police team searching the southern slopes of South Mountain, 5 miles west of the base, found two more survivors walking toward the installation. Maj Frank F. Hopkins had a broken arm and Capt Richard E. Marx suffered from cuts and bruises. Pedro II evacuated the two to the dispensary.

By 9:00 p.m., aircraft from numerous Air Force bases in the United States were en route to Thule. A C-97 left Pease Air Force Base, New Hampshire, and a C-130 departed Sondrestrom Air Base, Greenland, with signal flares aboard. A C-130 also from Pease with two investigating teams aboard stopped at Goose Bay, Labrador, to pick up two pilots. An Explosive Ordnance Disposal Team and an information officer, dispatched by the ADC's Command Post at Ent Air Force Base, Colo-

rado, were airborne. A Strategic Air Command Disaster Control Team under the command of Maj Gen R. O. Hunziker, Strategic Air Command Director of Materiel, took off from Offutt Air Force Base, Nebraska. During the next few days more than 700 military personnel, American and Danish scientists, and newsmen representing 72 different news media in North America and Europe would deplane at Thule.

At 1:30 p.m. Monday, 20 hours after the crash, searchers rescued the remaining survivor. Capt Curtis R. Criss was found wrapped in his parachute near South Mountain. Weak and suffering from a dislocated shoulder and severe frostbite. Captain Criss was evacuated by helicopter to the dispensary for treatment.

With the last crew member accounted for, the base's mission shifted to supporting the Strategic Air Command's recovery operation. All base personnel including the Danish Construction Corporation, the base's operations and maintenance contractor, began working 7 days a week along with the Strategic Air Command team to get the control and recovery effort started, and to support it as the tempo increased.

The first order of business was to establish a base camp at the site to provide shelter, equipment support, decontamination control points, and communications. The base shops

built six small 8x16 foot buildings—they marked each piece as to location, then disassembled the buildings and packed the pieces for movement.

Within three days, the Prime Beef (Base Engineers Engineering Forces) Team, working in almost total darkness and bitter cold, had built a heliport and six prefabricated buildings; installed generators for electricity, telephone leadlines and radio communications, and completed the first of three ice roads to the accident work area. Radiological monitoring teams had completely staked out the entire zero line with hundreds of reflectorized steel stakes made by the base shops. Floodlights were mounted on steel poles placed in weighted 55-gallon barrels to illuminate the area. Work crews now had an operating base for the recovery of aircraft debris.

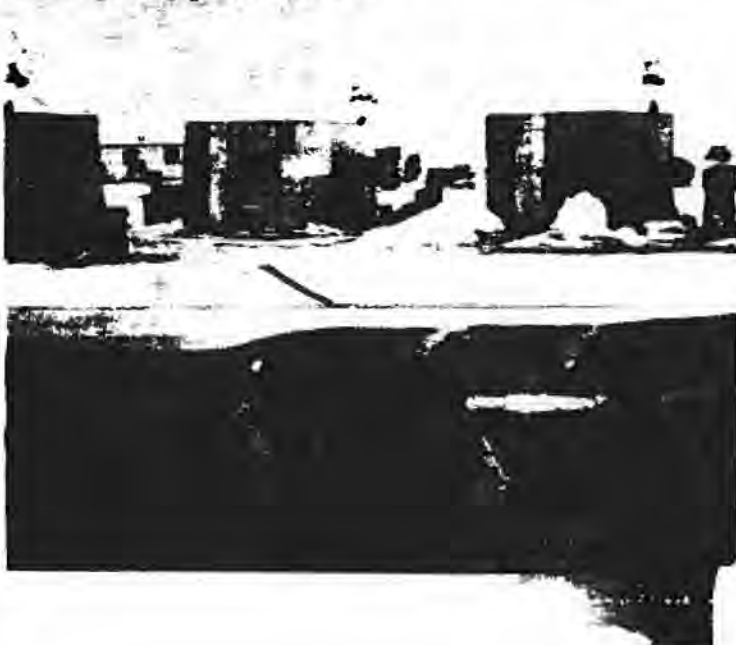
Greenlanders built survival igloos as backup shelters in case a severe arctic storm should blow away the prefabricated buildings. Jens Zinglensen acted as guide, interpreter, and consultant to General Hunziker, the On-Scene Commander, and to Col C. S. Dresser, Base Commander.

Danes in the Packaging and Crating Branch of the Transportation Section constructed 14 sleds for use on the ice by the recovery teams. With sleds and tractors, the recovery teams began collecting wreckage. Using hand tools, sacks, marker poles and steel barrels, the men

Placing a reflector on the ice.

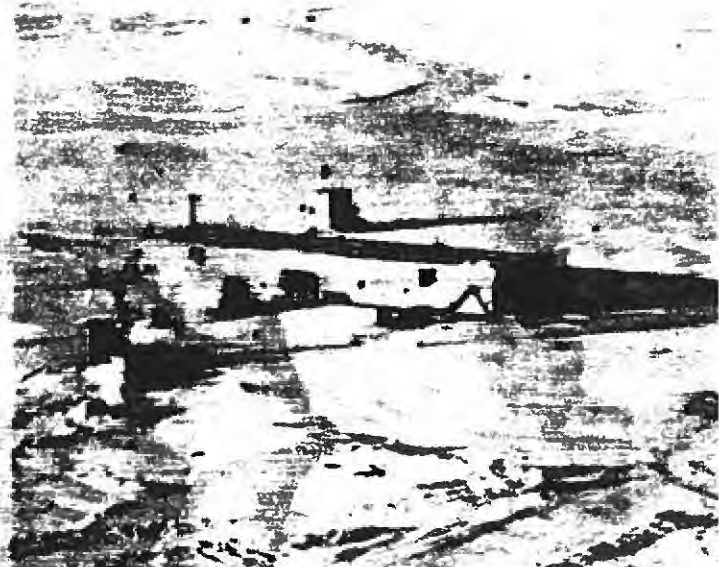


Prefabricated buildings and igloos—the beginnings of an operating base for the recovery of aircraft debris.





Recovery teams collecting wreckage—note the reflectors in the back ground.



Arctic building, 92- x 18-feet, on the sea ice.

walked shoulder-to-shoulder gathering bits and pieces of the aircraft ranging in size from a dime to a package of cigarettes. They piled the debris and secured it with wire net against the wind.

Road graders windrowed the snow in the area and personnel sprayed the windrows with foam to freeze them so that the winds would not spread the debris and contamination.

With the activities of the recovery operation increasing, there was a constant demand for more space at Camp Hunziker. A 92x18 foot arctic building was flown in and transported to the site in sections where civil engineers put it together. Civil engineers discovered three wannigans (portable buildings on skis) at Camp Tuto, an Army installation near Thule, and hauled

them to the site. One was placed outside the zero line for decontamination control of personnel leaving the crash site; one was moved with the work crews to serve as a coffee break facility; and the other was placed midway between the shore and the site to be used as an emergency shelter. The men also erected a Jamesway building to serve as a supply point and built a second heliport.

Fourteen large R-4360 engine containers were flown in to be used to hold aircraft debris. Civil engineers found 11 large tanks in the base salvage yard and these too were used to contain wreckage. Danish construction workers prepared the tanks for use by sealing existing holes and cutting access openings. The tanks were then hauled to the site on large flatbed trailers, filled, returned, and

welded shut. They were stored in the old Strategic Air Command munitions storage area. The cleanup of the aircraft debris was completed on 20 February.

During this period the various supporting base activities at Thule had performed their special functions. Security police controlled entry, exit, and traffic to the site; accounted for the numerous personnel on the ice and controlled the entry for the Disaster Response Force Command Post, and a holding area for classified material recovered at the crash site.

By 29 January, 65 security police from First Air Force had arrived fully equipped with arctic gear. After a 2-day familiarization briefing with local security police, the personnel manned the special posts

Road grader windrowing the snow in the crash area.

Danish construction worker cuts a filler pipe hole in the top of an R-4360 engine container.





Crane hoisting engine into container.

set up for the recovery operation.

One unique factor was that the supervision of security police forces was split. Base Central Security Control supervised security posts on base and in the debris storage area, while the On-Scene Commander directed security police activity at the crash scene. Both radio and longline communications were used to coordinate the activities of the two security forces.

Air Transportation Service coordinated, scheduled, and monitored all air traffic associated with Crested Ice. Due to Thule's isolated location and winter conditions, the only means of transportation was by airlift. Military Airlift Command and Strategic Air Command aircraft were used. Seventy-eight sorties were flown carrying 749 personnel and 1,770,499 pounds of cargo.

Air transportation was also the

primary means of moving personnel and cargo from Thule to the crash scene during the first few days of the recovery operation. A task force of three HH-43s of Detachment 18, Eastern Air Rescue and Recovery Center stationed at Thule and three UH-1Fs of the 341st Strategic Missile Wing flown in on a C-133 from Malmstrom Air Force Base, Montana, were used. The choppers flew 1,583 sorties, transporting 4,524 personnel and 185,128 pounds of cargo.

The Base Transportation Branch manifested all personnel and equipment going to the site at Hangar 6. Vehicle drivers presented a copy of the manifest, a modified entry and exit roster, to the guard at the entry control point at DeLong Pier. A person's name on the manifest was his authorization to proceed to the accident area. Transportation personnel forwarded copies of all manifests to the decontamination station in Building 773. As personnel returned from the site and were processed through decontamination, their names were crossed off the list. Personnel traveling to the site by helicopter were authorized to proceed to the site directly from Hangar 6. Upon their return, they were sent by bus to the decontamination center where their return was recorded.

Danish civilians employed by the Danish Construction Company controlled, dispatched, and maintained most of the surface vehicles. Three general purpose vehicles were made

available to the team on a 24-hour basis for the On-Scene Commander, the ice survey team, and the supply services section. Other transportation requirements were superimposed on the normal base needs. Taxi runs increased from thirty thousand to seventy thousand a month. Vehicles were often used for tasks which they were not designed, and it was frequently necessary to attempt to match cargo loads to the vehicles available. When buses and other vehicles arrived from the United States, Transportation scheduled regular passenger and resupply runs to the site.

Base Supply coordinated requirements of the Weapon Recovery Division, Communications Division, Radiological Health and Contamination Control Division, and the Base Support Division for Project Crested Ice.

Three supply locations were manned 24 hours, 7 days a week, to respond immediately to all supply requirements. Daily, supply personnel monitored all outstanding due-ins and receipts to insure that received property was made immediately available to the requester.

According to a Strategic Air Command-Aerospace Defense Command agreement, Thule went directly to depots for stock numbered items using their transceiver or telephone. For local purchase items, base supply called the requirements to the Strategic Air Command where they were passed to the procurement office at Westover Air Force Base, Massachusetts. Aerospace Defense Command furnished the necessary funds to Westover for the procurement. Requirements for support of Strategic Air Command assigned aircraft passed directly from Thule to 8th Air Force Not Operationally Ready Supply Control at Westover for lateral support and completed supply action.

Supply personnel processed more than thousands of line items ranging from long underwear to wheel tractors. They maintained a complete status of equipment and

Helicopter used in ferrying personnel to and from the camp site and Thule AB.



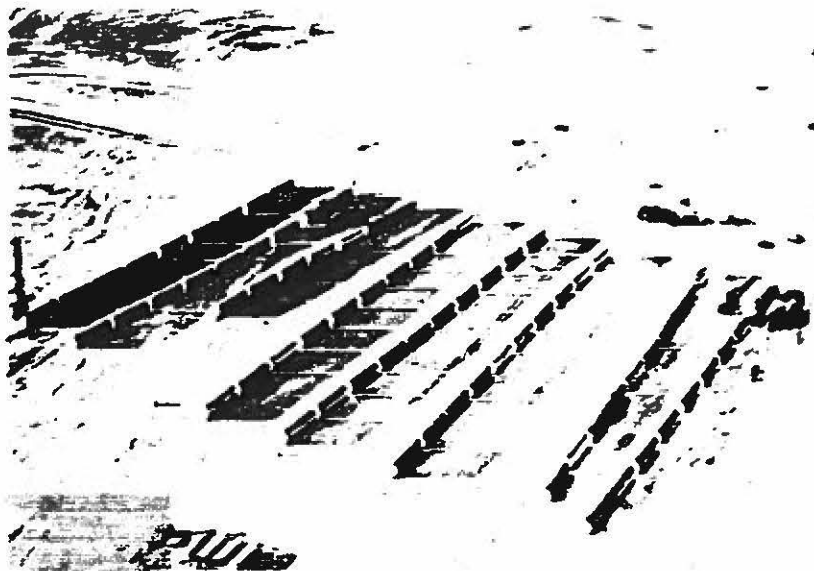
shipped including stock number, quantity, description, source and document number. All items were issued to the Strategic Air Command on custody receipt.

With the removal of the aircraft debris from the area completed, the Strategic Air Command Disaster Response Force departed and a new phase of operation began. The Danish-American meeting held in Copenhagen on 15 and 16 February had established the general conditions for the decontamination of the accident area. Tons of snow and ice contaminated at low-level would have to be removed. An expanded civil engineering division was established 1 March with full responsibility for directing the snow removal operation.

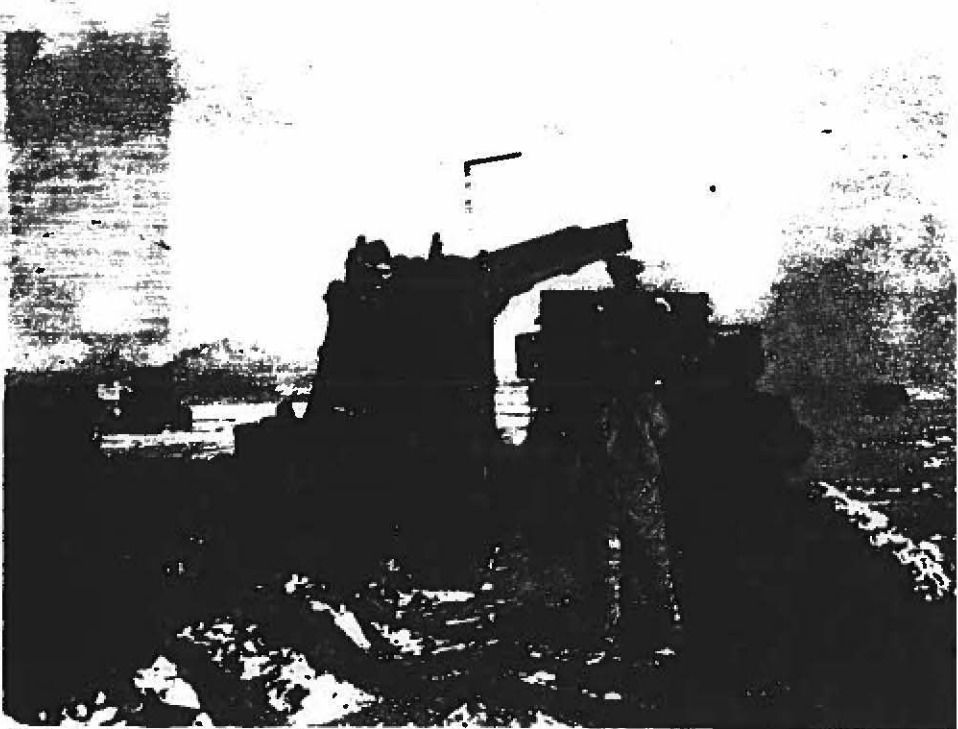
Under the direction of Lt-Col Thomas W. Evans, Base Civil Engineer, and the San Antonio Air Materiel Area team chief, Danish construction workers disconnected abandoned 25,000-gallon POL tanks and transported them on flatbed trailers to Hangar 2 where workers steamed the tanks clean of petroleum and other possible explosive material. They welded all unwanted openings and cut three 5x8 foot openings for snow-loading in each tank. Workers moved the adapted tanks to a storage area near the shore for filling.

At the site, Air Force personnel, driving road graders, windrowed the black crusted snow, and mechanized loaders poured it into 10-foot long, 7-foot wide, 4-foot deep wooden boxes placed on 30-foot flatbed trailers. When the boxes were full, military personnel at the site placed tarpaulins over the tops to keep the snow from blowing. The flatbed, covered with a double layer of plywood to facilitate decontamination, was swept clean inside the zero line and hauled to the site control point where another tractor pulled it to the tank storage area.

At the storage area, Danish crane operators lifted the boxes in slings and tripped the hinge on the end of



Aerial view of tank farm showing converted fuel tanks being loaded with ice.



Mechanized loaders filling wooden boxes with black crusted snow.

Tarpaulins being placed over the tops of boxes to keep the snow from blowing.



the box to let the snow tumble through a specially constructed metal chute into the tank. When the tanks were full they were sealed and fitted with a pressure vent. A total of sixty-seven 25,000 gallon tanks were filled with low-level radioactive residue. An additional four tanks were filled with contaminated equipment such as brooms, tires, and handtools.

After the area was clean of contaminated snow, civil engineers spread the cracked ice section (impact point) with black carbonized sand to absorb the sunlight and melt at a faster rate than the ice around it.

Workers painted the tanks black to absorb the sun's energy in order to melt the snow and ice inside. The

San Antonio Air Materiel Area shipped specially constructed plastic greenhouses to Thule to speed the process. These proved effective until the first arctic storm blew them out to sea. As it turned out, the black paint did the trick. The resulting water was pumped into smaller containers to facilitate shipping the residue and the lightened 25,000-gallon tanks to the United States for disposal.

During August, Danish and American scientists, using a 54-foot Danish motor launch, MS AGLANTHA, and a 24-foot minisubmarine, STARR III, conducted repeated radiological surveys and ecological studies along the shores of Wolstenholme Fjord to insure that no

contamination remained in the area.

The U.S. Navy Ship MARINE FIDDLER sailed with the last container of contaminated residue Tuesday, 17 September 1968, on an 11-day voyage to Charleston, South Carolina, where the containers and their contents were moved by rail to the Atomic Energy Commission's Savannah River Plant near Aiken, South Carolina.

As the huge cargo ship picked its way through the icebergs in North Star Bay and began slipping into fog-shrouded Wolstenholme Fjord, bystanders on the pier smiled as they read an inscription someone had painted on the end of the last barrel: "That's All Folks!"



Snow being poured through a specially constructed metal chute into 25,000-gallon tank.

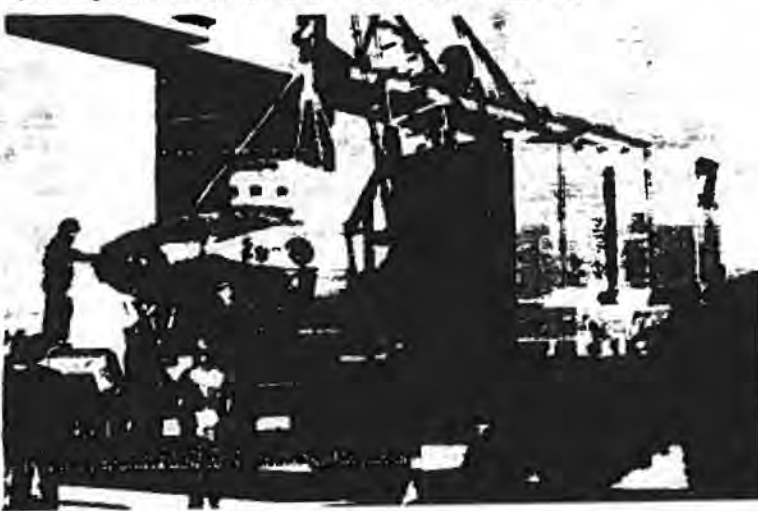


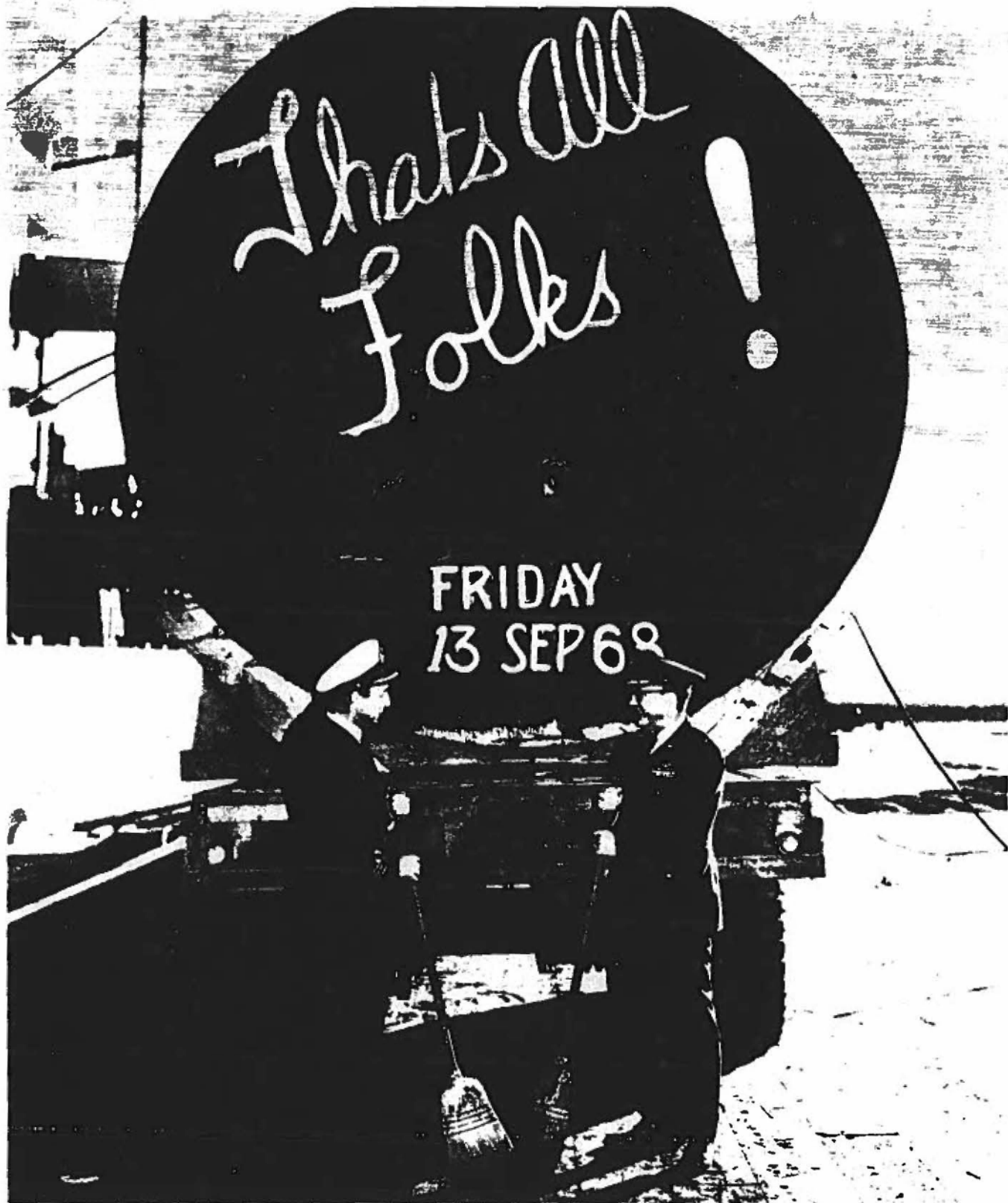
Landing gear being prepared for removal from the sea ice.

The Air Force tugboat at Thule AB eases the U. S. Navy Ship MARINE FIDDLER out into foggy North Star Bay.



Unloading mini-submarine, STAR III, onto flatbed at Thule AB.





Col C. S. Dresser, (right), base commander at Thule AB, and Commander Jorgen Molgard, Danish Liaison Officer, make a clean sweep of Project Crested Ice.

CRESTED ICE PUBLIC AFFAIRS PROGRAM



DIRECTORATE OF INFORMATION HQ, Strategic Air Command

MEMBERS of the Strategic Air Command Directorate of Information (DXI) are well aware that each aircraft accident is different. Each involves variable circumstances which often present unique problems in making complete and factual information available to news media as rapidly as possible.

Thus, when SAC DXI was alerted by the command post shortly before 3 p.m. (CST) Sunday, 21 January 1968, that a SAC B-52 Stratofortress was down near Thule Air Base, Greenland, reactions were prompt and based on well-established procedures.

THE ALERT

The first call was to the Public Information Division's Disaster Control Team (DCT) alert officer. He is always on telephone alert and is prepared to deploy immediately with the SAC DCT to the scene of any SAC accident having a major effect on a civilian community.

Within minutes the DXI office was staffed by the Director of Information, Col Mason A. Dula, his deputy, Col Alfred J. Lynn, and representatives from the Public Information Division. In addition to the sketchy initial notification of the accident, it was learned that the B-52, with nuclear weapons aboard, was from the 380th Strategic Aerospace Wing, Plattsburgh Air Force Base, New York.

While the DCT staff was forming, the Secretary of the Air Force Office of Information (SAFOI) alert officer was notified. The Director of Information also con-

tacted Phil Goulding, Assistant Secretary of Defense for Public Affairs (ASDPA), and Maj Gen William C. Garland of SAFOI. It was then agreed that SAC DXI would draft the initial news release and coordinate it with Mr Goulding's office for release. (As the only specified command in the Department of Defense, SAC works directly with the Office of the Secretary of Defense on many matters, particularly those involving public affairs.)

As a member of the DCT, Robert J. Boyd, a civilian historian, arrived at Thule on one of the early deployments. He was able to gather material and begin the documentation of events—as they occurred—rather than retracing past events.

By being on the scene during the critical first two weeks, the historian established his requirements for the staff, and built a foundation for his final report. As the search and recovery operation continued, the DXI staff was able to gather source documents and compile reports necessary for an accurate story.

It should be noted that the final report of the Palomares accident was on file with the Historical Division. It was taken to Thule and used as an organization guide.

THULE

The first news release concerning the accident was drafted by SAC and coordinated through the Defense and State Departments and also with the Government of Denmark. It was released by ASDPA at 9:45 a.m. (EST) 22 January.

The first announcement acknowledged that the crash had taken place, identified the aircraft's home station and unit, and stated the aircraft was carrying nuclear weapons which were unarmed so that there was no danger of a nuclear explosion at the crash site.

The announcement confirmed some of the rumors which had been circulating among a few news medium representatives in the Plattsburgh Air Force Base vicinity. The release naturally provoked a deluge of inquiries directed toward ASDPA, SAC, Thule Air Base, and Plattsburgh Air Force Base.

Weather and travel conditions from Thule to the accident scene, approximately 8 miles out on North Star Bay, prevented immediate response to most questions.

RELEASE RESPONSIBILITY

The responsibility for release of information for the United States rested with ASDPA, represented by Col Willis L. Helmantoler who arrived at Thule in a matter of hours after the SAC DCT. He remained for the next 7 days. Colonel Helmantoler and the SAC officers worked jointly on the early release of information on the Thule accident to the news media. After Colonel Helmantoler's departure, however, United States release responsibility rested with the SAC Information Officers on the scene who acted on behalf of ASDPA, USAF, and SAC.

On 1 February, ASDPA delegated the authority to the SAC Directorate of Information to release daily public affairs summaries, and later added the authority to periodically release photographs. Forty-one consecutive daily summaries were provided 14 addressees for reply to news queries. Once Project Crested Ice operations settled into a routine, the daily summaries were discontinued. Periodic reports were provided whenever new information warranted them.

There were three U.S. points of information release: ASDPA in Washington, SAC DXI at Thule, and the American Embassy in Copenhagen. The latter, however, generally deferred to the other two agencies in matters of technical expert opinion and facts. Particular care was taken to keep the Danish Government informed on all announcements. All other policies followed were general public information policies spelled out in Air Force Regulations 190-10, "Release of Information on Accidents," and 190-12, "Release of Information to the Public."

A second news release was made by ASDPA approximately 7 hours after the first. It described the aircraft's approach for an emergency landing after declaring an emergency because of fire in the navigator's compartment and intense smoke in the cockpit. It concluded by describing the locale and the extremely difficult environmental conditions under which searchers were operating. Because of these difficult search conditions the acquisition of new information was very slow. Thule

temperatures were below -25 F. The area was in polar darkness except for a 2-hour twilight period each day, thereby requiring flares to assist searchers in helicopters and dogsleds. This second news release noted that more details would be available as additional dogsled teams returned.

The third news release was made at 2 a.m. (EST), 23 January. It summarized a 2-hour visit made by a ground survey team by dogsled to the scene. This release described the fuel-burn pattern on the ice and the small fragments in and around the burn area. More important, the announcement stated that none of the parts located were identified as nuclear weapons or parts of them. Also, a nonhazardous amount of "light-fixed and closely confined" radioactivity was found in the survey area. In an effort to report all available information, this third release went on to point out that personnel on the scene had picked up limited amounts of low-level radioactivity on their footgear. All were reported to have undergone normal decontamination procedures with no resulting problems.

FIRST DAYS

During the first 3 days when these news releases were made, news media interest in the crash was intense in the United States and Europe—particularly Denmark. The initial public announcements generated a variety of questions. Some could be answered readily; most required research or coordination with Thule DXI who worked out replies with Danish, Greenland, and American scientists at the scene. Other questions touched on classified information and simply could not be answered.

Despite the fact Thule was geographically difficult to visit, newsmen indicated considerable interest in traveling to the accident scene. The difficulties in getting there, however, did discourage a number of them.

Two press visits materialized early. Members of the press arrived at Thule within an hour of each other, about noon on 25 January. The first group included 25 American newsmen flown in by ASDPA. The second group of 26 newsmen included Danish, French, West German, and British reporters who arrived on a Scandinavian Airlines System flight after coordinating the visit with Danish officials and the American Embassy in Copenhagen.

PRESS PROBLEMS

The arctic darkness and severe weather caused some problems in accommodating the 51 newsmen. Transportation of the newsmen to the accident scene was difficult and time-consuming. Two flights were made over the crash area in an Air Force C-121. Photographers and newsmen were airlifted to the scene by helicopter.

Darkness, extreme cold, and bulky arctic clothing made identification of newsmen at the crash scene and

the base a problem. Small DOD press badges were not adequate; therefore, armbands labeled "Press" were locally produced, easing the problem.

Photographs taken during the first few weeks following the accident were poor. The polar darkness and cold provided serious problems. Shutters became inoperative and batteries failed after only a few minutes exposure to the numbing cold. It was cumbersome to use many cameras due to bulky clothing. Rubber flash attachment extension cords became so brittle they disintegrated in the cold.



Maj Gen Richard O. Hunziker (2nd from left), SAC On-Scene Commander, and Dr Wright Langham (left) of the University of California's Los Alamos Scientific Laboratory, briefing Greenland officials shortly after their arrival at Thule AB.

PRESS CONFERENCES

Four press conferences were held during the early days when the first large group of newsmen were at Thule. Maj Gen Richard O. Hunziker, DCT commander, hosted four conferences which included participation by members of Danish and American scientific groups at Thule. The third conference in the series consisted of a short interview with the B-52's aircraft commander, one of the survivors still at Thule.

General Hunziker informed the press that there had been an explosion of the conventional materials in at least some of the nuclear weapons, that some radiation was present, and that there had been no nuclear yield. Credibility in the conferences was strengthened by the openness with which everyone answered questions and the maximum Danish and American scientific participation.

Because of the extreme sensitivity of all public affairs actions concerning the crash and recovery proceedings, the release of all information was triple-checked to make certain it did not mislead or distort, and that it was in the best interest of the nations concerned. Such a challenge was never-ending, for it required utmost integrity

and perception to distill the often technical, often classified facts into a releasable piece of information comprehensible to the general public. The fact that information of this nature could be exchanged during detailed press conferences attests to the briefers' overall knowledge of the situation. They received full support from the DCT staff and scientific groups in preparing for the conferences.

COMMUNICATIONS

Virtually nonexistent commercial telephone and wire service to outside points caused some communication problems for newsmen. Arrangements had been made for copy to be filed through Dundas Radio, a Greenland village station about 8 miles from Thule. Although a system had been established for hourly delivery of news copy, this proved untimely and awkward for the newsmen who wanted to file each story immediately as material became available.

One military telephone line to Cornerbrook, Canada, was made available. Calls out of Cornerbrook were placed collect to the United States or Europe. Those to Europe experienced some difficulty getting through since overseas calls had to be billed to a U.S. address, but generally the system worked well. Calls were normally limited to 5 minutes and priorities were established by newsmen drawing numbers from a hat. Photographs were sent at the conclusion of each daily session.

All of the American newsmen, except four, returned to the United States with their ASDPA escorts on January 27th. Thereafter, formal news releases were made almost daily. Many replies to queries were researched and answers provided. The newsmen remaining at Thule were handed a short statement on January the 29th which announced that parts of all four nuclear weapons had been found. The release stated that serial numbers on fragments found on the ice at the crash site corresponded with SAC records of numbers on various components of the four weapons. The three-sentence announcement concluded by saying that the search was continuing for the remaining weapons fragments. The last of the 51 newsmen left Thule on 31 January.

During the next 2 months only three more news media visits were made to Thule.

PROTOCOL

Although considerable time was required to escort the visiting newsmen, the DCT information representatives were also involved in protocol matters and liaison with scientific teams. Normally information personnel prefer to point out that events involving protocol also invariably have news media interest, and that the information man best be left to meet the needs of the press. However, events at Thule demanded the attention of a senior officer knowledgeable in all facets and ramifications of the operation, one capable of acting as an

intermediary between the military, scientific, and governmental agencies of the countries involved. Colonel Lynn, by virtue of his years of information experience and his close working relationship with General Hunziker, was ideally suited for this responsibility.

Since the Government of Denmark obviously had an inherent interest in all Project Crested Ice actions, Danish and Greenland officials and scientists had to be kept fully apprised of all actions taken with respect to the search, debris recovery, decontamination, and long-range clean-up planning. Similarly, American scientists and State Department officials had an equal requirement and interest. News releases and answers to media questions had to be discussed and coordinated with these individuals. The rapport established with these individuals and groups during the crucial early stages of operations extended to liaison on matters in many other areas and proved beneficial to the overall success of the public affairs program.

THE DXI TEAM

Unlike other Disaster Control Team members who remained at Thule throughout Project Crested Ice, the two SAC Directorate of Information representatives and Combat Documentation Team members were rotated every several weeks. While Colonel Lynn primarily directed public affairs throughout the first 5 weeks, other select officers and noncommissioned officers participated without in any way diminishing the daily effectiveness of the information program. The rotation provided a training experience that could never be "simulated." The experience gained by those involved fully justified the rotations.

Mr Jens Zinglersen, a Danish citizen who was the Thule area representative of the Royal Greenland Trade Department, Ministry for Greenland, provided invaluable services throughout the operation. The importance of his technical assistance and untiring efforts at the accident scene during the first days were obvious to all who depended upon him. It was therefore gratifying that the United States Government officially acknowledged Mr Zinglersen's valued contributions by award-

Ambassador White presenting Mr Zinglersen with the U. S. Air Force Exceptional Service Award.



ing him the Air Force Exceptional Service Award. The presentation was made by the U.S. Ambassador to Denmark, The Honorable Katharine E. White, in a specially arranged ceremony on 24 February 1968.

The DCT information personnel were responsible for making arrangements for the visit of Ambassador White and her party, which included distinguished Danish officials and five Danish news media representatives.

After Ambassador White presented the award to Mr Zinglersen the entire visiting party toured the accident scene and held a press conference.

IN RETROSPECT

If one were to attempt to pinpoint a single reason for the success of Project Crested Ice's public affairs program, he would undoubtedly have to hedge a bit and attribute it generally to cooperation. True, full disclosure about the presence of weapons and the search for them was made rapidly, and daily follow-up reports about the status of operations at Thule contributed immeasurably to a lessening of public concern.

None of this information could have been made available as quickly, fully, and as frequently as it was without the unqualified cooperation and coordination of the United States and Danish Government officials, scientific team members, and the many agencies involved with Project Crested Ice.

Such cooperation permitted spokesmen for both countries to discuss the accident and subsequent proceedings candidly and fully with newsmen, thereby discouraging uninformed speculation and any resultant unnecessary fear.

When the last 25,000-gallon tank of melted snow from the accident site was loaded at Thule for shipment to the United States, the most significant thing about the event was that it was Friday, the 13th of September 1968. There was no ceremony, no need to call attention to the climax of a gigantic task, and no requirement to reassure everyone that all was well. This confidence had been established and accepted long before.

Instead of any fanfare, some unknown soul merely annotated the final tank: "That's all folks!"—and it was.

General Hunziker talking with Ambassador White's party on the sea ice.



TECHNICAL AND LABORATORY SUPPORT



A contamination incident such as the one described in other articles in this magazine invariably creates a real or anticipated need for specific technical information not readily available or easily obtained under field conditions. The type of supplemental information required is usually determined by the specific needs of the field commander and various special committees and policy-setting groups as an adjunct to their making decisions as to the extent of contamination, the magnitude and nature of the potential hazards to operational personnel and the inhabitants of the region (whether direct or through ecological modes), and the extent of decontamination that is acceptable and technically feasible.

Within 5 days after the incident an American technical advisory group was assembling at Thule, and discussions were initiated with a similar group of Danish and Greenland scientists. In the next few weeks various agencies (Atomic Energy Commission [AEC], Department of Defense [DOD], etc.) assembled expert committees to advise them. In addition, joint U.S.-Danish policy-setting groups met in Copenhagen and Washington to consider the technical aspects of the incident. The final decisions as to clean-up levels, methods of disposal and many other issues were made by these high-level groups and committees. Since these authoritative committees and groups needed all the information possible within the time frame of the negotiations, the demands placed upon the field operations became one of the field commander's biggest problems. Often these demands could not be met without additional technical and laboratory support beyond that available at the scene. To comply with these demands, data and samples were sent

to the Los Alamos Scientific Laboratory and other laboratories in the U.S. for analysis and interpretation. This article summarizes the early work done at the Los Alamos Scientific Laboratory and elsewhere in an effort to provide some of the information requested.

PARTITIONING OF THE CONTAMINATION

In an incident of this type the most important information to have as soon as possible is the absolute quantities of material partitioned among the various vectors, modes or regions of dispersal, and deposition. At Thule the important considerations in this regard were:

- The amount of contamination carried aloft in the cloud from the detonation of the high-explosive and fire and dispersed over the general area by the prevailing meteorological conditions.
- The amount deposited on the surface locally.
- The amount deposited on aircraft and weapon debris.
- And the amount in and beneath the ice at the impact point.

Contamination associated with debris would be expected to be distributed beneath, in, and on the surface. Absolute determination of the quantities of contamination associated with each of these vectors or modes of dispersal and deposition was essentially impossible. However, from the practical viewpoint, the most important considerations at Thule were the amount, form, and fixation of plutonium and tritium on the surface in the immediate vicinity of the crash site and in the refrozen ice at the impact point where decontamination operations were technically feasible.

The speed of the plane at impact was in excess of

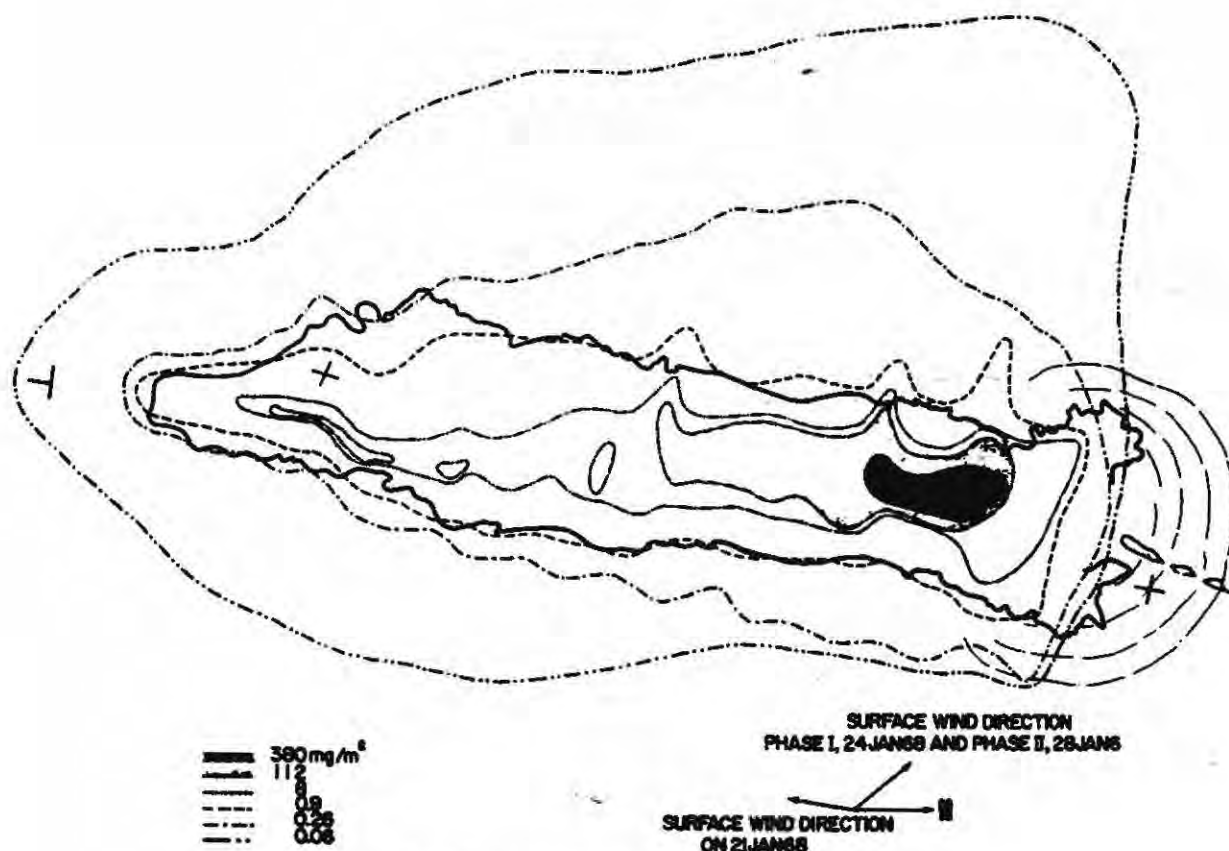


Figure 1 Plutonium contamination levels observed.

500 knots. Its gross weight was about 410,000 pounds—this included about 225,000 pounds of JP-4 fuel. The shallow impact angle and mass and speed of the aircraft resulted in a great forward vector of momentum. When the high-explosive components of all four weapons detonated, the contamination was blown out in all directions and impinged into the materials of the weapons and the aircraft and blown into the splashing, burning fuel. The fuel and much of the debris from the aircraft were catapulted forward on the surface of the ice. When the burning fuel fell back to the surface the fire was soon extinguished, leaving the blackened re-frozen crust on top of the snow pack (Figure 1). The ice was completely shattered and disoriented at the impact point and sustained circular cracking out to a distance of about 100 yards in all directions. The peculiar markings on the ice showed the drag and destruction of the left wing, from this the crash attitude of the plane was deduced. From momentum considerations and the pattern on the snow pack, one would expect to find a large fraction of the surface contamination confined to the blackened crust where it was fixed by refreezing of the melted surface. This was indeed found to be the case.

The remainder of the contamination was dispersed in the smoke plume, impinged on the debris of the bombs and the aircraft, and blown into the ice at the site of impact.

CONTAMINATION OF THE SURFACE

Plutonium Distribution and Amount. Simple autoradiographic studies, as well as instrument measurements, established unequivocally that the depth-distribution of plutonium in the snow pack was strictly a function of the depth of blackening and melting of the surface. Over a large part of the blackened area, this depth was no more than about one-half inch. More plutonium contamination was found and its distribution was to a greater depth in those areas where more fuel collected and burned resulting in more melting of the snow pack. In the most highly contaminated area, the snow pack had melted down to the surface of the ice. Surface distribution of plutonium (other than that adhering to large pieces of aircraft debris which were picked up) is shown in Figure 1. The contours were established by the monitoring teams using the Lawrence Radiation Laboratory Field Instrument for Detection of Low Energy Radiation (LRL FIDLER instrument). Because of the variable thickness of the overburden of ice and snow (complicated further by the two phases of 25 and 28 January), it was necessary to apply different calibration factors to the instrument readings for the areas within each contamination contour. As an example, where the contamination level was highest (380 mg/m²) more fuel had burned and the snow pack had melted down to and even into the ice. Upon refreezing, the

TABLE 1

Distribution of plutonium on the surface in the vicinity of the crash (excluding that picked up on aircraft debris).

Contamination Boundary (mg/m ²)	Enclosed Area (m ²)	Plutonium (g)	Deposition* (%)
380	1.97 x 10 ³	845	27
112	1.10 x 10 ⁴	2816	89
8	2.49 x 10 ⁴	3014	96
2.4	3.90 x 10 ⁴	3079	98
0.9**	5.97 x 10 ⁴	3109	99
0.26	1.10 x 10 ⁵	3135	99+
0.19	1.34 x 10 ⁵	3140	99+
0.06	2.23 x 10 ⁵	3151	100

*Total out to the specified boundary.

**Edge of the blackened area.

absorption characteristics for the soft X rays from plutonium and americium were quite different than where little depth of melting and refreezing had occurred. Absolute contamination levels were obtained by taking representative samples in each contour area subsequent to a careful instrument reading and returning them to Los Alamos for plutonium and americium analysis. Total amounts of plutonium were obtained by integrating the surface concentration as a function of area (Table 1).

The plutonium values are probably good to ± 20 per cent out to the edge of the blackened crust area, which corresponded roughly with the 0.9-mg/m² contamination contour. This information indicated 3150 ± 630 g of plutonium on the surface (excluding that picked up on aircraft debris), of which about 99 per cent was in the blackened pattern and would be removed by removing the snow pack over this area. Assuming removal of the crust and packed snow to an average depth of 4 inches, the volume removed would be 6000 m³ (1.6 x 10⁶ gallons). Assuming further that the volume ratio of packed snow to water is approximately 2.5, this would constitute about 6×10^4 gallons of water, which would contain between 2500 and 37 b of plutonium.

Plutonium-Form, Particle Size and Fixation. It was felt that the ultimate distribution of the plutonium in the event large amounts of the blackened crust were allowed to break up with the ice and go into North Star Bay might be influenced by its form, particle size, and fixation. Detailed nuclear track autoradiographic and microscopic studies of melted crust samples were conducted to obtain pertinent information. These studies showed the plutonium to be in the form of oxide particles with a very wide size distribution. The count median diameter was 2 microns, with a standard deviation of about 1.7. The calculated mass median diameter was about 4 microns. The particles were associated with or adhering to particles and pieces of inert debris of all

kinds (metal, glass and nylon fibers, plastic, rubber, flecks of paint, etc.) of all sizes. The mass median diameter of the inert particles with which the plutonium was frequently associated appeared to be at least 4 to 5 times larger than the plutonium particles themselves. Many of the melted crust samples showed the presence of unburned jet fuel. A very crude estimate suggested that as much as 18 per cent (4 x 10³ pounds) of the fuel may have remained unburned in the blackened crust. Sedimentation studies showed that up to 80 per cent of the plutonium was associated with low specific gravity debris that remained suspended in the jet fuel. The general feeling was that this fact increased the probability of contamination of the shoreline should the blackened crust be allowed to melt and enter the bay.

Tritium-Form, Distribution, and Amount. Laboratory examination of samples of the snow pack from the blackened area showed the presence of tritium oxide confined largely to the depth of the blackened crust. As water, a major fraction of the tritium contamination would have been expected to be carried away and dissipate with the smoke plume. Only that would remain which condensed on surfaces and nuclei that were rapidly cooled to the ambient temperature (-25° to -35°). The tritium fixed in and on surfaces in this manner would be expected to dissipate at rates that would fluctuate with temperature and wind conditions.

It is not possible to establish tritium surface deposition levels with field monitoring instruments because of the extremely low energy (17.9 kev maximum) of the beta radiation it emits. To determine the amount of surface tritium contamination present with any degree of certainty would have required an extensive and intensive sampling program which hardly seemed justified under the circumstances. It was considered adequate, therefore, to determine tritium in a relatively few samples of the blackened crust to confirm its presence and to establish the magnitude of contamination as assurance that no personnel exposure problems would occur during the operations. Analyses of these samples were considered representative of the areas within the plutonium contamination boundaries (Figure

Table 2
Distribution of tritium on the surface in the vicinity of the crash (excluding that picked up on aircraft debris).

Plutonium Contamination Boundary (mg/m ²)	Enclosed Area (m ²)	Tritium (curies)	Deposition* (%)
380	1.97 x 10 ³	365	27.2
112	1.10 x 10 ⁴	657	49.1
8	2.49 x 10 ⁴	986	73.7
2.4	3.90 x 10 ⁴	1337	100

*Total out to the specified boundary.

1) from which they were taken. Integration of the tritium levels within these boundaries gave a very crude estimate of the distribution and total amount of tritium within the blackened pattern. The results are shown in Table 2 and suggest a total of approximately 1350 curies of tritium confined to the area in the form of tritium oxide. The estimates are probably accurate to ± 50 per cent. This amount of tritium would have to be diluted into only 4.5×10^6 l of water to be at the maximum permissible concentration for continuous consumption.

CONTAMINATION IN THE ICE AT IMPACT POINT

The ice at point of impact was approximately 3-feet thick. Impact of the plane and detonation of the high-explosive components of the four weapons on board completely fractured and displaced the ice over an area of about 2100 m² (46 m x 46 m). The ice sustained circular cracking without displacement out to about 100 m from the impact point. Isotropic propagation of the shock wave from the high-explosive detonation accelerated a fraction of the contamination and debris from the disintegrating aircraft in the downward direction, impinging it into the fracture area. When fractured, the pieces of ice were displaced downward into the water, randomly oriented, and returned to the surface where they refroze in position. The attitude of the plane at impact was such that essentially all of the fuel was forward and above the weapons. This would be expected to result in the majority of the fuel and contamination entrained from a large solid angle being accelerated up and forward on the surface of the ice by the dominant forward momentum. The general feeling, however, was

that additional information regarding amount, distribution, form, fixation, etc., of the contamination of the fractured area was desirable before making decisions as to its ultimate disposition.

Plutonium—Distribution and Amount. A closely spaced core sampling grid was laid out over and around the fracture area (Figure 2), and 49 full-thickness core samples were taken and examined. These cores were studied visually and microscopically and were scanned inch by inch with monitoring instruments. Representative cores were transported to Los Alamos for further study and chemical analyses for plutonium as a means of standardizing the scanning measurements made at Thule. Results showed that the plutonium contamination was usually confined to a narrow band which often could be detected visually because of the associated debris from the disintegrated aircraft and bomb casings. The band of debris with the associated contamination was sometimes on the bottom of the core, sometimes on the top, and sometimes displaced from either end. Some cores showed diagonal bands and others no bands at all. These observations reflected the fact that the fractured ice was displaced downward, returned to the surface, and refrozen in a more or less random pattern with respect to the reconstituted surface.

The fact that cores were scanned inch by inch permitted a crude statistical estimate of the depth-distribution of the plutonium in the ice. It appeared that about 13 per cent of the total plutonium in the crushed and refrozen area was in the top 2 inches, 36 per cent was in the top 4 inches, and 45 per cent was in the top 6 inches. About 15 per cent was in the bottom 10 inches. The remaining 40 per cent was distributed between 6

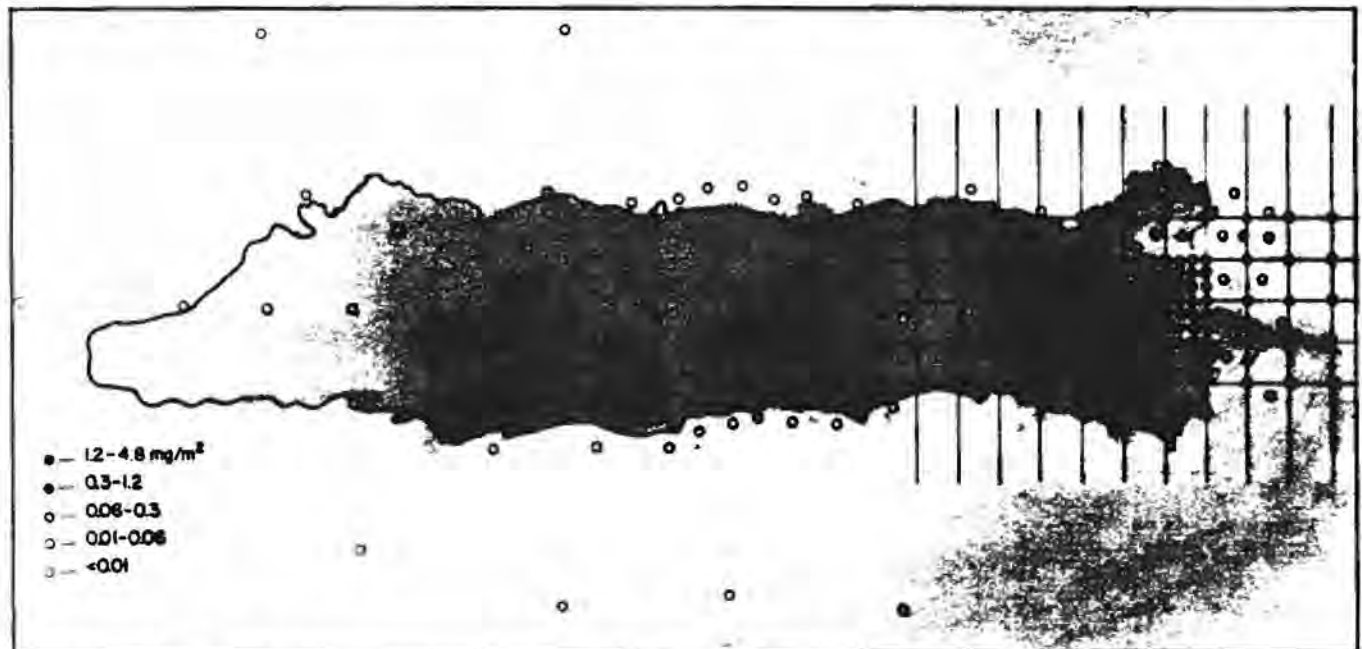


Figure 2 Ice core sample locations.

inches from the top and 10 inches from the bottom.

The plutonium distribution pattern, in terms of contamination per m^2 of surface area, was highly erratic, and it was not possible to represent the results by any simple contour pattern (Figure 2). There was a tendency for the most highly contaminated cores to extend to the back and sides of the center of impact, which might be expected from the relative position of the bombs with respect to the main body of fuel and the crash attitude of the plane. However, cores of comparatively low radioactivity were interspersed among the most radioactive cores, suggesting a highly segregated pattern probably related to reorientation of blocks of ice by the force of the impact and explosion. The random orientation of the rectangular grid with respect to the crushed ice pattern supports the assumption that the cores were statistically representative of the primary impact area in terms of total plutonium and range of local concentrations. Results from the 49 cores showed that 16 per cent contained 65 per cent of the contamination and 52 per cent contained 97 per cent. An estimate of the total amount of plutonium in the fractured ice area ($\sim 2100 m^2$) showed about 350 g. The accuracy of estimate was probably $\sim \pm 25$ per cent. The amount of plutonium in the ice would have to be dispersed in about $5 \times 10^4 m^3$ of water to be at the maximum permissible concentration. This is about 60 times the water volume produced by the melting of the porous ice itself.

Plutonium—Form and Fixation. It was felt generally that information on form and fixation of the plutonium in the fractured area might have bearing on questions regarding its ultimate availability to local ecological chains. Microscopic and autoradiographic observations of the residues filtered from melted ice core samples showed fine particles of plutonium oxide impinged into or adhering to pieces of aircraft and bomb casing debris of all sizes. The blackened bands in the ice cores consisted of small pieces of metal, rubber, fiberglass, paint, plastic, etc., up to 1 mm in size to which the plutonium oxide particles were fixed. Sedimentation studies of melted ice cores showed that 85 to 95 per cent of the debris and associated plutonium oxide sank immediately. No JP-4 fuel floated on the surface; only a thin film of fine carbonized material. The remainder of the plutonium was retained on the surface associated with this carbonized film. Only about 1 per cent was suspended through the water phase as very fine particles. This rapid settling of most of the plutonium greatly decreased the possibility of shoreline contamination from floating debris subsequent to melting of the ice.

Tritium—Form and Amount. Only a very few cores from the crushed ice area at point of impact were examined for tritium contamination. The contamination was in the form of oxide, and the amount appeared to be of the order of 17 mCi/ m^2 assuming the ice averaged 1 m in thickness. This value, multiplied by the area ($2100 m^2$), suggested a total of only about 35 Ci of tritium

activity in the ice at the point of impact.

CONTAMINATION BENEATH THE SURFACE

A very difficult question involved the possibility that contamination might have been dispersed beneath the ice in a form that could reach the shoreline or be concentrated by some biological process in the local food web. Two possible modes of contamination and dispersal beneath the ice were proposed for examination.

One possibility was that a pool, or pools, of highly contaminated jet fuel might have been trapped beneath the surface near the impact point. To examine this possibility the field teams took an additional 133 core samples, 85 on a grid pattern around the fractured area and over the blackened surface pattern and another 48 outside the periphery of the pattern (Figure 2). None of these cores showed any contamination on the bottom end, and no jet fuel or other floating debris was forced up through the core holes by the hydrostatic pressure beneath the ice.

The second possibility considered for plutonium to have gone beneath the ice was in connection with contaminated aircraft debris that might have been blown through the ice and sunk to the bottom. Pieces of the aircraft found on the surface were transported to Los Alamos to observe the amount, form, and fixation of the associated plutonium contamination. No tritium observations were attempted. Debris consisted of pieces of steel, aluminum, and other materials. Some pieces were highly contaminated on both sides, others on only one side, and still others showed hardly any contamination at all. Due to the numerous unknown quantities and inherent inaccuracies, no attempt was made to determine from the contamination observed on the debris the amount of plutonium that might have gone through the ice. However, later underwater observations during the summer season, dealt with in a separate article in this magazine, established that the aircraft debris which penetrated the ice was stabilized on the ocean floor.

Microscopic and autoradiographic observations showed that the contamination on the pieces of debris consisted of particles of plutonium oxide impinged into or adhering to the surface. Lavation tests in sea water were conducted on contaminated pieces of steel and aluminum to determine removal as a function of time. Different rates were observed for different materials, as well as for different pieces of the same material. The observations supported what might be expected, i.e., that removal rate would depend on the nature and hardness of the surface and velocity of the impinging particles, which would be dependent on the distance of the surface from the detonation. In any event, these observations suggest that, if indeed a large amount of plutonium was carried to the bottom associated with aircraft wreckage, it would not all be released rapidly or at the same time. This would make the possibility of high concentrations at any given time very unlikely.

ATMOSPHERIC DISPERSAL AND GENERAL AREA CONTAMINATION

The amount of plutonium and tritium taken up in the cloud from the explosion and fire and its distribution as long-range or general-area contamination were virtually impossible to predict with the available information. All available data, including cloud height, regional meteorological conditions at the time of the crash and for 10 days after, pyrotechnic information, etc., were sent to the Sandia Laboratory for consideration in view of that organization's experience with nonnuclear detonation experiments. These field tests have resulted in the development of detailed data and calculational models for estimating deposition patterns and contamination levels from nonnuclear detonation of plutonium-bearing weapons. The principal parameters needed are source strength, aerosol characteristics, high-explosive yield, and detailed local and long-range meteorology. Unfortunately, conditions at Thule were such that several of these parameters were either obscured, unknown, or unpredictable. Based on the inadequate information and several assumptions, the Sandia Laboratory was able to draw three general conclusions which are summarized as follows:

- Deposition of the aerosol produced initially would have been expected in a west-southwesterly direction on open ice and Wolstenholme Island. No deposition levels could be estimated, since the source term was obscured by the crash conditions and aerosol characteristics were unknown. However, the original long-range deposition pattern would be expected to be changed under the prevailing phase conditions during the first few weeks after the crash.

- Wind-resuspended contamination probably traveled around and possibly over Saunderson Island. However, the condition responsible for the transport made redeposition of much activity on the island unlikely.

- The levels of long-range contamination expected would be radiologically insignificant but, because of the inherent sensitivity of chemical methods, plutonium should be detectable in surface samples taken south and west of the crash site.

Plutonium analyses of surface samples from the principal land masses in the general area are presented and discussed in another article in this magazine.

SUMMARY AND CONCLUSIONS

Immediately following the Thule incident a technical and laboratory support effort was mobilized to comply with requests by the field commander, expert committees, and policy-setting groups for additional technical information and consultation. This effort contributed, in part, to the following factors thought pertinent to the Thule situation:

- Laboratory calibration of field instrument readings

and integration of deposition contours at the crash site suggested that the amount of plutonium on the surface was 3150 ± 630 g, approximately 99 per cent of which was confined to the blackened pattern on the snow pack. The plutonium in the crust was in the form of oxide particles, often associated with larger particles of low density inert material which tended to remain suspended in unburned JP-4 fuel. Tritium contamination in the form of tritium oxide was found on the surface largely confined to the blackened crust. The amount present was estimated at about $1350 \text{ Ci} \pm 50$ per cent. These observations suggested that removal of the blackened crust and its associated plutonium contamination was desirable.

- Laboratory analysis of representative ice cores taken from the fracture pattern at the impact point, which were related to field instrument scans of other cores from the area, gave an estimate of 350 g of plutonium trapped in the ice. Reorientation and refreezing of the broken ice resulted in a segregated contamination pattern both with respect to depth and area. In this area also, the plutonium was in the form of oxide particles associated with inert debris from the bombs and aircraft. There was little or no unburned jet fuel, however, and upon melting of the ice the contamination did not float or remain suspended. This fact was further assured by covering the entire fracture area with black carbonized sand, which in addition to accelerating melting of this area, absorbed and sank any jet fuel film that might have remained afloat to suspend contamination. The estimated amount of tritium (as the oxide) trapped in the ice at the impact point was about 35 Ci. These and other factors, such as distance of the impact point from shore and depth of the bay, suggested that it was unnecessary to remove the approximately 2,000 tons of ice involved.

- Projection of contamination through and beneath the ice at impact point was considered also. Additional core drillings made throughout the general area of the crash failed to reveal any floating pools of jet fuel trapped beneath the surface.

All contaminated large pieces of aircraft wreckage on the surface were picked up and confined. Laboratory studies were carried out to determine the form, fixation, and lavation rates of plutonium from the surfaces of wreckage. These studies suggested that, if indeed large pieces of contaminated wreckage had broken through the ice and sunk to the bottom, there was little likelihood that high concentrations of plutonium could enter some aquatic factor of the local food web.

- Attempts to calculate meteorological transport and deposition of long-range contamination, although quantitatively unsuccessful, did suggest that contamination levels on land masses south and west of the crash site would be radiologically insignificant but probably measureable by chemical analysis of surface samples.

*A report on the Danish
Scientific Group investigations,
immediate actions and long-range
planning regarding the B-52 accident
at Thule.*

DANISH SCIENTIFIC GROUP INVESTIGATIONS

JØRGEN KOCH
Director of the Physical Laboratory II
University of Copenhagen
Counsellor to the
National Health Service of Denmark

AT the meeting in the Ministry of Foreign Affairs in Copenhagen on Tuesday morning (23 January) it was decided at once to send a scientific group representing the Danish Government to the Thule Air Base in order to cooperate with the Disaster Control Team of the Strategic Air Command, and if necessary to carry out independent investigations related to the consequences of the B-52 accident. The group was primarily assigned the task of finding out whether any Danish citizens had been injured as a direct consequence of the crash or by the subsequent fire, either of which might have spread radioactive materials around the point of impact, and in case of such injury to arrange at once for appropriate measures. The ultimate goal of the mission was to assure that no harm could possibly occur to the population living in the area neither immediately nor in the future.

The vanguard of the Danish Scientific Group consisted of the following radiation experts: Henry L Gjørup, Director of the Health Physics Department, Danish AEC; Per Grande, Director of the Radiation Hygiene Laboratory, National Health Service of Denmark; Professor Otto Kofoed-Hansen, Director of the Physics Department, Danish AEC; and Professor Jørgen Koch, Counsellor to the National Health Service of Denmark. Representing the Greenland administration the Group was joined by Hans J. Lassen, Head of Department, Ministry for Greenland.

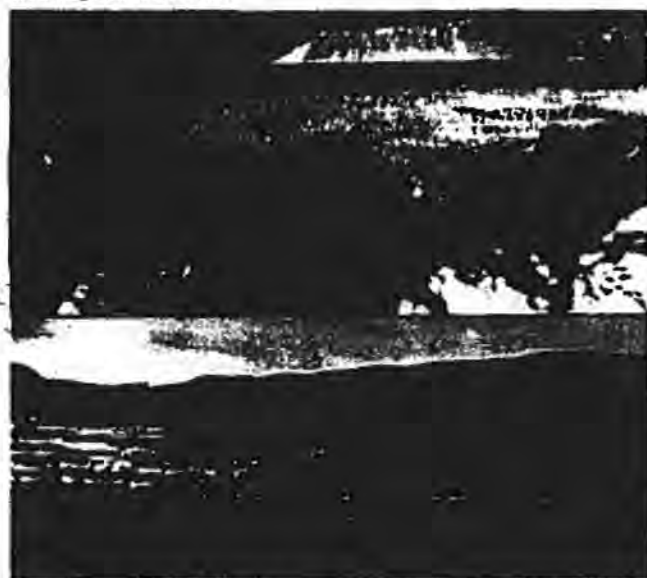
It was originally planned to use the regular SAS flight bound for Thule on Wednesday 24 January, but due to bad weather conditions departure was delayed until the next day. This delay enabled the members of the group to attend a meeting on Thursday morning with The Honorable Carl Walske, Assistant to the U.S. Secretary of Defense for Atomic Energy, who had come to Copenhagen in order to inform the Danish Govern-

ment about the accident.

The plane arrived in Thule at about 1:30 p.m. (local time) and was met by the Danish Liaison Officer, Commander Svend Olesen, who introduced the members of the Group to the Air Base Commander, Col Cornelius S. Dresser. Representatives of the Danish as well as of the International press arrived aboard the same plane. It may be added here that the relationship between the group and the press was taken care of by Kaj Johansen, Deputy Permanent Under Secretary of State for Press and Information, Ministry for Foreign Affairs.

In a meeting, which was convened immediately upon landing, Commander Olesen informed the Danish dele-

Sled dogs on the sea ice.



Greenlander in dogsled on the sea ice.

gation about the events which had taken place since the B-52 plane crashed on the ice. As soon as it became known that the bomber was carrying nuclear weapons the potential radiation danger from the spread of plutonium had been recognized. Commander Olesen and Police Inspector F. Skov had been active in the organization of an operation to warn the small number of Greenlanders hunting in the Bylot Sound. The search itself was carried out by Jens Zinglersen (head of the trade station at Dundas), together with a few Greenlanders equipped with dogsleds, who combed the area and asked the hunters to visit the air base in order to be tested for radioactivity. A dramatic situation occurred during this meeting: A telephone call revealed that a Greenland, Jessi Kujaukitsok, living in a hut at Narssarssuk, had approached the fire as near as possible in order to look for survivors; finding nobody he had returned to Narssarssuk, without having been checked for radioactivity. A helicopter was started right away to clear up the situation. A search for radioactivity in the hut gave a negative result and a few hours later when Jessi Kujaukitsok together with his dogs arrived at the decontamination station, it was ascertained that they too were clean. Consequently, already a few hours after their arrival, the members of the group felt convinced that no injury had occurred to Danish citizens as a direct result of the accident. This impression was later fully confirmed by careful tests of the uptake of radioactivity in the body of the persons concerned.

Later in the afternoon H. Davis Bruner, Assistant Director, Division of Biology and Medicine, AEC, Washington, and Wright H. Langham, Group Leader, Biomedical Research, Los Alamos Scientific Laboratory, who had just arrived from the United States, came to discuss the situation with the Danish Group, and soon afterwards the head of the operation, Maj Gen Richard O. Hunziker, joined the meeting. The General gave an exhaustive description of the situation. However, due to bad weather conditions not too many details could be given, but air photographs revealed that aircraft debris were spread over a drop-shaped area of approximately 750 x 150 m², and survey measurements indicated that the major part of radioactivity was confined to this area and partly fixed to the aircraft debris. This information was also given at the press meeting, which was held later in the evening.

A close cooperation between the Danish Group and the SAC Disaster Control Team was thus established from the very beginning. The spirit of joint effort was underlined by quartering the group in a large office located in the Base Service Club, next door to the headquarters of the operation. The members of the Danish Group had unlimited access to the headquarters during the entire operation. Furthermore the Air Attache of the U.S. Embassy in Copenhagen, Col Redgely Kemp, was seconded to support the Danish Group. A secretary

was assigned to the group for assistance in the daily work.

The information given to the Danish group upon arrival was confirmed next day by visiting the crash scene. Messrs Gjørup and Koch were brought to the site by General Hunziker, and they were escorted on their 3-hour tour by two members of the Disaster Control Team. Due to the fact that a layer of clean, firm snow had been blown over the area the participants returned without being contaminated to any significant degree.

Meteorological data collected at the local station showed that the heavy storms (phases)—which occur frequently in this part of the Arctic—are generally blowing snow from the ice cap westwards into the Bylot Sound. Transfer of radioactivity from the crash scene to the air base and to Dundas therefore seemed to be very unlikely. This information, together with the fact that the U.S. recovery teams were picking up radioactive debris, indicated that the situation was well under control. On Sunday, 28 January, it was established beyond any doubt that all four bombs had disintegrated following the impact on the ice. The possibility that at least one of the bombs might have passed through the hole in the ice to the bottom of the Bylot Sound, was thereby definitely excluded.

With this background in mind the Danish Scientific Group felt that it was justified to concentrate its main effort on the question related to the radiation levels outside the immediate crash area, since considerable amounts of microscopic particles covered with plutonium might have been injected into the atmosphere and settled down on the shorelines of the Bylot Sound (or even further away), or radioactivity might have been deposited in the seawater, from where it via biological materials could enter the food chain. It was realized that it would be necessary as soon as possible to start long-range planning for the measurements of the spread of radioactivity in order to take care of any eventuality.

As a preliminary precaution, it seemed necessary to warn the population against the potential dangers of entering into the neighborhood of the crash scene. On Monday, 29 January, an announcement was issued by Kaj B. Beck, Head of the municipality at Qanaq, the Reverend Erling Høegh, Chairman of the Greenland National Council, and Claus Bornemann, Governor of Greenland, whereby it was prohibited to stay, or even to pass, the area defined by the following geographical locations: Manson Islands, Mount Dundas, Alanguarsuk, and Inersussat. At the same time a warning was issued against the collection of materials of unknown origin (souvenirs). By request, about a week later, it was decided that hunting of foxes and ravens should be prohibited due to the fact that these animals are inclined to pick up all kinds of materials and to travel far around in the country. These restrictions were gradually relaxed and finally cancelled as the clean-up operation

progressed.

In order to enable the Danish group to cope with the manifold problems mentioned above, further scientific and technical support was requested from Copenhagen. On Tuesday, 30 January, the following experts arrived in Thule: Børge Fristrup, Glaciology, University of Copenhagen; Poul M. Hansen, Marine Biology, Greenland Fishing Investigation; Frede Hermann, Oceanography, Danish Fishing and Marine Investigation; and Christian Vibe, Zoology, University of Copenhagen. Apart from their special fields of competence these scientists are intimately familiar with the area around Thule and they were thus able to give advice on a number of pertinent questions.

At the same time two radiation experts were added to the group: Leif Lövborg and Emil Sørensen (both members of the scientific staff of the Research Establishment Risø). Lt Col Otto Krarup, Chief of Staff to the Island Commander of Greenland, had arrived a few days earlier from Søndre Strømfjord.

Evidently it was of primary importance to make the newcomers acquainted with the location and conditions of the crash site by personal inspection. Already from their first visit on the ice it was possible by observation of the size, form, and position of the ice blocks at the point of impact to confirm the supposition—deduced from infrared photographs—that the 80 cm thick ice had been broken up in an area approximately 50 m. in diameter. Consequently, the presence of radioactive aircraft debris on the bottom of the bay had to be taken into consideration.

As a result of the series of plenary meetings—with the participation of the U.S. representatives, Mr Bruner, Dr Langham, Mr Wolfe and all members of the Danish scientific group—it was decided that further investigations by the Group should be focused on the following topics:

1. Collection of a series of samples of snow and ice from representative locations outside the point of impact, e.g., from the shorelines and the ice of the Bylot Sound, from Thule and Dundas (including the water reservoir). Sampling should start at the points, which, according to meteorological calculations, seemed likely to be most heavily contaminated.
2. Collection of water and bottom samples, especially with regard to biological materials, which might go into the food chain.
3. Collection of specimens of wildlife such as walrus, seals and foxes, which are used in the household of the Greenlanders.
4. Evaluation of the ice conditions in order to enable planning for the recovery of contaminated ice and snow, and to judge the danger which might arise from the drift of contaminated ice during the following spring.

5. Preparation for a summer expedition with the purpose of checking the region around the entire Wolstenholme Fjord for remaining plutonium.

After having participated in the work for about 1 week, Mr Bruner, Dr Langham, Mr Wolfe, and Mr Kofoed-Hansen left Thule. In order to preserve contact between the U.S. and the Danish scientists, which had turned out to be so advantageous for carrying out the investigations, a meeting was held on Sunday, 4 February, in which a representation of the U.S. health physics team headed by Col Jack C. Fitzpatrick, Field Command Surgeon of the Defense Atomic Support Agency, and all remaining members of the Danish group took part.

At that time contour lines of the spread of plutonium had been roughly determined by gamma ray measurements using the FIDLER instruments, which had promptly been sent to Thule. On this basis it was possible to conduct realistic discussions on the clean-up operation. Details of the above mentioned measuring program were also discussed.

A briefing was given in the meeting hall of the Danish Construction Corporation (DCC) in order to inform the members of the Danish community, who at that time were engaged in civil work at the Thule Air Base (more than 1,000 people) about the consequences of the B-52 crash. Contact was hereby established between the DCC personnel and the health physicists from Risø, who later were stationed on shift in Thule during the entire period of the operation "Pacer Goose." On invitation from Mr Beck and other members of the Qanaq Community Council, a few members of the Danish Scientific Group went to Qanaq by helicopter in order to brief the local Greenland population about the situation.

After having stayed in Thule for about 2 weeks, the Danish Scientific Group felt that its primary mission had been completed. On Wednesday, 6 February, Messrs Fristrup, Grande, Hansen, Lassen, and Koch returned to Copenhagen. A press meeting was arranged at the airport, and it was a relief for all that the situation could be described in reassuring terms, although a number of problems were still not fully explored.

The remaining members of the group stayed another week. Messrs Hermann and Vibe collected a series of samples of seawater and biological materials. Mr Gjörup continued the surveillance of plutonium and organized the health physics duties, which should be carried out during the forthcoming months by his colleagues from Risø coming to replace him.

Other articles detail the work carried out by the Danish Scientific Group during its initial stay in Thule and the subsequent months until the operation was called off. The activity of the group in connection with the summer expedition is described later in this publication.

RADIOLOGICAL MONITORING

CAPT WILLIAM K. McRANEY
Directorate of Nuclear Safety

(Editor's note: Capt William K. McRaney is an Air Force Health Physicist (AFSC 9176) assigned to the Directorate of Nuclear Safety, Hurland AFB, New Mexico. There are less than 50 Health Physicists currently on active duty in the Air Force. Captain McRaney has a Master's degree in Health Physics/Radiation Biology from the University of Rochester, New York. He responded to the Thule accident as part of the Technical Assistance Team provided by the Directorate of Nuclear Safety, and arrived on site approximately 25 hours after the accident. He remained at Thule 63 days and served as part of the American Scientific Group which provided technical advice to the On-Scene Commander.)



Capt William K. McRaney working on the core.

AT any accident involving nuclear materials, the radiation detection personnel must be ready to go. Such was the case at Thule where a number of instruments were employed for both health physics and weapons recovery purposes. In some cases these applications were not unique.

The hostile environment created many problems for all aspects of the operation, including radiological monitoring. For example, during the several weeks of the operation, the ambient temperature ranged from 10 to 20 degrees below zero. At these temperatures, electronic equipment quickly became inoperative and the lifetime of electronic cells is considerably reduced. In addition, most of the instruments used in the cold were powered by external battery packs that could be used to power operators' clothing. This modification of the equipment problems has been a major handicap. The most troublesome of these were the electronic instruments affected by the cold, becoming very difficult to use. This created an additional burden for the operators. Extreme care was necessary for personnel working in the



PAC-15 with external battery pack.



Field monitoring problems: Darkness, brittle electrical cables, and bitter cold.

Despite these problems, radiation detection equipment was successfully used at Thule and the data obtained played a key role in the operation. This narrative describes the scope of radiological monitoring at Thule, the instruments used, and how they performed.

INITIAL RECONNAISSANCE

The first actual monitoring at Thule was accomplished by a small reconnaissance team of five people. The team size was limited by the only mode of transportation to the site available at that time—five dogsleds with Greenlanders drivers. Their monitoring objective was twofold: (1) to assure, by the absence of fission product beta-gamma radiation, that there had been no nuclear contribution to the accident, and (2) to check for the presence of plutonium contamination. The team took with them an AN/PDR-27 and a PAC-1S. The AN/PDR-27 is the standard low-range beta-gamma survey meter used by the U.S. military services. This is a Geiger-Mueller instrument with a range of 0-300 mr/hr. The PAC-1S is the standard U.S. Army and U.S. Air Force alpha survey meter and is a zinc sulphide scintillation detector and has a range of 0-2 million counts per minute. The detector probe face has a sensitive area of 59 square centimeters.

Both instruments were operational upon arrival at the crash site but the carbon zinc batteries in the PDR-27 and the mercury batteries in the PAC-1S soon failed in the extreme cold (-30°F). Neither type of battery is rated below 0°F. During the short operational period no beta-gamma radiation was detected with the PDR-27; however, using the PAC-1S, widespread alpha contamination was detected on the surface of the snow, ice, and aircraft debris.



Aerial photograph of the crash site.

ENVIRONMENTAL SURVEYS

The initial reconnaissance team established the presence of plutonium contamination, the next task then was to determine the degree of contamination and how it was dispersed. The material was largely bound up in a thin frozen crust of blackened ice containing the residue of a fuel fire, some unburned JP-4, and general debris. Also, an arctic storm occurred after the accident and covered some of the surface contamination with fresh snow. Since alpha particles will not penetrate a thin layer of snow or ice, an alpha survey under these conditions would have been meaningless.



PAC-1S with PG-1.



FIDLER

Low-energy gamma and X rays are associated with the alpha decay of the fissionable materials used in nuclear weapons. For example, plutonium 239 emits a 17KEV X ray and americium 241 emits a somewhat stronger 60KEV gamma ray. Americium 241 is a daughter product of plutonium 241, which is normally present as an impurity in plutonium 239. Therefore, the americium content is a function of the age of the material and the original Pu 241 content. Since X and gamma radiations will penetrate a thin snow or ice cover, an instrument that would be sensitive to these emissions would be very useful.

PAC-IS AGA instruments with PG-1 gamma scintillation probes capable of detecting these low energy emissions were available, but this type of instrument was designed to be a detector only, and would not provide quantitative results. Also, this instrument has a high background count, so fairly large concentrations of plutonium would be necessary before the material could be detected. For these reasons, this instrument was not used.

Soon after the accident, the Lawrence Radiation Laboratory at Livermore, California, volunteered an instrument they had been testing. The instrument was called the FIDLER—an acronym for Field Instrument for Detection of Low Energy Radiation. As the name implies, the instrument would detect low-energy X or gamma radiations from plutonium and americium; moreover, the instrument readout could be related to surface area contamination through a somewhat unique calibration procedure.

The instrument consists of a PRM-5, a small single Channel analyzer and a scintillation detector. The detector is a 1/16-inch thick NaI(Tl) crystal, 5 inches in diameter coupled to a 5-inch photomultiplier tube through a quartz light pipe. The instrument was modified for arctic use by the addition of an external battery pack and thermal insulation around the detector.

Two days were spent testing the instrument in the



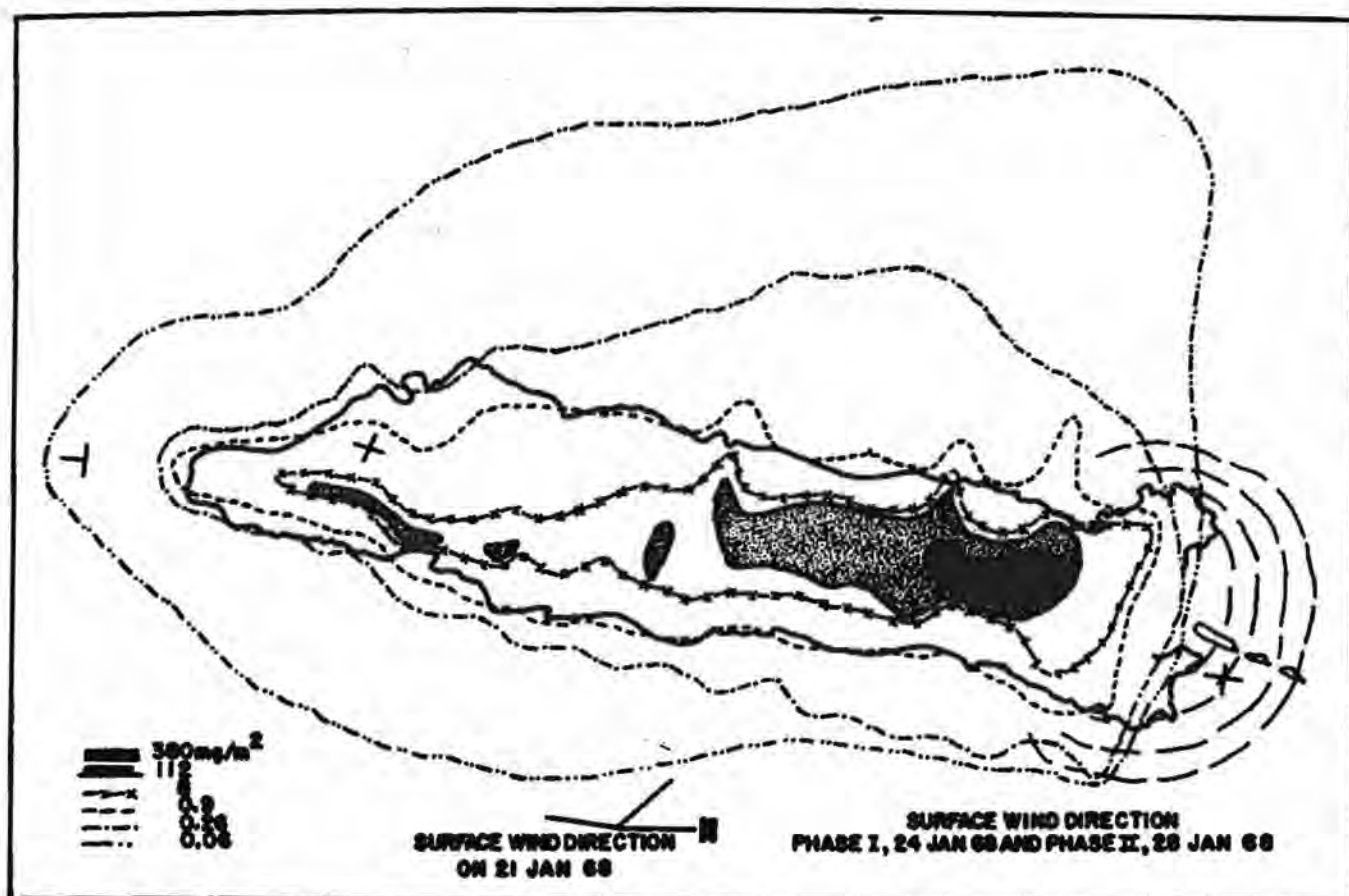
FIDLER detector with thermal insulation.

field, its performance was satisfactory. Laboratory and field testing had shown that the PRM-5 electronics were temperature dependent, i. e., the proper operating voltage would change with the temperature; consequently, the instrument had to be calibrated and adjusted in the field after at least a 30-minute cold soak.

After the instrument was calibrated, experiments were performed to determine snow attenuation data and the optimum photon energy to monitor—the single channel analyzer permits discrimination of all but the desired photon energy. The americium 60KEV photons produced better instrument sensitivity; therefore, 60-KEV was chosen for survey work. Attenuation experiments showed that 6 inches of snow would reduce the 60KEV photon intensity about a factor of 2.

After this preliminary testing, the first area survey was conducted. Since the data was urgently needed and the weatherman was predicting another storm, a simple 30° radial survey was decided upon. A center point was established and a crude "transit" was constructed to keep the survey on line. The survey team consisted of four men—an instrument operator, a recorder, a transit man, and an operator's assistant to relay data via radio to the recorder, pace off distances, and carry a lantern so that the survey team could be seen and guided by the transit man.

For survey work, the PRM-5 was strapped around the operator's neck to hang about chest height and the detector was carried like a bucket of water at the calibration height of 12 inches above the ground. The detector weighed about 11 pounds and the PRM-5 only 5½ pounds, but after several hours of use they seemed much heavier. A flashlight was also suspended from the operator's neck to illuminate the meter since a built-in lamp is not provided in the PRM-5. The instrument had to be readjusted periodically to keep the electronics set precisely on the 60KEV peak. This was accomplished by fine tuning a small high-voltage adjustment screw on the PRM-5 with a tiny screwdriver—a real trick while



Isocontour map of plutonium contamination.

wearing two or three layers of gloves. The PRM-5 has a new type of meter called LINLOG and scale or range switching is not necessary. This proved extremely valuable since operating a small-scale or multiplier switch with these gloves on would have been very difficult.

In spite of these problems, the FIDLER performed well and the first survey was completed in 2 days. More FIDLERs were ordered, but due to a limited supply of PRM-5s and thin 5-inch diameter crystals, only three more instruments could be obtained.

Monitoring teams were trained at Thule to use the FIDLER and the area was resurveyed. This time a 30° radial survey was refined by a grid plot with 50-foot centers. The survey was accomplished using four instruments simultaneously and was completed in 1 day. After normalizing the data from the four instruments, considering snow attenuation factors and comparative data from actual snow samples analyzed in a laboratory, an isocontour map of the contamination was prepared.

The FIDLER was used throughout the clean-up operation to detect "hot spots" missed by the snow removal equipment. The instrument was also used to monitor the tank farm storage area for spills and to conduct the final grid survey of the crash site after the

cleanup. The final survey indicated that 93 per cent of the radioactive material was removed from the decontaminated area.

Besides these instrument surveys, a great deal of environmental data was obtained through the laboratory analysis of snow and ice samples. Samples were submitted to the USAF Radiological Health Laboratory, Los Alamos Scientific Laboratory, and Lawrence Radiation Laboratory. A great deal of attention was focused on the immediate impact area where the ice had actually broken. To gain information about the distribution of the contamination in this area, over 150 ice core samples were taken. A crude field method was developed to analyze these cores using the PRM-5 analyzer, PG-1 detector, and a homemade scanner. The ice cores were placed in a wooden box, and using a piece of lead with a 1-inch slit as a collimator, the entire length of the core was scanned at 1-inch intervals. The method was calibrated by comparing scan data with laboratory analyses of a few ice cores. Ice core data proved that significant contamination had not penetrated the ice and that only a small percentage of the total contamination was trapped in the ice at the impact point.

Tritium was detected in some of the snow and ice



Drilling for ice core.



Ice cores from impact area.



Radiological monitoring
with FIDLER.

samples submitted to stateside laboratories. Although this did not indicate a significant hazard, laboratory equipment capable of analyzing snow and urine samples was quickly dispatched to Thule. A "Tri-Carb" liquid scintillation counter and operators were furnished by the Sandia Corporation at Livermore, California. Use of this equipment did indeed prove that the tritium present was not a hazard to "Crested Ice" personnel since insignificant amounts of tritium were detected in urine samples taken on location.

A new type of tritium detector was used to monitor the second phase of the operations at Thule, i. e., the transfer of the melted contaminated snow from the large 25,000-gallon storage tanks at Thule to smaller 1,800-gallon containers prior to shipment to the States in the summer. This instrument, the T446 Tritium Alarm Monitor, recently developed by Sandia Laboratories, is a portable instrument comprised of a flow-through, ion chamber and a vibrating reed electrometer. The instrument also has a urinalysis capability, the T449 Radiological Urinalyses Kit. The T449 uses a disposable gas generator cartridge to liberate hydrogen (tritium) gas from the urine sample (calcium reduction reaction). The gas is then analyzed by the T446. No tritium hazard was detected during this phase of the operation using the T446/T449.

Several buildings at Thule were used for decontamination purposes and one was used to package recovered weapon components. These buildings were continuously monitored by swipe sampling and with PAC-IS instruments. PAC-IS instruments were also used to monitor all tanks or drums containing recovered aircraft debris or contaminated snow and ice. No instrumentation problems were encountered in these programs.

Many air samples were taken at Thule to evaluate the airborne hazards associated with operations such as contaminated snow removal and delivery to the storage area, personnel and equipment decontamination, etc. A hi-volume sampler was used—both 110V AC and 24V DC models were available. Air sample results indicated that resuspension of plutonium was not a problem.

PERSONNEL AND EQUIPMENT MONITORING

A personnel decontamination station was established in a vacant barracks building that contained hot running water and shower facilities. Alpha contamination limits, as measured by a PAC-IS, were established at 450 cpm on U.S. personnel and "none detectable" on foreign nationals. No beta-gamma contamination was detected on the initial reconnaissance team using the AN/PDR-27, and the absence of a nuclear yield was verified by field measurements; therefore, beta-gamma personnel monitoring was unnecessary. This personnel decontamination center grew into a sizable operation with 12 monitors processing up to 200 people a day. A second decontamination station was established at the site for gross work such as removal of anticontamination of



T446 Tritium alarm monitor.



T446 tritium alarm monitor with T449 urinalysis kit attached.



Personnel monitoring at decontamination station.

Nasal swabs were included in the personnel monitoring routine.



clothing, gloves, booties, etc.

Nasal swabs were also included as part of the personnel monitoring routine. These swab results were used as a rough indicator of any airborne hazard and in general revealed no detectable activity. However, since most everyone's nose ran profusely in this climate, there was a reasonable doubt as to the validity of this check.

Everything from dogs and dogsleds to 10-ton trucks leaving the crash site was monitored with a PAC-1S at an exit control point. If possible, all loose snow and ice was removed before the item was monitored. Items found contaminated were labeled and sent to a decontamination station on base where they were washed and monitored again after a drying period. Surfaces had to be dry since any moisture would mask the alpha radiation. Swipe samples were also taken on vehicles and equipment before the item would be released for general use. Contamination limits were agreed upon by Danish and U.S. authorities.

The USAF Radiological Health Laboratory provided a capability to count nasal swabs, air and swipe samples locally. Three gas flow internal proportional counters were set up in the Thule Dispensary. This laboratory equipment proved quite beneficial in providing quick results needed to make immediate judgments.

The PAC-1S was satisfactory for personnel and equipment monitoring considering the problems inherent to any alpha detector. For example, the short range of alpha particles requires that an alpha detector be placed not more than one-eighth of an inch from the surface to be monitored; and direct contact has to be avoided to prevent the probe face from becoming contaminated or punctured. Due to contaminated and punctured probe faces or other malfunctions, up to 20 instruments were required for a full day's operation.

False readings on the PAC-1S occurred occasionally. Static discharges were quite common in this cold, dry climate; this was particularly noticeable since everyone wore arctic clothing made of a mixture of wool and rayon. It was thought that these false readings were due to this static discharge when the detector would make contact with items being monitored. If a reading was due to this phenomenon and not contamination, the meter reading would return to background after a few seconds. This did not create a serious monitoring problem as long as technicians were briefed on the matter.

WEAPONS RECOVERY

Still another application of radiac instrumentation was employed at Thule. The PRM-5 analyzer and the SPA-3 scintillation detector were used in search for weapons components. The SPA-3 detector contains a 2x2-inch NaI(Tl) crystal coupled to a 2-inch photomultiplier tube. This device is particularly suited for detecting 185KEV gamma rays from the uranium 235 used in various weapon components.



PRM-5 with SPA-3.

Although searching by walking and hand-carrying the instrument proved to be the most effective technique, other methods such as suspending the detector from a helicopter and mounting the detectors on a surface vehicle were tried. In the helicopter and vehicle-mounted techniques, the instrument's power supply had to be increased because of excessive voltage drops caused by longer electrical cables. Other instrument problems were caused by vehicle vibration and noise interference.

EQUIPMENT MAINTENANCE

In the past, experience had clearly demonstrated requirements for additional radiac instruments and an on-scene instrument repair capability to support operations. Within this concept, three air-transportable radiac packages were developed for response to this type of emergency. The air-transportable packages were designed to be self-sufficient; each contained 15 complete PAC-1S, two PDR-27, and two PDR-43 instruments (high-range beta-gamma survey meter). Spare parts, and the tools and test equipment necessary for the maintenance of these instruments were included. Two civilian electronics technicians, with one of these packages, were dispatched from the San Antonio Air Materiel Area to



Air-transportable radiac package.



SPA-3 probes on the weasel.

Thule immediately after the accident. This proved invaluable to the operation as instrument repairs and modifications were numerous.

At the peak of the activity approximately 70 PAC-1S instruments, four FIDLERs, and three PRM-5/SPA-3 combinations were being maintained. The instrument repair group expanded to four Air Force civilian technicians working two 12-hour shifts. A technician from the Lawrence Radiation Laboratory at Livermore, California, assisted with the PRM-5s and FIDLERs.

SUMMARY

Almost every phase of the operations at Thule depended on radiological monitoring results. The conditions at Thule created many problems in obtaining accurate radiological data both after a few equipment modifications and the use of new instrumentation, but the necessary information was gathered.

The most significant aspect of radiological monitoring at Thule was the use of a gamma detector, the FIDLER, for area survey. Undoubtedly, the addition of this instrument to our kit represents a sizable contribution to the tools of the trade; however, there will always be a requirement for alpha survey meters such as the PAC-1S for equipment and personnel monitoring.



Inside the air-transportable radiac package.

FIDLER ON THE ROOF OF THE WORLD



JAMES BECKER and GARY SHAW
Lawrence Radiation Laboratory
University of California
Livermore, California



A FIDLER assembly converted for field use in the arctic.

DURING the search and recovery phase of Project Crested Ice, a team of scientists and technicians from the University of California Lawrence Radiation Laboratory (hereafter referred to as LRL) advised and aided the Air Force Disaster Response Force in locating and measuring the plutonium contamination and packaging the contaminated debris. Besides the crew at Thule, the Laboratory's facilities at Livermore, California, participated by analyzing data and testing materials that were sent down from the site.

Administratively, the LRL team at the crash site was assigned to the American Scientific Group. Two LRL men—Walter Bennett, head of the Hazards Control Department, and James Olsen of the Director's office—served successive terms as on-site scientific advisors to Maj Gen Richard O. Hunziker, the On-Scene Commander. From the first arrival to the last departure, LRL personnel were at Thule for a total of about 6 weeks. They worked closely with the Scientific Group and helped the Radiological Monitoring Team in data evaluation, sampling, sample counting, electronic maintenance, and in several other areas where they could make a contribution.

LRL became involved in Project Crested Ice via a roundabout route. As one of this country's major weapon laboratories, LRL was immediately notified that an accident involving nuclear weapons had occurred. Since the nuclear bombs aboard the downed B-52 were not of LRL design, we had no direct responsibility in early recovery efforts. But we did have something of value to add to the operation—a staff of experts specifically trained to deal with such nuclear emergencies, and a portable scintillation counter called FIDLER (Field Instrument for Detection of Low Energy Radiation) specifically designed to rapidly survey large areas for plutonium contamination. We promptly notified the Air Force through the Joint Nuclear Accident Coordinating Committee that FIDLER was available; an invitation was extended by the Strategic Air Command (SAC) on 24 January, and within 4 hours two men and two FIDLERs were on their way from California to Green-

land. The men were Nathan Benedict, weapon engineer and member of LRL's "Hot Spot" Emergency-Response Team; and Dr. Joseph Tinney, a member of LRL's Hazards Control Staff and the physicist in charge of developing FIDLER.

Because of its importance in getting LRL involved in Project Crested Ice in the first place, we will pause here to explain what FIDLER is and how it came to be. The development of FIDLER was prompted by the incident at Palomares, Spain, in 1966. Although LRL did not participate in the Palomares cleanup operations, our Hazards Control people became aware of the difficulties experienced by the Disaster Response Force in locating and measuring plutonium contamination from the debris covered by sand and water. Clearly, there was a need for a portable instrument that could easily detect and measure plutonium deposition under adverse conditions. Alpha counters, which are routinely used for this purpose, are quite adequate when the contaminating debris is exposed. If the debris is even shallowly buried, however, alpha detection is seriously compromised as alpha particles are not very penetrating.

Plutonium emits low-energy X rays, which are far more penetrating than alpha particles. While these X rays are of such low intensity that they are relatively insignificant biologically, they may be detected using a suitable, sensitive detector. In particular, an X-ray detector should be able to measure contamination that would be "invisible" to an alpha detector. Thus, scientists of LRL's Hazards Control Department undertook to develop a portable instrument for measuring plutonium deposition that operated on the principle of X-ray detection rather than alpha detection.

The result, FIDLER, is basically a sodium-iodide scintillator, about 5 inches in diameter and 1/16-inch thick, coupled to a photomultiplier tube. The signal produced when X rays strike the scintillator is amplified by the photomultiplier and fed to a portable analyzer and count-rate meter.

At the time of the Thule crash, the prototype

FIDLER had been successfully tested at Livermore and under desert conditions at the Atomic Energy Commission's Nevada Test Site, but it had never been tested under conditions anything like those found in Greenland in January. Still, we felt that an X-ray detector like FIDLER would have a better chance of success under the arctic conditions than alpha counters would, particularly since much of the debris was covered with snow and ice.

In the 4 hours that elapsed between our receipt of the invitation from SAC and the departure of Benedict and Tinney for Thule, personnel of the Hazards Control Department converted two prototype laboratory-model FIDLERs into instruments suitable for field use in the arctic. Basically, this conversion involved "ruggedizing" the units against the shocks of transportation and handling, and providing for operation in the severe cold. For example, the battery packs were separated from the rest of the assemblies so that they could be kept warm under the monitors' parkas. The illustration shows the converted FIDLER.

When Benedict and Tinney arrived at Thule, only a few days after the crash, the crash site was still in a primitive state—the support facilities consisted of a wooden shack, and the only light available at that time of year came from Coleman lanterns. The prospect, as Joe Tinney described it, was depressing. But with the cooperation and support of the Air Force Disaster Response Force, Benedict and Tinney managed to calibrate their FIDLERs, check attenuation through various thicknesses of snow, improvise techniques and auxiliary equipment, and start making meaningful measurements of plutonium contamination.

Aside from the natural difficulties of the site, other problems soon arose that were even more critical. For instance, where in Greenland do you find spare parts for a unique and very delicate electronic instrument? Where can you obtain a cooling coil of just the right size? Where do you take your instrument when it needs servicing? A portion of the Defense Atomic Support Agency Nuclear Emergency Team had been airlifted to Thule on the C-141 aircraft that delivered the Air Force's Air Transportable Radiac Package (ATRAP) with its adequate supply of the standard alpha meters, spare parts and maintenance facilities. The ATRAP, prepositioned by the San Antonio Air Materiel Area at Kelly AFB, included a staff of maintenance personnel who were equipped to maintain standard radiation detection instruments, but there was no store of general testing and repairing equipment. So Benedict and Tinney had to live by their wits until Don Knowles, an LRL electrical technician, arrived with testing equipment, spare parts, and two additional FIDLER units. Wits still came in handy, however, since it was necessary to innovate and improvise in order to cope with the unanticipated conditions that always plague field operations.

Besides the initial work with the FIDLERs in locating and measuring contamination at the crash site, the LRL team rendered important services in connection with the packaging of the contaminated ice, snow, and debris. As the material was initially deposited in drums and tanks, each container had to be assayed to make sure that the aggregate of fissile material could not create a critical configuration under any condition the packages might encounter. Even more important was the need to be absolutely certain that later, when the blackened ice crust was loaded into the 25,000-gallon tanks and melted, a critical mass could not be accumulated.

One member of the LRL team, Milan Knezevich, addressed himself to this criticality problem. He estimated the accumulation of fissile material by monitoring the radiation emitted from each container. To assist and double-check his work, criticality experts at both Los Alamos Scientific Laboratory and LRL made calculations and measurements on samples of known sizes and shapes. By relating all the information that could be obtained from the crash site to the data furnished by the laboratories, the Disaster Response Force was able to establish packaging specifications for precluding a criticality accident.

The huge 25,000-gallon fuel tanks that were used as the interim repositories for the debris presented some ticklish problems of their own. For example, were the tanks strong enough to be lifted and handled after they were filled, or would they break open? Again, LRL's Livermore facility helped to solve the problem. Data from the tank manufacturer's tags and the physical measurements of the tanks were sent to Livermore. With this information, the original specifications for the tanks were obtained from the manufacturer and handling tests were run on mock-ups. Samples of metal from the tanks were also sent to Livermore for metallurgical analysis. The information from these tests furnished the Disaster Response Force with a sound basis for evaluating some of the engineering problems involved in packaging and transporting the debris.

Thus LRL's participation in Project Crested Ice grew from a small beginning into a diverse effort involving men and equipment both at the crash site and at Livermore. We at LRL are glad to have been able to help the Air Force in this sensitive operation, and we feel that the experience we gained at Thule is invaluable.



Fuel tanks in hangar being modified for ice containers.

USAF RADIOLOGICAL HEALTH LABORATORY SUPPORT

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INTRODUCTION

ON 22 January 1968, the day after the accident, the USAF Radiological Health Laboratory prepared and shipped its first lot of supplies to support the Strategic Air Command's Disaster Control Team operations on-site.

As investigation of the crash proceeded, and the extent of radioactive contamination became better defined, more definitive Laboratory support requirements evolved.

ON-SITE SUPPORT

The Laboratory provided four categories of on-site support: materiel, equipment, consultation services, and personnel. Materials requested were varied in kind and amount—from three rolls of masking tape to 10,000 envelopes for swipe samples. Containers for ice cores, swipes, and urine samples were the most critical items, since few or no comparable items were available locally. The Laboratory, however, maintains large inventories of all materials needed by field personnel as part of its Broken Arrow response posture. Experience during Palomares and Thule proved the value of this stockpiling, because it permits on-site officials one source for nearly all emergency medical supplies. Thus, pipeline time is limited only by transportation capabilities.

Equipment deployed to Thule consisted of three gas-flow proportional alpha counters and gas cylinders. This equipment was not designed for portability and field use; however, as a result of the experience gained during Crested Ice, the Laboratory designed a portable and automatic counting system in the event the field requirement should be levied again. An additional feature of the new system will be the use of solid-state detectors, thereby eliminating the need for transportation and resupply of heavy, bulky gas cylinders.

Consultation services between the Laboratory staff

and on-site staff were conducted by telephone on a daily basis early in the operation, and then weekly as progress continued. However, queries concerning sampling procedures, supply sources, laundry services, and permissible radioactive levels, were usually answered the same day as received. Many times the formation of answers required library research, and the Laboratory staff provided this service.

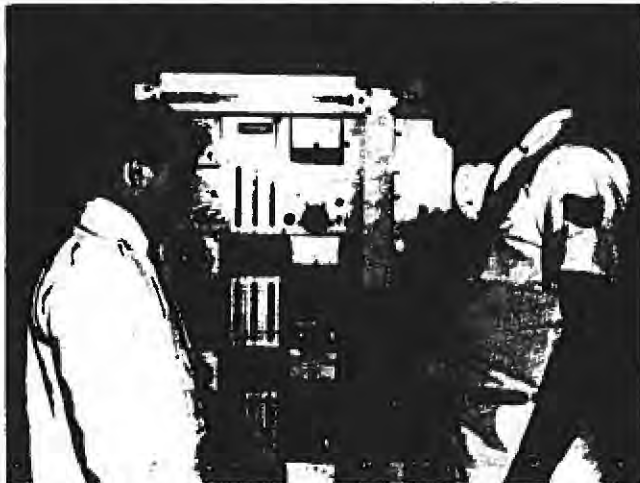
Five staff members—two officers (health physicists), one civilian (electronic engineer), and two airmen (a Preventive Medicine Technician and a Radioisotope Laboratory Technician) from the Laboratory—were deployed to the site in support of the operation. In aggregate this time totalled 220 days, including the periods when contaminated waste was removed from Thule during which a health physicist provided 45 days of on-site consultation services. The enlisted men processed samples and operated the counting equipment, as well as assisting with other details as required. Electronic maintenance support was provided by the engineer. A health physicist served on the staff of the On-Scene Commander during the phase of operations directed by the Strategic Air Command team. His duties included monitoring the crash site for contamination levels, supervising procedures for decontamination of personnel and equipment, advising on hazards and practicability of various proposals for waste disposal, and conducting such special studies as were necessary to answer operational problems.

IN-HOUSE LABORATORY SUPPORT

In this as in all other events of an emergency nature where Radiological Health Laboratory support is required, the entire staff and capability of the organization were placed at the disposal of the Strategic Air Command needs. This was a professional, technical and

administrative staff of 32 individuals, and over one-half million dollars of laboratory equipment and supplies. Initially, the work load was insignificant, but as clean-up procedures started, samples increased enormously. During one week, nearly 2,000 samples were processed—a figure 10 times that routinely completed. All material processed on site at Thule was reanalyzed at the Laboratory to permit preparation of permanent records for computer processing, and as a quality control procedure. In addition, it was essential that the practicability of field analyses be evaluated for accuracy. In many cases we found duplication of sample numbers and incomplete sample identification data. These deficiencies were corrected by telephone with officials at Thule. The Laboratory also served as the personnel contact agency for submission of urine samples. From the Palomares accident we learned that urine samples routinely collected at the scene for later plutonium analyses were often contaminated with minute amounts of the isotope; thus, it was necessary to resample individuals after their return to base of assignment. As a daily screening procedure at Thule, nasal swipes were taken and immediately analyzed.

Rosters of personnel participating in Crested Ice were prepared at Thule, along with a letter to the individual advising him of the requirement to submit a 24-hour urine specimen to the Laboratory for analysis upon returning to his base of assignment. The Laboratory served as a clearing center to insure that each individual submitted the required sample and, of course, conducted the analyses. In-house analytical services provided results on urine samples for plutonium (^{239}Pu) and tritium (^3H), gross alpha counts on nasal and surface swipe samples, specific analyses for certain nuclides in water, soil, rock, snow plankton, dog hair, and air. Over 20,000 separate samples were processed between 22 January and 1 September 1968.



Robert Farr, Electrical Technician, and TSgt Donald Eudy processing nasal swipe samples.



Decontamination team monitoring barrels of debris.



SMSGT Lesly G. Leeder and Kenneth Blackburn begin initial steps in the processing of urine samples in the Laboratory at Wright-Patterson AFB, Ohio.

The results of these analyses are a tribute to the outstanding program designed and implemented by the On-Scene Commander and his staff. The nearly 800 urine samples were uniformly free of ^{239}Pu , indicating that no participant in the operation was internally contaminated with this radioactive material. Each sample was also analyzed for tritium. The highest value found was 1.29×10^{-6} curies. Studies have shown values as high as 30×10^{-6} are of no significance insofar as a health hazard is concerned. Of even greater significance are the results of the nasal swipes. Only 3.5% of the 10,000 analyzed showed any detectable alpha activity. The highest value found was 208×10^{-12} curies. The "action level" or point where internal contamination hazard becomes significant is 300×10^{-12} curies.

One hundred and ten water samples were studied for plutonium and tritium: 246×10^{-9} curies per liter of plutonium and 626×10^{-6} curies per liter for tritium were found. These samples were gathered from known areas of contamination, and the results were provided as additional data upon which to base operational decisions. Over 5,300 surface swipes were taken from vehicles, work areas, containers, etc. The highest level of activity of alpha particles detected was $33,000 \times 10^{-12}$ curies. Action levels were set at 200×10^{-12} and decontamination teams took necessary steps to clean up the contaminated surfaces.

Air samples were taken throughout the operation to insure safety to personnel. One hundred and seventy-nine such samples were analyzed. The highest value found was 23×10^{-9} curies per meter³.

In addition, miscellaneous type samples were assayed for radioactivity. Sewage, dog hair, and plankton from the ocean floor showed varying but insignificant amounts of alpha activity. Samples of snow heavily laden with JP-4 contained the greatest amounts of radioactive material— 991×10^{-6} curies per liter of ^{239}Pu and 7×10^{-6} curies of tritium per liter were detected in some of these samples.

SUMMARY

The Crested Ice operation demonstrated the advisability of having one unit with instant response capability for supplies, services, and personnel, able to respond in the event of a nuclear accident. The use of nasal swipes in lieu of routine on-site urine sampling resulted in simplified screening procedures on scene, reduced time to feed back results to decision-making levels, and permitted orderly collection of uncontaminated urine samples far removed from the environment of urgency and expediency that surrounds on-site activities. Deployment of limited Laboratory capability to the scene was very helpful in this case because of the fixed nature of facilities from which operations emanated.

Bagged and boxed ice cores ready for shipment.



Maj Joseph S. Pizzuto and helper bag ice cores for shipment.

INVESTIGATION AND EVALUATION OF CONTAMINATION LEVELS

HENRY L. GJØRUP et al*
Danish Atomic Energy Commission
Research Establishment Risø

INTRODUCTION

SHORTLY after arrival at the Thule Air Base on Thursday, 25 January 1968, the Danish Scientific Group was informed that the chemical explosives in the four nuclear weapons had detonated in the crash, and that their contents of plutonium had been scattered.

The main concern of the Danish group was, of course, to estimate the potential hazard to the inhabitants of the Thule region. Immediate consideration was given to a dogsled driver, Jessi Kujaukitsok, who had observed the accident from a position southwest of the crash site and had moved up to a position east of and close to the fire in order to look for survivors. As a man of common sense, Jessi Kujaukitsok had moved to the east of the big fire because the surface wind was blowing westwards; however, since he had been subject to the risk of contamination, he, his equipment and his home in Narssarssuk were carefully monitored. Results showed they were not contaminated. Monitoring of other persons and dogs that had been moving through the area, or to and from the crash site during the days after the accident, revealed only very slight contamination or none at all. It was, therefore, concluded that the radioactive contamination—mainly plutonium oxide dust resulting from the scattering and burning of plutonium metal in the weapons—was firmly attached to debris and to the crystals of the snow that covered the ice, and that there was no immediate risk of transfer of plutonium to the metabolic system of human beings. Anyhow the group considered it important to determine the distribution and amount of contamination in the environment and at the crash site, in order to evaluate the exposures which might have resulted from airborne contamination during the fire, and which in the future might result from the introduction of plutonium into the food chain.

METEOROLOGICAL CONDITIONS

The first step made to obtain a picture of the accident was to study the meteorological conditions at the time of the accident. On the basis of interviews with eye-

witnesses and meteorological and radar observations made at Thule Air Base, Professor O. Kofoed-Hansen concluded that the smoke cloud from the fire had probably drifted towards the south and southeast. The horizontal extent of the fire was about 800 m and the height of the fire column about 850 m. The smoke cloud rose even higher. The atmosphere was very stable up to a height of 830 m due to inversion. At greater heights up to 2,200 m the thermal stratification was still stable. At ground level a slight wind was blowing from the east. The wind direction veered counterclockwise with increasing height; at 1,000 m it was blowing from the north and at 3,500 m from the west. The wind speed was about 3 m/sec at all heights.

Although the finer particles would be carried far away and precipitated in very low, probably undetectable, concentrations, some measurable contamination could be expected in the direction of the hunting huts at Narssarssuk approximately 5 miles south of the crash site, where some 15 Greenlanders lived. Also some activity from the heavily contaminated blackened area might have been resuspended by the snow storms on 24 and 29 January and carried towards the west in the direction of Saunders Island.

ENVIRONMENTAL SNOW MONITORING

The next step was to organize an environmental monitoring program. The kitchen of an unused mess-hall was made available to the Danish group as a lab-



Figure 1. General view of the mess hall kitchen laboratory.

*Niels Edvard Busch, Physics Department, Hans Flyger, Jørgen Lippert, Herbert C. Rosenbaum and Asker Aarkrog, Health Physics Department, Heinz Hansen, Medical Laboratory, Helmar Kunzendorf and Leif Løvborg, Electronics Department, Bror Skytte-Jensen and Emil Sørensen, Chemistry Department.

oratory (Figure 1) and the first snow samples from the ice in the vicinity of Narssarssuk were collected by helicopter on 28 January. By very primitive means (oral counting of the clicks from an alpha-ratemeter and keeping time with a wristwatch) it was established that the snow samples from Narssarssuk contained long-lived alpha activity, whereas snow samples from the Thule Air Base contained no activity (samples of old snow) or only natural activity in the form of radon and thoron daughters (drift snow deposited by recent snow storms).

The laboratory situation was considerably improved when, by request, additional Risø staff, E. Sørensen and L. Løvborg, arrived on 30 January, bringing with them equipment that included a variety of chemicals, glassware, etc., a solid-state alpha detector, a scintillation gamma detector, a 100-channel pulse-height analyzer, a portable single-channel analyzer, and two alpha scalars. The only thing lacking was suitable evaporation equipment. A search in the Base Exchange revealed some Teflon-coated frying pans, which proved to be ideal for the purpose. They were responsible for the nickname "Operation Frying Pan" given to the activities of the laboratory. It soon turned out that standard analytical procedures were not suited to the actual circumstances, and Sørensen and Løvborg immediately

improvised a simple and adequate analytical procedure. The group was further strengthened when Erling Johansen from the Electronics Department and a specialist in environmental monitoring, and A. Aarkrog, arrived from Risø on 12 February, 1969.

The laboratory made it possible to make quantitative measurements. The snow sampling was intensified during the first days of February. It was carried out in a pattern planned in accordance with the existing possibilities of navigation on ice, hence most samples were taken from locations along straight lines. The ice was crossed by dogsleds driven by Greenlanders and by a truck from Dundas. Later on a belt-driven vehicle was loaned to the team by the base commander. The difficult and exacting sampling operations were carried out successfully, thanks to the skill of J. Zinglensen.

At each sampling location, six discs of snow with a diameter of about 15 cm and a thickness of about 3 cm were cut out using an empty sugar can. Before each sample was taken, the inner surface of the can was lined with a plastic bag folded over the edge of the can. In this way cross-contamination between samples was avoided.

The six snow samples from each location were bulked in the laboratory where they were melted and partially

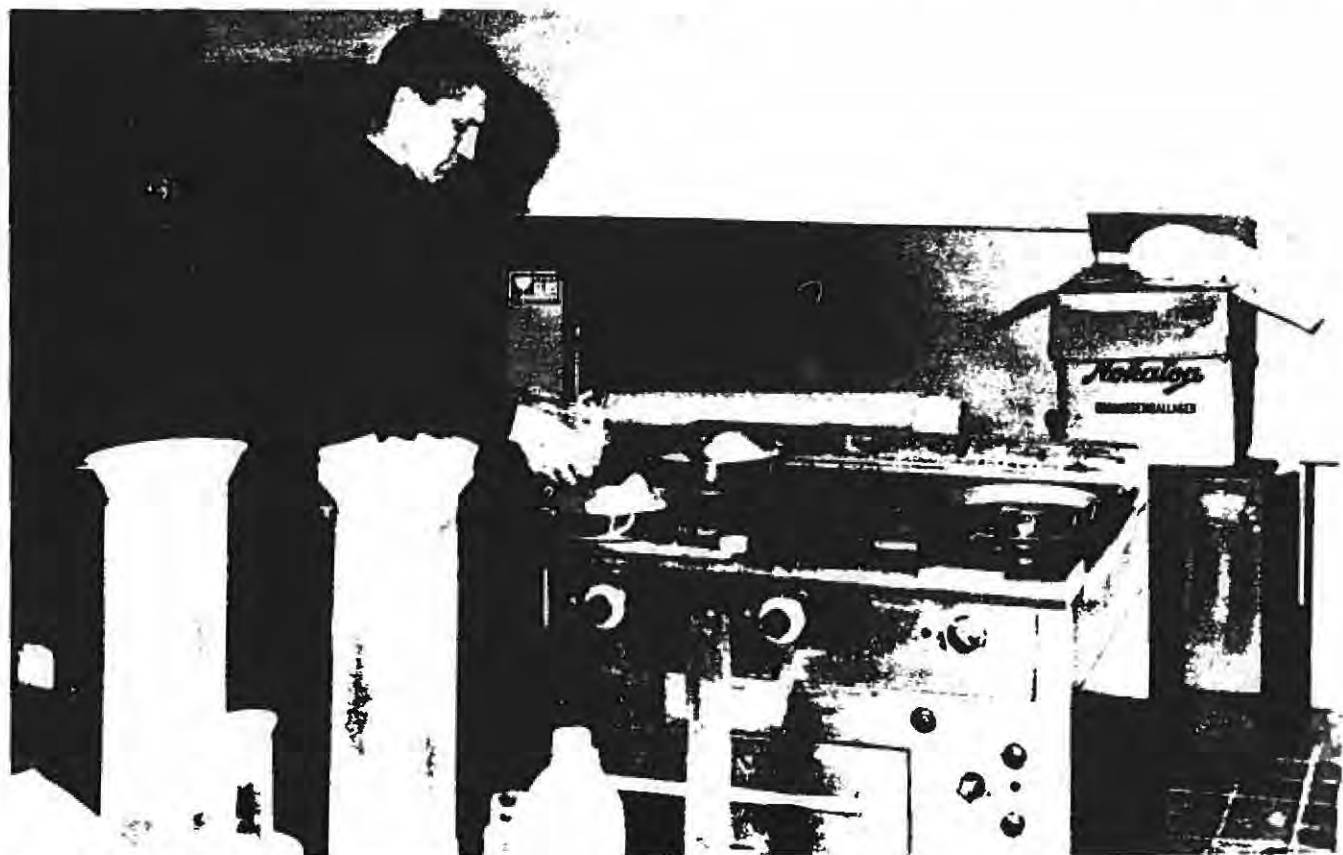


Figure 2. Melting and evaporation of snow samples.

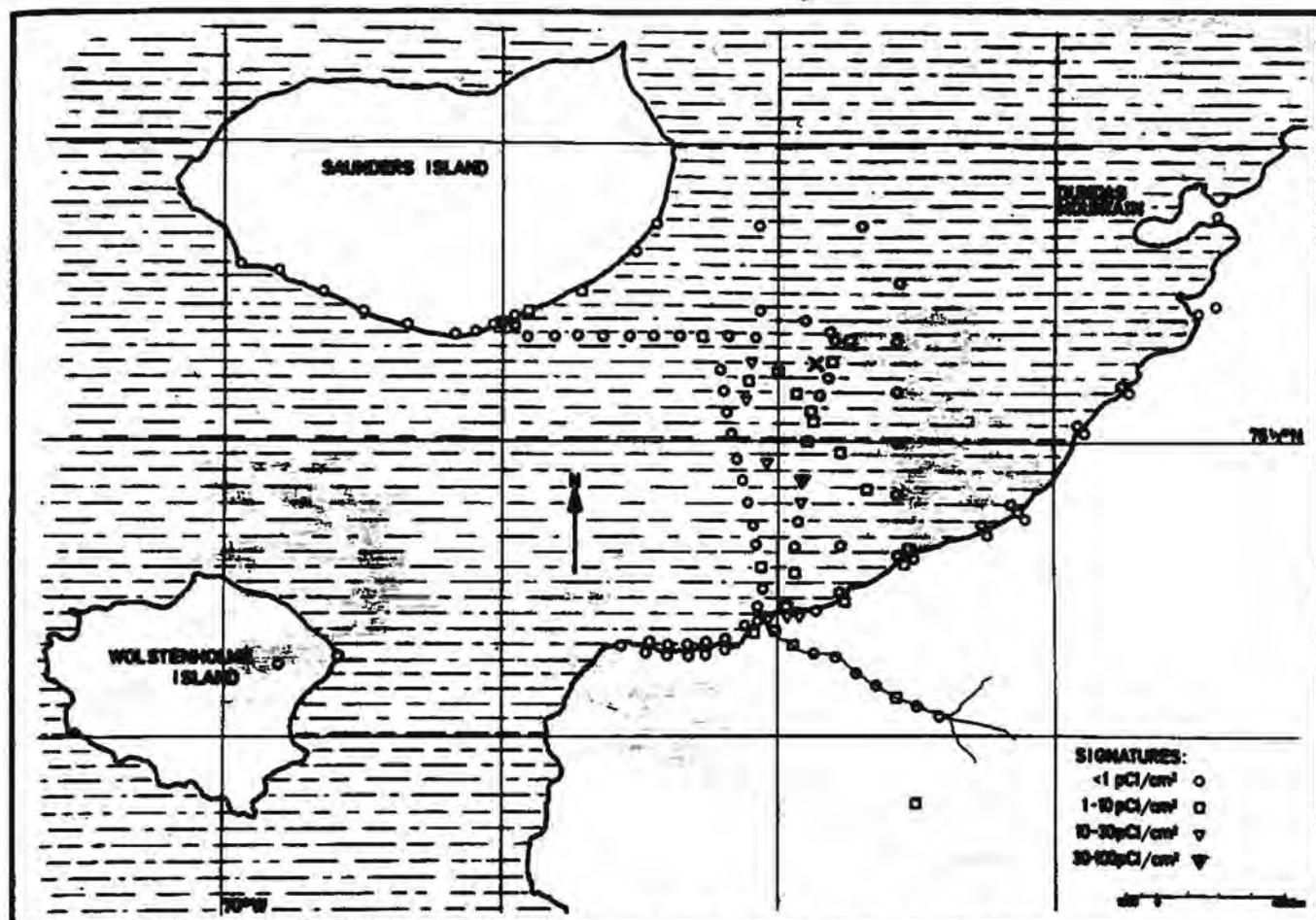


Figure 3. Map of the Bylot Sound area showing plutonium contamination levels. The point of impact is marked with a cross.

evaporated in the Teflon-coated pans (Figure 2). It was found that on filtration of the water from the melted sample through ordinary filter paper, usually more than 90% of the alpha activity was retained by the filter. The few exceptions to this rule were ascribed to the content of salt in some of the samples collected from the surface of the sea ice. After the filtration, each filter was incinerated and the ashes dissolved in HNO_3 . The solution was evaporated on a stainless steel disc, and the alpha activity of the disc was measured by alpha counting. By comparison with a standard, the countings were finally converted to contamination levels at the corresponding sample locations expressed as pCi of Pu 239 per cm^2 ($1 \text{ pCi} = 10^{-12} \text{ curie}$).

The sampling locations and the contamination levels (Figure 3) at these locations are shown on the map of Bylot Sound. The first samples were taken along the coastline from Thule Air Base to Cape Atholl in order to find the point of maximum contamination. As expected, it was found in the vicinity of Narssarsuk. However, the contamination at this point was quite low—only 24 pCi/cm^2 —corresponding to what is accepted in laboratories where the staff is allowed to work for a life-

time. The sampling was continued on the ice of Bylot Sound. The south coast of Saunders Island and the river valley extending inland from Narssarsuk towards the southeast were also sampled.

The program was completed on 18 February after more than 100 snow samples had been collected and analyzed. The contamination was found to be concentrated in two zones, one extending southwards and one westwards from the point of impact, presumably caused respectively by direct fallout from the smoke plume and by resuspension from the blackened area. Generally, the levels, including those quite close to the blackened area, were very low; only at a few points did they reach values of the same order of magnitude as at Narssarsuk. The highest value measured was 40 pCi/cm^2 , and the geometric mean of all samples was about 0.4 pCi/cm^2 . In comparison, the accumulated fallout of Pu 239 from weapon testing is about 0.1 pCi/cm^2 in the temperate zones of the northern hemisphere. It appeared that resuspension had occurred only to a very slight degree.

The total amount of Pu 239 contamination in the Bylot Sound area—outside the well-defined crash site—was estimated to be only 1-5Ci, and it was concluded

that this amount could be of no biological significance neither as a surface contamination nor as a contaminant of the waters of Bylot Sound later on when the ice cover would gradually melt.

For the sake of completeness it should be mentioned that snow samples from the ice that covered the lake supplying the Thule Air Base with water did not contain detectable amounts of plutonium. Nor was it possible to detect plutonium in samples collected from the base area, from Dundas and from Qanaq.

EVALUATION OF INHALATION EXPOSURE

Another point to be considered was the amount of plutonium that the population at Narssarsuk might have inhaled during the passage of the smoke cloud. Naturally no air sampling had been performed at that time, and since lung measurements are difficult (at any rate they could not be performed at Thule) the snow samples formed the only basis for an evaluation. The surface contamination is the product of the deposition velocity of the particles and the exposure integral, i.e., the integral of the air concentration versus time. The amount inhaled is the product of the exposure integral and the breathing rate. In order to make a conservative (pessimistic) evaluation, a very low deposition velocity

(corresponding to very small particles) was assumed and a maximum inhaled amount of $0.05 \mu\text{Ci}$ was arrived at. Even this amount was not considered to be harmful, and the actual value must be much smaller because the particles would have had to be much larger than assumed here in order to have reached the ground at this short distance from the ascending cloud. Moreover, these larger particles would not penetrate deeply into the lungs. The absence of any significant exposure was later confirmed by urine samples. It is difficult to take urine samples in a contaminated area without introducing extraneous contamination, which inhibits correct measurement, because only a very small fraction of the inhaled or ingested plutonium oxide is transferred to the urine. Some of the first samples were slightly contaminated, but later uncontaminated urine samples were collected from the Greenlanders in Narssarsuk—including Jessi Kujaukitsok—which showed that no detectable systemic body burden had resulted.

MONITORING OF BIOLOGICAL AND MARINE SAMPLES

It was considered important to get an impression as soon as practicable of the possibility of contamination through the local ecological system. The environmental



Figure 4. Three deepfrozen polar foxes are received at Risø for analysis.

snow samples were therefore supplemented by biological samples, including polar foxes (Figure 4), seals, walrus, and a dog. Christian Vibe and F. Hermann carried through the difficult task of sampling the seawater and the bottom of Bylot Sound at six different locations—some of them as close as 800 m to the point of impact—and down to depths of about 200 m. Samples of the sea bottom, snails, lugworms, plankton, and seawater were obtained. All these samples were shipped by air to Risø, where they were analyzed by Aarkrog, who returned to Risø on 20 February. Of special interest was a sample of faeces from sled dogs used for transport to and from the crash site. These dogs do not drink water, but eat snow instead. It was remarkable, and very reassuring, that the total quantity of faeces collected (50 g) contained only 100 pCi (10^{-10} Ci). All the other samples contained no significant activity.

COUNTRY-WIDE SNOW MONITORING

This article mentioned earlier that the smoke cloud rose to appreciable heights, and that the finer particles would be spread over long distances and precipitated in very low, and, in all probability, undetectable concentrations. In order to confirm this latter assumption, snow samples were collected by the Greenland Technical Organization from 25 locations all over Greenland, from Nanortalik and Prins Christian Sund in the south, to Dundas and Station Nord in the north. These samples

were analyzed at Risø and as expected they did not contain any activity significantly different from the fallout background.

PARTICLE SIZE DISTRIBUTIONS

As already mentioned, the size of particles containing plutonium was of interest in connection with the distribution of fallout from the smoke cloud, the evaluation of exposure integrals, and the penetration of particles into the lungs.

By means of an autoradiographic process an estimate of the size distribution of alpha-active particles in samples of snow from the blackened area, and in crushed and refrozen ice from the impact point was made at Risø by H. Flyger and H. Rosenbaum. Attempts were also made to determine the size distribution in snow samples from Narssarsuk.

Droplets of particle suspensions were deposited on glass slides, which had been freshly smeared with a thin layer of an epoxy resin. The preparations were placed in an oven at 100°C for 1 hour and afterwards covered with a nuclear emulsion stripping film. The total exposure times before development were 30 minutes for the snow samples and 120 minutes for the ice samples. Dark-field microscopy revealed the alpha tracks in the transparent emulsions, and, adhered upon the resin surface, the particles generating these tracks. The particles were sized with an ocular micrometer. Figure 5

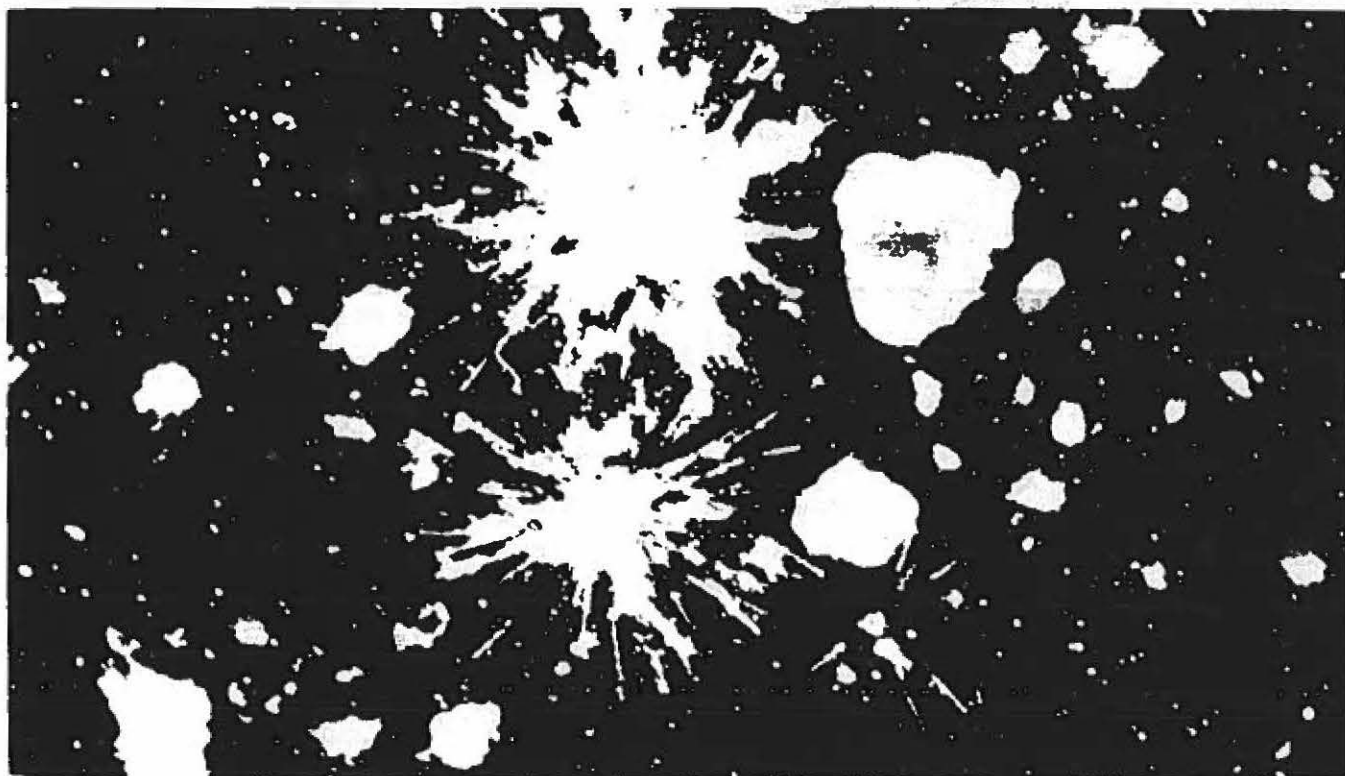


Figure 5. Microphotograph showing alpha tracks from plutonium particles in a sample from the crushed ice.

shows a microphotograph of some of the particles.

In the case of both snow and ice samples, particle distributions near to a straight line on log-probability paper were obtained. The snow samples gave a geometric mean particle diameter of 5.6 microns, and the ice a geometric mean diameter of 2 microns. The diameter of the smallest observed particles was 0.7 micron. The distribution curves were in each case based upon a count of about 100 particles.

The snow samples from Narssarsuk contained too few particles to make a determination meaningful. Meteorological considerations indicate that the fallout particles at Narssarsuk should be expected to have a diameter of around 20 microns.

MEASUREMENTS OF BLACK SNOW AND CRUSHED ICE

Although the total amount of radioactivity carried aloft with the smoke cloud and finally deposited on the ground could not be determined, it was obvious from the environmental monitoring program that the resulting concentrations were so small they could not in any way be considered harmful.

What remained to be done now with respect to district monitoring was to assess the amount of activity left at the crash site, in the black snow crust, on debris, and in the crushed ice. The first ice cores—3" in diameter and approximately 40" long—were taken by G. E. Frankenstein (U.S. Army Terrestrial Sciences Center) and B. Frstrup (University of Copenhagen) on 1 February. The cores were manually scanned with a single-channel gamma analyzer by Maj J. Pizzuto and Capt W. E. McRaney from the U.S. Air Force. The results and one of the cores were placed at the disposal of the Danish team. Soon afterwards Mr Frankenstein handed over a sample of snow from a point approximately in the center of the black patch. From rough measurements of these samples with the gamma-multichannel analyzer in the kitchen laboratory, it was estimated that the amount of Pu 239 remaining in the ice and on the blackened area was a few kilograms. This estimate was of course very uncertain because of the scarcity of samples available at that time, but later measurements showed that it was not too wide off the mark.

At the beginning of February a systematic ice core sampling program was started by the American Ice Reconnaissance Team. More than 180 ice cores were taken, and they were all scanned in the same way as those first obtained. All the scanning results and 12 representative ice cores were placed at the disposal of the Danish group. The problem of storing these cores in a secure, cool place was solved by the base commander, who allowed the old disused jail at Thule Air Base to be used for that purpose. On 12 February the cores were sent by air to Risø in plastic bags, packed in a wooden box lined with dry ice.

Meanwhile an apparatus for making continuous

gamma scanings was constructed by the Electronics Department at Risø, where H. Kunzendorf was performing the gamma measurements. Roughly this apparatus consisted of a 2 m-long plastic tube with a diameter somewhat larger than that of the ice cores and mounted in a heat-insulated wooden box placed on an iron frame together with a chain-driven feed mechanism for the ice core holder.

The ice cores were packed in an additional plastic bag to prevent contamination of the tube, and the box was filled with dry ice to keep the cores frozen. During the scanning process the cores passed the 10 x 50 mm slit of a 5 mm-thick cylindrical lead collimator, which surrounded a 2" x 2" NaI(Tl) integral-line scintillation crystal. The channel of a single-channel analyzer was set at 60 keV, the main photon energy emitted in the decay of Am 241, which was present as a decay product of Pu 241. The pulses were fed to a rate meter and to a recorder.

The box with ice cores was stored in the hot-cell building, and the measurements were carried out here to prevent contamination of the health physics laboratories, where low-level measurements were to take place.

The measurements of the 12 ice cores were repeated by setting the channel of the single-channel analyzer at approximately 17 keV, the energy of L X-rays emitted in the decay of both Am 241 and the Pu isotopes. The shape of the scanning curves was similar to that obtained when the channel was set at 60 keV, although a thinner scintillation crystal is to be recommended in this energy region.

A comparison between the American and the Danish gamma-scanning results from the same cores showed excellent agreement, and it was therefore possible to utilize the American scanning curves for other cores in the evaluation of the plutonium content of the crushed ice.

The determination of the actual content of Pu 239 in the ice core samples was carried out in two different ways. One way was to measure the content of Am 241 in concentrated samples by gamma spectroscopy and determine the ratio of Am 241 to Pu 239 by alpha spectroscopy. The other way was to determine the plutonium content directly by chemical separation and alpha counting. The gamma spectroscopy was carried out in the Electronics Department by Kunzendorf and Løvborg, who also performed the alpha spectroscopy in collaboration with J. Lippert of the Health Physics Department. The chemical separations were carried out by B. Skytte-Jensen of the Chemistry Department.

The problem of isolating the plutonium in the ice core samples was attacked by drawing on the experience of the analytical chemists at Eurochemic, Mol, Belgium, and on our own experience of solvent extraction with acyl pyrazolones.

The melted ice samples were first filtered through

fluted filters, and the containers were cleaned with pads of cotton. The filtrate was then passed through millipore filters, which allowed only insignificant amounts of α -activity to pass through. The plutonium was contained in a mixture of jet fuel, soot, silicone oil, and minute fragments of plastics and insulation materials from the aircraft. The greater part of the plutonium was in the form of very sparingly soluble plutonium oxide.

Thus the standard procedures for plutonium analysis were not applicable, and it was necessary to develop a new and rapid method.

The fortunate circumstance that a pyrosulphate melt rapidly dissolves plutonium oxides and quantitatively converts plutonium to the tetravalent state, and the fact that the acyl pyrazolones are capable of extracting tetravalent plutonium ions from sulphate-containing media were the basis for the method developed.

The combined filters and cotton pads were destroyed by treatment with hot nitric acid containing acid potassium sulphate (10 g); to this mixture 30% hydrogen peroxide was added cautiously to avoid excessive foaming. It was possible to speed up the destruction by the addition of small amounts of cupric salts. When the vigorous destruction reaction of organic matter had ceased, the mixture was evaporated to dryness in a quartz crucible and then heated to 300-400°C for 10-15 minutes whereby the acid potassium sulphate melted, forming a pyrosulphate melt. During this treatment the last traces of organic matter were destroyed. After cooling, the solidified melt was dissolved in 1 N nitric acid and an aliquot extracted by means of a 0.1-0.05 M solution of 1-phenyl-3-methyl-4-benzoyl-pyrazolone-5 in xylene.

The advantage of this reagent over commonly used extractants such as TTA, etc., is that it can effectively compete with sulphate ions for the tetravalent plutonium ions. A practically quantitative transfer of the plutonium to the organic phase occurred. Samples for alpha spectroscopy were prepared by the evaporation of aliquots of the organic phase on stainless-steel discs and subsequent heating to destroy any excess of reagent. The alpha spectra obtained were of excellent quality with well-resolved peaks.

A total analysis including destruction of organic matter could be made within 10 hours.

The result of the Risø measurements was that the crushed ice contained approximately 20 curies or 320 grams of Pu 239.

On 6 March, O. Walmod-Larsen, who had taken over the Danish health physics duties at Thule, shipped 16 samples of black snow from Thule to Risø. These samples were analyzed in the same way as the ice cores. Unfortunately they were not quite representative of the blackened area (60,000 m²)—especially samples from the most contaminated parts of the black patch were lacking. The Danish estimate of 70 curies (1200 grams) of plutonium in the black snow crust is therefore a mini-

mum value. The actual value was supposed to be two or three times as high, and is thus not in disagreement with the far more extensive American measurements made with the FIDLER (Field Instrument for Detection of Low Energy Radiation) instrument by the team from the Lawrence Radiation Laboratory.

The tritium content in the samples of black snow, where the concentration was appreciably higher than in the crushed ice, was measured at Risø by H. Hansen of the Medical Laboratory. The highest value measured was 47 mCi/m² or 2.7 mCi/l. This means that, as far as tritium is concerned, in a year a man might ingest the tritium contained in 5 sq. ft. of the black snow crust or drink 2 gallons of the undiluted meltwater without exceeding the maximum acceptable intake recommended by the ICRP for occupational workers. This is a farfetched example and even if the tritium concentration in places might be 10 times as high as the highest value observed, it was concluded that tritium could not be considered a hazard.

PENETRATION THROUGH THE CRUSHED ICE

For the following three reasons it was considered to be fairly certain that the amount of activity injected into the water through the crushed ice was relatively small. For one thing it was impossible to detect any activity in the bottom samples taken by Messrs Vibe and Hermann in February 1968. For another the activity in the contaminated ice cores was associated with straight dark bands in the ice. These bands appeared to be identical with the top layer of snow that had covered the original surface of the ice before it was broken up into blocks and pieces, churned around, drenched with water, and refrozen in random positions. Finally, the bottom 2 inches of the ice cores, which consisted of new ice formed after the accident, contained no floating debris, dark material, or jet fuel or oil, and no americium or tritium could be detected in this part of the cores. The cores taken outside or at the rim of the crushed ice were uncontaminated all the way through.

The radio-ecological investigations made during the summer of 1968 confirmed that the amount of activity in the marine environment was quite small.

CONCLUSION

The amount and distribution of plutonium in the Thule area after the accident was such that it could not be assumed to be of significance to the health of the inhabitants. As a consequence of the decision to remove the black snow crust—made at the meeting in Copenhagen on 15 and 16 February between U.S. and Danish officials and scientists—the amount was substantially reduced. Even so it was decided to make a radio-ecological investigation in the summer of 1968 to confirm the above mentioned assumption, and to exploit the opportunity presented here to obtain new knowledge about the radio-ecology of plutonium.



THE area of the B-52 accident is situated in the middle of the Thule district which stretches from Melville Bay to the Kane Basin. As of 1 January 1967, this area was inhabited by 538 natives as well as a small number of Danish officials. (This does not include Dundas and Thule Air Base.) These people's only way of living is hunting seals, walrus, narwhals, white whales, foxes, polar bears, and seabirds. There are only two settlements near the site of the accident: Narssarssuk, on the southern side of Bylot Sound, with two families, and Maniussak on the northern side Wolstenholme Fjord with 6-8 families.

Below is a survey of the mammals, birds and lower animals which form part of the food chain in this area, that are of interest in the B-52 case.

LOWER ANIMAL SPECIES ON THE SHORE.

The beach is made up of rocks, here and there broken up by flat areas of sand, pebbles and stones mixed with clay. In the ebbing zone between the high and low tides, only very few lower animal species are found; important are amphipods *Gammarus* and *Pseudalibrotus*, the *Margarita* snail and the bivalves *Mya*, *Saxicava*, *Modiolus*, and more rare *Mytilus*.

During low tide, these animals hide under stones in rock crevices or under seaweed, which is only visible during low tide.

LOWER ANIMAL SPECIES ON THE SEA BOTTOM.

The sea bottom in North Star Bay and in the fjord consists of very fine clay, which in some places near the

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BACKGROUND

coast is mixed with sand and pebbles.

Bottom animals are found in the bottom material and on the bottom surface from the water's edge down to the greatest depths in the crash area, approximately 235 meters (approximately 771 feet).

In 1936, at a depth of 14 meters (approximately 46 feet) in the bay itself near Dundas, 41 lower animal species were demonstrated, among them eight species of bivalves, but the fauna is far richer than this as later investigations have revealed. In 1939-41, near Saunders Island and northward in the vicinity of Inglefield Fjord, at depths between 0 and 54 meters (0 to 177 feet), 151 lower animal species were found to be living on the sea bottom and in the free masses of water, including 20 species of bivalves, 23 species of snails, 16 species of Poly-

chaeta and species of Crustacea, as well as several species of Echinodermata and corals. On the walrus banks the density of bottom animals amounted to 450 grams per square meter.

SEA PLANKTON.

The production of phytoplankton begins in the spring with the return of sunlight and the dispersion of the ice. It can be extremely abundant, especially near the birds cliffs on Saunders Island, where the sea is fertilized by bird excrement.

Zooplankton can be found the year round from the bottom to the surface. In winter, the greatest amount is found near the bottom, where the water is warmer and saltier than at the surface under the ice. The zooplankton thus consists mainly of *Sagitta*, *Aglantha*, but also *Calanus* occurs numerously. In the summer, there are several species of *Medusas*, *Stenophores*, *Pteropods*, *Euphausians*, *Copepods*, *Amphipods*, and fish larvae, and at the lower depths *Amphipods* and *Mysis* are found in large quantities along the beach.

THE IMPORTANCE OF THE LOWER ANIMAL SPECIES IN THE FOOD CHAIN.

The phytoplankton is consumed by zooplankton animals as well as by many of the bottom animals.

The zooplankton is eaten by many lower sea animals as well as, in particular, by the *Boreogadus saida*, the little auk, and certain other seabirds.

The littoral fauna is eaten by various waders, sea gulls, ravens and white and blue foxes.

The sea bottom bivalves are eaten by the walrus (in depths of 5 to 80 meters [16 to 262 feet]), and by eiders and long-tailed ducks (in the lower depths), as well as by man who occasionally collect *Mytilus* and *Mya* along the beach during the lowest ebb. Man also eats undigested bivalves (*Cardium*, *Mya* and *Saxicava*) from the stomach of the walrus.

The larger species of Crustaceans (*Euphausia*, *Themisto*) in the zooplankton are eaten by ringed seal. The larger species of Crustaceans on the sea bottom (*Amphipods*, *Decapods*) are eaten by ringed seal and narwhal, the smaller ones by the eider, and the long-tailed duck (in lower depths).

FISH.

The *Boreogadus saida* occurs in large quantities in the water area between the bottom and the surface, according to where the most food is to be found, especially plankton. There are a number of species of bottom fish of the families *Liparidae*, *Lycodidae*, *Cottidae*, et al., the more rare *Reinhardtius hippoglossoides* and *Somniosus microcephalus*, and in July and August *Salvelinus alpinus*.

During the winter, the Greenlanders catch some *Reinhardtius hippoglossoides* from the ice, but only in the south at Melville Bay and northward in the Inglefield

Fjord. *Salvelinus alpinus* is caught during the summer in McCormick Fjord, more rarely in other places. A few *Somniosus microcephalus* are caught through holes in the ice for dog food, and *Coregonus* is likewise caught during the spring for the same purpose.

There is no commercial or shrimp fishing in the Thule district.

WHALES.

The white whale and narwhal usually occur in the Thule district and are caught by the population from June until October. During the winter some whales stay in the ice free water of Baffin Bay, but the majority migrates to the south.

In rare cases, the Greenland whale (Bowhead) is observed during the spring, while the killer whale occasionally appears in herds during the summer, usually in the Inglefield Fjord. These whales rarely go into North Star Bay. The most important hunting ground for whales is Inglefield Fjord.

The white whale lives on *Boreogadus saida* and *Reinhardtius hippoglossoides*, the narwhal furthermore feeds on the larger *Crustaceans* of the sea bottom.

The Greenlanders eat the skin of whales (mattak), as well as the meat, blubber, heart, kidneys and liver.

SEALS.

The seals found in the Thule district are the walrus, the bearded seal, the ringed seal, and the harp seal.

The walrus is one of the most important animals hunted in the Thule district—a couple hundred are

caught each year. The meat, liver, diaphragm, kidneys and heart are consumed, and at times also some of the contents of the stomach (bivalves).

The most important feeding ground for the walrus is the stretch between Cape York and Etah, where it stays within the outer coast where the depths do not exceed around 80 meters (approximately 262 feet), and where the bottom consists of pebbles mixed with clay inhabited by bivalves (*Cardium*, *Mya*, *Saxicava*, *Macoma* and *Astarte*). It also often eats ringed seals.

The walrus spends the winter in the northern district (Inglefield Fjord) and stays out along the edge of



Greenlander walrus depot on the southern beach of Saunders Island, summer 1968.



A small section of contents from a walrus' stomach. This walrus has foraged at 70-80m depth. (Top to bottom): Rows 1 through 5 are siphons of *Saxicava arctica*; Rows 6 through 9 are of *Mya truncata*; Row 10 contains 1 foot of *Cardium greenlandicum*, 2 of *Macoma calkari*, 10 of *Astarte borealis*, 1 of *Cucumaria*, 1 *Priapul* and 1 *Psolus*.

the ice. It does not go up through ice which is thicker than about 10-15 cm., and it does not go down to depths greater than approximately 80 meters (approximately 262 feet). Thus, the walrus does not occur in the area of the crash where the ice in January is 80 cm (31 inches) thick and the depth is 235 meters (approximately 771 feet).

During the month of July, walrus swarm up from the south. They stay along the outer coast and rarely come closer into the fjord than to the eastern tip of Saunders Island. By end of July they continue northwards to Murchison Sound and the shores of Smith Sound.

The bearded seal is common in the Thule district during summer and winter and is eagerly hunted by the population. They eat its heart, kidneys and liver, and cut up the skin for straps and harpoon lines and the like. The bearded seal eats everything except bivalves. Its most important food is the *Boreogadus saida*, *Cottus* and other fishes from the sea bottom, as well as large snails (*Buccinum*) and *Crustaceans*, but also animal species such as *Cucumaria*, *Psolus* and *Rossia*. During the summer it lives all over in the fjords, but during the winter only near the outer coast, since it cannot maintain its breathing-hole open through ice thicker than 20-30 cm (ap-

proximately 8 to 12 inches). Therefore, bearded seals were not in the impact area at the time of the crash.

The ringed seal is the most common seal hunted in great numbers by the Greenlandic population. It occurs in the sea and in the fjords both summer and winter, and it can keep its breathing-hole open through 1 to 2 meters (approximately 3 to 6½ feet) of ice. Its food in the Thule district consists mainly of the *Boreogadus saida* and other fish, but also *Crustaceans* constitute an important part of its nourishment. This seal is found in the area of the accident, winter and summer. From April until June, ringed seals can be seen lying on the ice next to the breathing-hole. They sleep here during the warm-

est hours of the day, but only for brief periods at a time. When the ice drifts out, most of the ringed seals move to the glacier edge of Wolstenholme Fjord, where the seal hunting then takes place.

During the month of June, the harp seal comes in swarms from the south where it breeds on the drift ice off Newfoundland. Its most important habitat in the district is Inglefield Fjord between Qanaq and Siropaluk, but it can be found in smaller numbers everywhere. It feeds on fish and *Crustaceans*. It leaves the district with the beginning of the ice formation in September and October. During the time it is available, the population hunt it a good deal. They eat its meat, liver, heart, and kidneys.

The bladdernose and harbor seal are very rare summer guests.

BIRDS.

Only the most important species are mentioned here.

The little auk (*Plotus alle*) occurs by the millions in the mountains from Cape Atholl and southward to Melville Bay, as well as on the island Kiatak and on the northern coast of Murchison Sound as far north as Etah. It arrives at the end of April and goes into the mountains to breed in May. It lays its eggs under the stones in the scree along the coast and high up in the mountains far inland. It leaves the mountains late in August. Its nourishment consists of plankton (*Calanus*). It can be found at the beginning of the summer in small flocks everywhere where there is open water. Later in the summer it goes further out to sea. It serves as the chief food for the Arctic fox during the summer. In May and June the Greenlanders catch it in nets and collect its

Stomach content of a bearded seal from Neqa. (Top to bottom): Row 1 shows 8

Decapoda, 1 *Anonyx nuxar*, 1 *Nothella maxima*, 1 *Arcturus borealis*, and 1 *Rossia*. Rows 2, 3, and the left half of Row 4 shows 26 *Buccinum* sp. The right half of Row 4 and Rows 5 and 6 show 49 shell lids of *Buccinum* sp. Bottom Row shows same intestinal parasites, parts of 1 *Gadus saida*, 2 beaks of *Rossia*, 2 otolith of *Gadus saida*, and 3 *Lycodes* sp.



Stomach content of a bearded seal from Neqa. (Top to bottom): Row 1 shows 8 Decapoda, 1 *Anonyx nuxar*, 1 *Nothella maxima*, 1 *Arcturus borealis*, and 1 *Rossia*. Rows 2, 3, and the left half of Row 4 shows 26 *Buccinum* sp. The right half of Row 4 and Rows 5 and 6 show 49 shell lids of *Buccinum* sp. Bottom Row shows same intestinal parasites, parts of 1 *Gadus saida*, 2 beaks of *Rossia*, 2 otolith of *Gadus saida*, and 3 *Lycodes* sp.



Eider eggs and down

eggs, in August they catch the young ones before they can fly. The catching of the young is done by women and children who crawl around amongst the stones and pebbles of the scree and roll the stones down, thus exposing the young. Life expectancy is approximately 8 years or more. For the most part, the little auk from the Thule district spends the winter in Newfoundland.

The Brünnich's guillemot (*Uria lomvia*) breeds in quantities on the western side of Saunders Island, but also in several other places in the district. There would be a few of them to be found in the crash area during the summer. Their food consists mainly of *Boreogadus saida*, but they also consume larger planktonic *Crustaceans* (*Themisto*, *Thysanoessa*). Their life expectancy is up to 16 years or more. The eggs are collected in the bird cliffs, and the birds are shot in numbers both in June and July when they come into the crevices of the sea ice, and during the summer in the bird cliffs, and on the sea south, west and north of Saunders Island. They seemingly spend the winter in central west Greenland and in Newfoundland.

The black guillemot (*Cephus grylle*), can be found during the winter in places with open water owing to currents in and along the ice edge. It breeds in the scree along all of the coasts. Its food consists

mostly of *Crustaceans*, especially *Mysis*, but also of smaller fish. It is shot a good deal along the coast, especially in the spring along the crevices in the ice. During the summer it is common along all the coasts around the area of the accident.

The glaucous gull (*Larus hyperboreus*) breeds in many places in the Thule district. It arrives early in the spring, while the sea ice is still there. It has its nests on the mountain ridges on Saunders Island, but also in many other places. It begins to lay its eggs in May. Its food is varied and is searched for everywhere on the ice, along the beach and in the mountains: other birds' eggs and young (especially the little auk), carrions, beach debris, fish, *Crustaceans*, snails, bivalves, berries in the mountains, etc. During the entire summer, it can be seen searching the beach and taking what it finds. It is shot a good deal, especially the young, in August and September. It spends the winter along the coast of West Greenland. Its life expectancy is approximately 20 years.

The kittiwake (*Rissa tridactyla*) breeds several places in the mountains of the outer coast. Its most important food is small fish and plankton, which it finds on the surface of the sea. It spends the winter on the Atlantic Ocean, especially off Newfoundland, but it can also roam about. It is shot to some degree during the summer.

The eider (*Somateria mollissima*). Some eiders spend the winter beyond the ice edge, but the majority leaves during the winter and returns in early spring when crevices begin to form in the ice. They can thus be found in crevices and openings in the ice along the coast, especially around certain breeding islands, of which the closest are Eider Islands, Dalrymple Rock and Manson Islands. The eider's food consists mostly of bivalves and snails, which it eats from the lower bottom depths, but it also eats pteropods in great quantities. Some eider hunts are carried out during the summer, but the collecting of eggs and eiderdown is of the greatest importance, although this is only allowed on one occasion at each breeding place before 1 July, after which access to the islands is prohibited. The collecting of eiderdown is again carried out at the deserted nests after August 10. *The collection of eiderdown and especially its cleansing is a dust-making process.* The population does the rough work of cleaning themselves, while the fine cleaning is done at Upernavik. The eider from Thule spends the winter outside the ice edge between Godhavn and Sukkertoppen.

The king eider (*Somateria spectabilis*) has a similar way of life as the eider, except that it breeds near the inland fresh water lakes. But when not breeding, it also gets its food from the lower sea depths. Eiderdown is not collected from the nest of the king eider.

The long-tailed duck (*Clangula hyemalis*). This bird breeds near the inland lakes, but during the spring and summer it frequents the sea along the coast where its food consists of Crustaceans, bivalves, (*Modiolaria*, *Mya*, *Macoma*, *Saxicava*) and snails (*Margarita*). It is rarely shot in the Thule district, although more are shot at its winter residence. It spends the winter for the most part along the coast of West Greenland, but birds from Greenland can also be found in the northern areas of the entire world, including Denmark.

Waders in small numbers frequent the beach where they search for food during their autumn migration in August and September: Turnstone (*Arenaria interpres*); Bairds sandpiper (*Calidris bairdii*); purple sandpiper (*C. maritima*); knot (*C. canutus*); ringed plover (*Charadrius hiaticula*); and the red-necked phalarope (*Phalaropus lobatus*). The waders live on the amphipods, snails, bivalves and insects from the beach.

Falcons. Both the gyrfalcon (*Falco rusticolus*) and the peregrine falcon (*Falco peregrinus*) are breeding in a few places in the district. Their food consists of other birds, especially little auk, Brunnich's guillemot, gulls and ptarmigan.

The Ptarmigan (*Lagopus mutus*) breeds in small numbers inland. It feeds on plants, especially willow buds during the winter. It spends the winter in the district.

The raven (*Corvus corax*) is common everywhere both in summer and winter. It is particularly numerous around the dumps at the base. It seeks its food every-

where on the sea ice, along the coasts and on land, and collects objects and flies around with them and consumes everything edible: Carrions, birds, eggs, fish, Crustaceans, snails, bivalves, berries, fox excrement, etc. Many young birds are shot at the end of the summer, and the raven is often caught in fox traps. It is tasty and eaten with great pleasure.

LAND MAMMALS.

The Arctic fox (*Alopex lagopus*) occurs both as a blue fox and as a white fox. It is common throughout the district, but is particularly numerous in the base areas and in the little auk cliffs around Cape Atholl and southward. During the winter a varying number of white foxes come in from Ellesmere Island. These are larger than the Thule fox. During the summer, the fox lives mostly on little auks (*Plutus alle*), but it also seeks food along the shore, where it eats snails, bivalves, Crustaceans, fish, seaweed and dead animals. In the mountains it collects berries: *Vaccinium uliginosum* and *Empetrum nigrum*. During the winter, the fox wanders around a good deal and collects whatever it can find on the ice, and along the tidal cracks of the beach. It feeds on dead birds, berries and plants in the mountains, and at Thule base, particularly on garbage from the dump.

The fox and man: The fox is shot or caught in traps at a rate of 1000-1500 yearly in the entire district. The hunting season is from September to March 31. The fox is taken home, thawed and skinned by the women. The skinning begins at the mouth, and the entire body of the fox is taken out through the animal's mouth. *During the skinning and working of the hide, the women use their lips and teeth to a great extent.* Before World War II, the meat of the fox was always eaten after having been cooked for a very long time. It must be supposed that this still holds true. The inner organs are not eaten. Few foxes live to be more than 2-3 years old.

The polar bear (*Ursus maritimus*) is an occasional guest in the populated Thule district. One to two bears wander through the crash area per year. The polar bear may also be found hibernating in the district, either on the islands or on the mainland. The real bear hunts take place at Melville Bay, Kane Basin or on the sea ice off Ellesmere Island. The most important foodstuff for the polar bear is the ringed seal. Between 20 and 25 bears are shot annually. The meat, except for the liver, is eaten, and the fur is used for trousers. The life expectancy of the polar bear is 30-40 years.

The hare (*Lepus variabilis*) is found on the islands and mainland, especially in the little auk cliffs where there is good grass vegetation. Its most important food is grass, herbs and willow branches. It is shot in small numbers. Its meat, heart, lungs, liver and kidneys are consumed.

The caribou (*Rangifer tarandus*) is not found in the immediate vicinity of the base. A few are to be found in Olriks Fjord.



Bottom sampling is seen on the ice placed on a plastic sheet to avoid contamination (middle left). The snowmobile was used for transportation as well as for hoisting the grab.



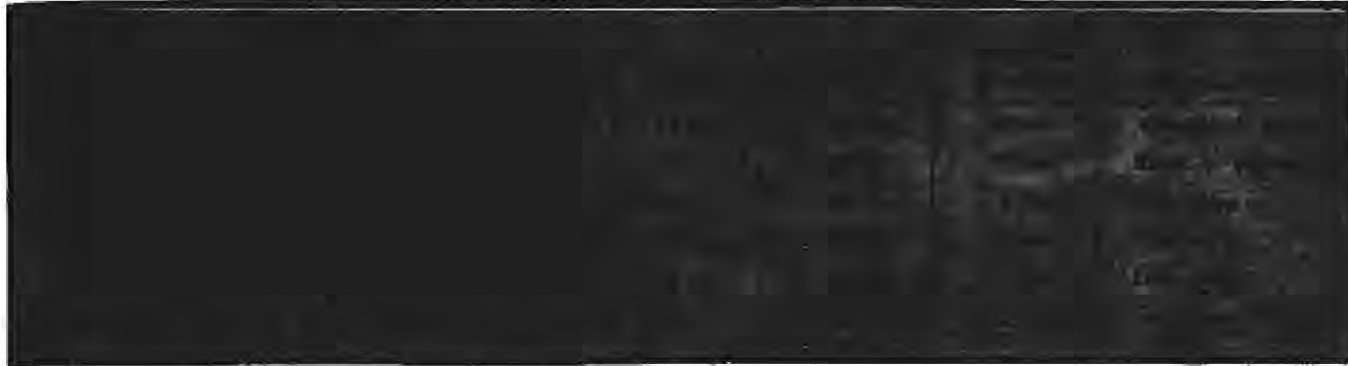
The water sampler is hoisted on board AGLANTHA.

ECOLOGICAL SURVEY

SAMPLING IMMEDIATELY AFTER THE ACCIDENT

SOON after their arrival at Thule, the Danish Scientific Group realized that the sea ice had been broken through by the disintegration of the bombs and that some of the released plutonium might have ended up in the water and on the bottom of the sea. An examination of water, plankton, bottom material, bottom animals, and marine mammals of the area was therefore considered necessary in order to establish to what extent a danger might be present for the native population through contamination of the various links in the food chain.

As such an examination had been anticipated, a bottom sampler and a water sampler had been brought along from Denmark. For the practical performance of the examination the base made two weasels and their crews available with Capt William McRaney in charge



on 7th February and Capt Wallace A. Warren on 9th and 11th February. The Danish leaders of the operations were H. Gjørup, F. Hermann and Christian Vibe.

Examinations were made at six stations on the sea ice. Three stations were placed from the southern side of the fjord and outwards towards the area of impact, the remaining three stations were placed some 100 meters west, north and east of the crash site.

At each station six snow samples were taken on the ice, two water samples close to the bottom, one plankton sample from bottom to surface, and one sample of 1/10 m² sea bottom including bivalves, snails, worms, etc. In addition, samples of the bottomside of the sea ice were taken at stations 3 to 6.

The low temperature of the air made the samples freeze immediately, so plankton and bottom samples were taken to the laboratory in a frozen condition in plastic bags. Each bottom and plankton sample was divided into two; one of which was handed over to the American health physicists, and the other still frozen was brought home for analysis at Risø Research Establishment.

In addition to these samples from the area under the ice, samples of the animals of the area: ringed seal, walrus, Arctic fox, and dog, were procured with the assistance of Jens Zinglensen. These samples were flown to Denmark and examined at Risø Research Establishment.

When the winter samples were collected the entire area was covered by ice and snow. Further sampling had to await the disappearance of the sea ice when an entirely new situation would exist.

SUMMER ECOLOGICAL EXPEDITION

In the spring of 1968 the Danish Atomic Energy Commission decided to dispatch the fishery research cutter AGLANTHA as operational vessel for a scientific team, who were to determine the extent of the consequences that the spreading of plutonium might have had for the ecology of Bylot Sound. The tasks of the team were:



The beach on the north side of Wolstenholme Fjord is searched for possibly contaminated debris.

- To collect samples of seawater, bottom material, bottom animals (food elements for walrus and bearded seal), *Crustacea* (food elements for little auks, narwhals and seals), fish (food elements for several sea birds), mussels and other invertebrates from the littoral zone (food elements for arctic fox and eider), sea birds, marine mammals, seaweed, lichen, eiderdown, and dust.
- To investigate the shores of Saunders Island, Wolstenholme Island, the Eiderduck Islands, the Manson Islands, the southern shore of Bylot Sound, and the northern shore of Wolstenholme Fjord.

The samples were collected in three zones. Zone 1 was bounded by a circle with its center in the point of

impact and a radius of 1 km, Zone 2 consisted of Bylot Sound and Wolstenholme Fjord, Zone 3 (control zone) of the region between Cape Parry and Qanaq.

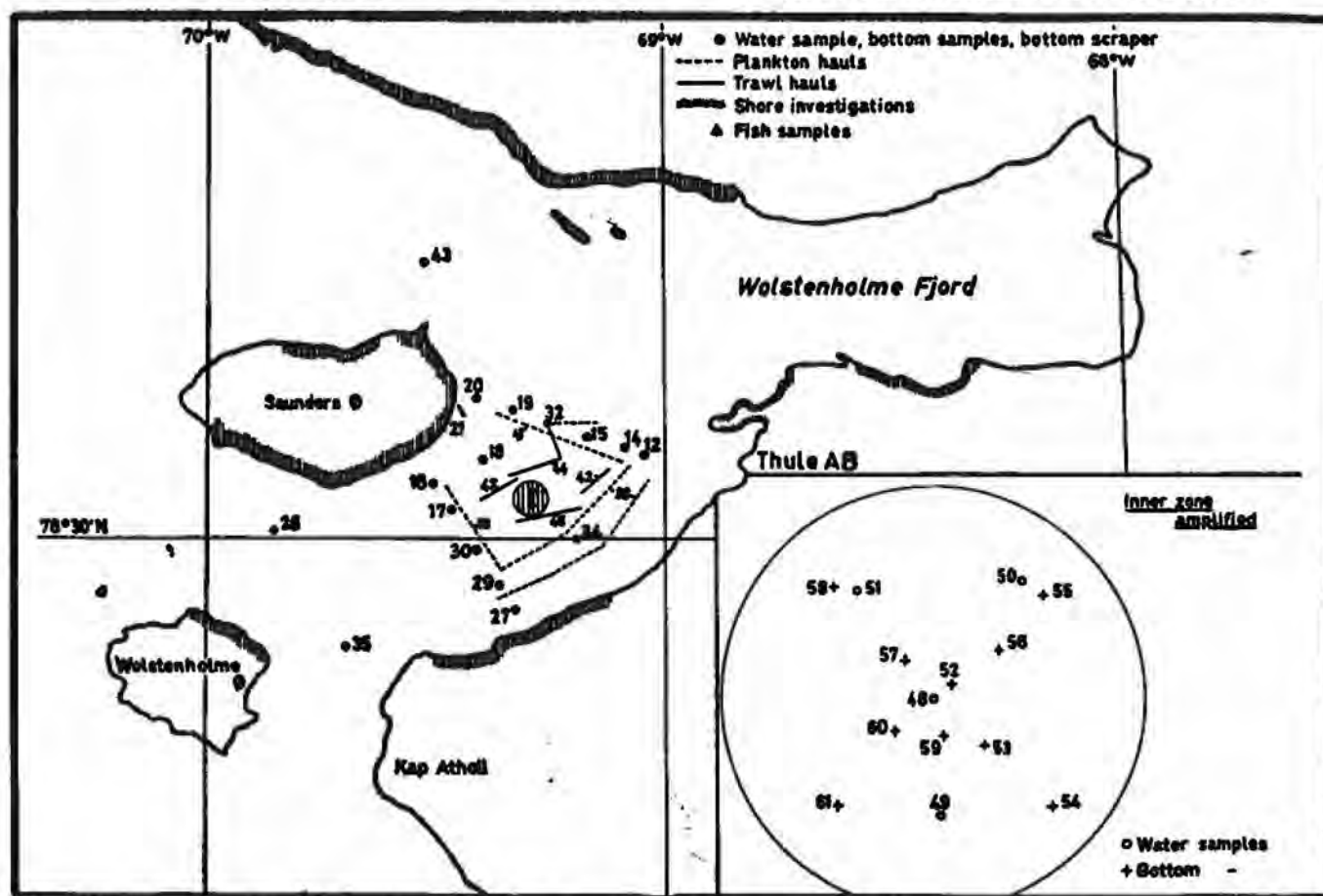
The implements necessary for the investigation were made in the spring at the Risø workshops with valuable assistance from Robert Jensen.

The Danish group consisted of health physicists from the Risø group at Thule (see Mr Walmod-Larsen's article); Messrs G. Jensen and P. Kristiansen, assistants from Risø; Frede Hermann, hydrographer from the Danish Institute for Fisheries and Marine Research; and Jean Just and Christian Vibe, Zoologists from the Zoological Museum of the University of Copenhagen. Professor Jørgen Koch visited the group during the field work at Thule and participated in the investigation for some days.

The Danish ecological group arrived in Thule on

The map below shows the sea stations where samples of water, sea bottom, and animals were collected. These comprised:

- 250 water samples from bottom to surface, collected for hydrographical purposes at 22 stations.
- 4 water samples, each of 100 litres, from Zone 1 (the impact area).
- 14 water samples, each of 50 litres, from Zone 2 (outside the impact area).
- 10 samples of bottom material from Zone 1.
- 10 samples of bottom material with animals, including bivalves, from Zone 1.
- 14 samples of bottom material from Zone 2.
- 25 dredge hauls for bottom animals at 14 stations in Zone 2.
- 6 trawl hauls for *Crustacea* and fish in Zone 2.



Map showing the sea stations where samples of water, sea bottom, and animals were collected.

24 July 1968. On the same day W. C. Hanson, Department of Biology, Ecology Section of the Hanford Laboratory, U.S.A., joined the group with the special purpose of collecting lichens on the coasts of Bylot Sound. The fishery research ship AGLANTHA arrived on 1 August, and the scientific equipment arrived on the PERLA DAN on 8 August.

- 16 plankton hauls in Zone 2.

In addition, the team collected seven seals, six walrus, two eiders, five guillemots in Zone 2 and four in Zone 1, six black guillemots, eiderdown from the Manson Islands and from the Eiderduck Islands, excrements from about 30 eiders on Saunders Island, dust from Saunders Island, Wolstenholme Island and Narssarssuk.

seaweed from Narssarsuk, the north coast of Wolstenholme Fjord, the north coast of the Dundas peninsula, and from Thule (Qanaq), lichen from Narssarsuk, Wolstenholme Island, the southern, eastern and northern shores of Saunders Island, Nunatarssuak, Cape Atholl, the northern shore of Wolstenholme Fjord, Herbert Island, and Inglefield Fjord near Thule (Qanaq). In addition, Mr Hanson collected samples of lichen from a great number of shore stations round the area of impact. Numerous samples of sea and bottom animals were collected for scientific purposes from Bylot Sound, Whale Sound and Murchison Sound.

The surveillance of shorelines was carried out on foot. American helicopters and cars were used for transportation to and from the investigation areas. The map shows the stretches of coast examined for wreckage from the B-52. Nothing was found.

Greenlanders from Maniussak found flat pieces of wood from two huts in the camp by the point of impact on the sea ice, which washed ashore at the northeast point of Saunders Island. A black flag on a short bamboo stick—the same kind as those used to mark the area of impact—was found on the southern side of the island. A few long bamboo poles—used to mark the driving lanes on the ice—were found washed ashore on the south coast of Bylot Sound, on Wolstenholme Island, on Saunders Island, and on the north coast of Wolstenholme Fjord. They were found to be clean from radio activity.

Greenlander equipment found in depots on the shore, driftwood and other flotsam that washed ashore were tested for contamination and found negative.

An exception was the remains of a helicopter crash, several years old, the ashes of which showed some radium activity originating from the luminescent coating of the instrument dials.

The Greenland villages Narssarsuk and Maniussak, as well as the hunting huts on the Manson Islands and Saunders Island, were tested for contamination and found negative. Some urine samples from Greenlanders at Narssarsuk were taken to Risø for testing. These Greenlanders hunted in the vicinity of the impact area.

All collected material was taken to Risø. The zoological and hydrographic samples were forwarded to the Zoological Museum and the Danish Institute for Fisheries and Marine Research.

The ecological group finished its work on 26 August 1968.

The last day at Thule Air Base the members of the ecological group were shown a recording of the bottom survey conducted by Lt Col Marshall E. Neal.

During their stay at the Thule Air Base the Danish scientists received prompt and valuable assistance from the Thule Air Base Commander, Col C. S. Dresser, as well as from all other American personnel at the base, especially the helicopter pilots Maj Frank Schnee, Maj Charles Simmons, Maj Sam Scamardo, and TSgt G. R. Matthews.



The remains of an old helicopter found on the southern shore of Bylot Sound.



The zoological material from the sea bottom and lichens gathered in the summer of 1968.

The purpose of the radio-ecological study was to determine whether plutonium was present in the environment in concentrations which might be harmful to man and animals and to collect information on the radio-ecology of plutonium.

RADIO-ECOLOGICAL INVESTIGATIONS

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INTRODUCTION

DURING the first week after the accident, environmental samples of seawater, bottom sediments, and zooplankton were collected from holes drilled through the ice in Bylot Sound (see Christian Vibe's articles titled "Ecological Survey"). Most of these samples showed no or only a small Pu 239 content; however, a few samples showed levels significantly above background. As it was extremely difficult to ensure that the marine samples collected in the early period had not been contaminated by surface snow (which contained Pu 239 in most cases), it was decided to make a more detailed radio-ecological study of the environment in August, when the ice had broken up in Bylot Sound.

The purpose of such a study was to examine whether plutonium was present in the environment in concentrations that might be harmful to man and animals, and to collect information on the radio-ecology of plutonium, which is only imperfectly known.

FALLOUT LEVELS

Since the beginning of nuclear weapon testing, plutonium has been present in nature. The global inventory of Pu 239 in worldwide fallout is at present approximately 0.3 megacuries, or approximately 5 tons. In the temperate zone of the northern hemisphere the accumulated Pu 239 fallout is approximately 1-2 mCi Pu 239/km², and in the arctic environment the level is estimated at 0.2-0.4 mCi/km². Hence in Bylot Sound (approximately 300 km²), before the B-52 accident we had approximately 0.1 Ci Pu 239 or 1-2g plutonium from fallout.

EARLIER MEASUREMENT OF PLUTONIUM IN MARINE ENVIRONMENTS

The measurements of plutonium from fallout in marine environments have been few. A 1964 American report (Pillai et al.^{*}) found extremely low concentra-

*K.C. Pillai, R.C. Smith and T.R. Folsom, Nature 209, 568-571 (1966)

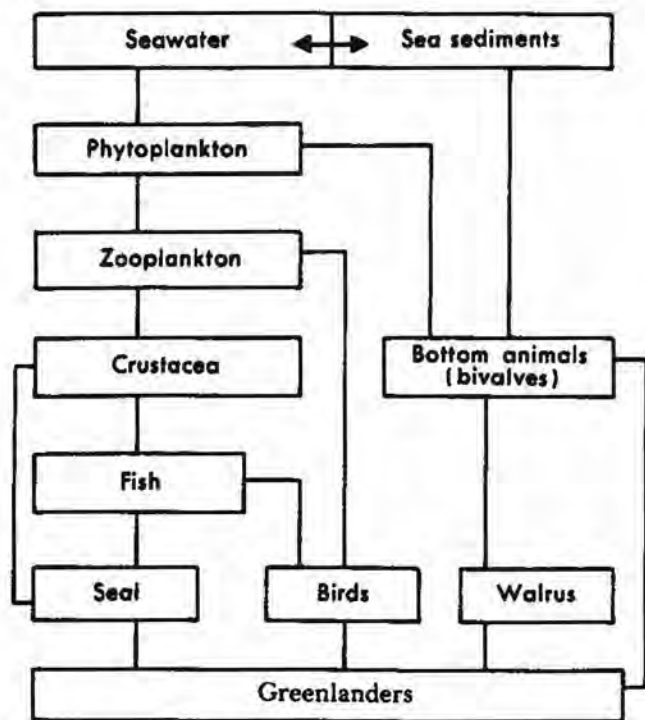


Figure 1 Food chains in an arctic, marine environment.

tions in seawater, of the order of fCi/l (1 fCi = 10^{-15} curies). Pillai found that especially zooplankton and bivalves concentrated plutonium from the seawater. The activity ratio between 1 kg fresh weight of zooplankton and 1 kg seawater was approximately 2,500, and for bivalves Pillai found a ratio of approximately 250.

FOOD CHAIN

The ultimate goal of a radio-ecological survey is to evaluate whether the radioactive substance under study reaches man in harmful quantities. Figure 1 shows a simplified model of the food chain in an arctic marine environment like the Thule area. The Greenlanders are hunters, not fishermen. The animal most important for their nutrition is the seal; they eat the meat, heart, liver, and kidneys. The Greenlanders also eat walrus, although this animal is normally used for the dogs; from the stomach contents of the walrus they get bivalves. As mentioned by Vibe, birds are hunted during the summertime and eggs are collected in appreciable quantities.

• *Primary Samples.* As will appear from Figure 1, seawater and sea sediments are the first links of the food chain. The levels in these media determine the levels in the remaining part of the food chain. Samples of seawater and sea sediments were hence considered primary samples, and were as far as possible to be collected at all locations. The collection of these samples was carried out with special equipment constructed by the Danish Atomic Energy Commission. The water sampler (Figure 2) had a collection capacity of 100 l of water

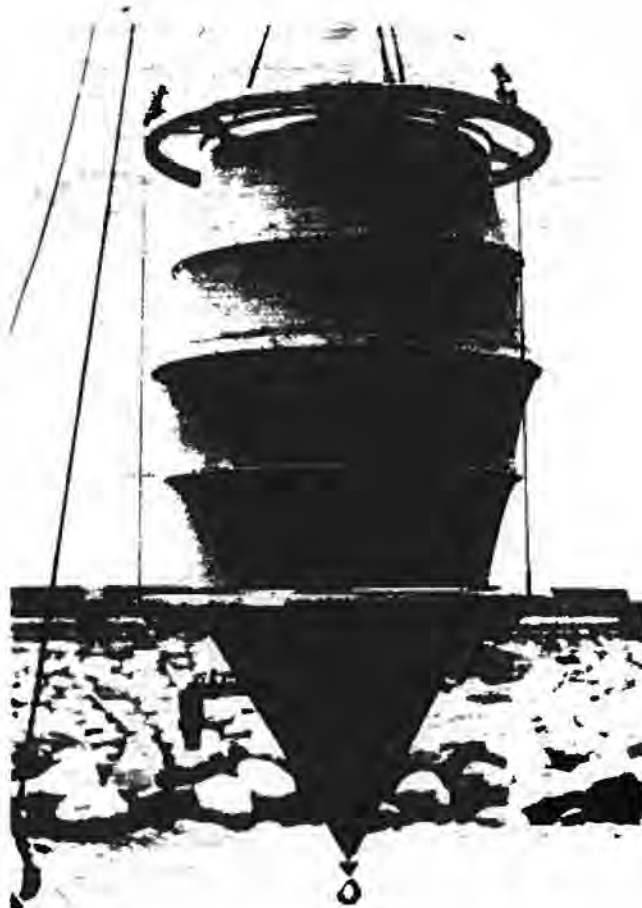


Figure 2 100-litre water sampler.



Figure 3 0.1 m² sediment sampler.

from any depth from the surface down to the bottom, and the sediment sampler (Figure 3) scraped the uppermost layer of the sea bottom to a depth of 1 cm over an area of 0.1 m².

• *Secondary samples.* The secondary samples: with the aid of the ship AGLANTHA, bivalves, zooplankton, crustacea, and fish, were collected by using triangle dredge, plankton net and shrimp trawls.

• *Ternary samples.* The ternary samples: seal.

birds and walrus, were mostly obtained by the Greenlanders. But a few were killed by lucky members of the expedition.

• *Urine samples.* Finally, urine samples were collected from the Greenlanders for the purpose of checking any human body burden of plutonium.

• *The sampling area.* The sampling area (Figure 4) was divided into two zones, I and II. Zone I was a circular area with its center at the point of impact and with a radius of 1 km, and Zone II was the remaining part of the surrounding area in Bylot Sound and Wolstenholme Fjord.

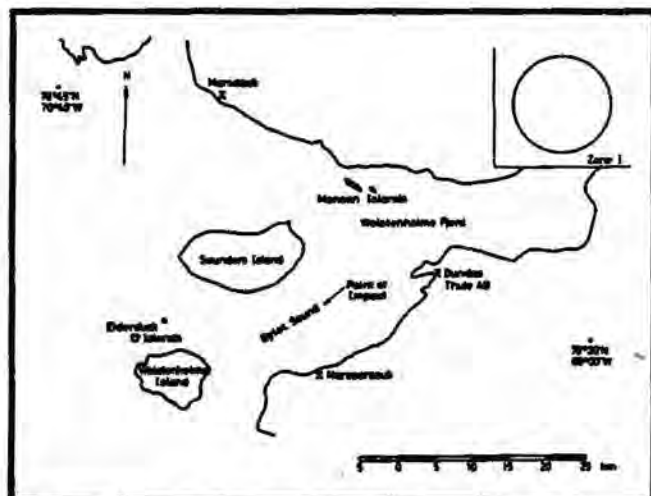


Figure 4 The sampling area at Thule AB, Greenland. Zone I has its centre at the point of impact.

• *The sampling team.* The scientific expedition consisted of one zoologist, one marine biologist, one hydrographer, two physicists, two assistants for the sampling, and an American lichenologist. The sampling began in the last week of July and was finished by the end of August. By then more than 150 samples had been collected for plutonium analysis.

• *Sample treatment.* The samples were kept at -10°C until they could be processed in the laboratory. The solid samples were ashed at 600°C, and after the addition of carriers and spikes, the ash was melted with potassium pyrosulphate to ensure that all plutonium was in a soluble form before the radiochemical analysis, developed especially for this purpose by a combination of an American ion-exchange procedure and a Danish extraction method. After the radiochemical analysis, which could be accomplished within a day for most types of samples, the samples were counted for 3-4000 minutes on silicon-surface-barrier α -counters in connection with a multichannel analyzer. Figure 5 shows a typical spectrum from one of the stronger samples. Seawater samples were processed by a similar method; iron hydroxides were in this case precipitated directly from a 50-litre sample.

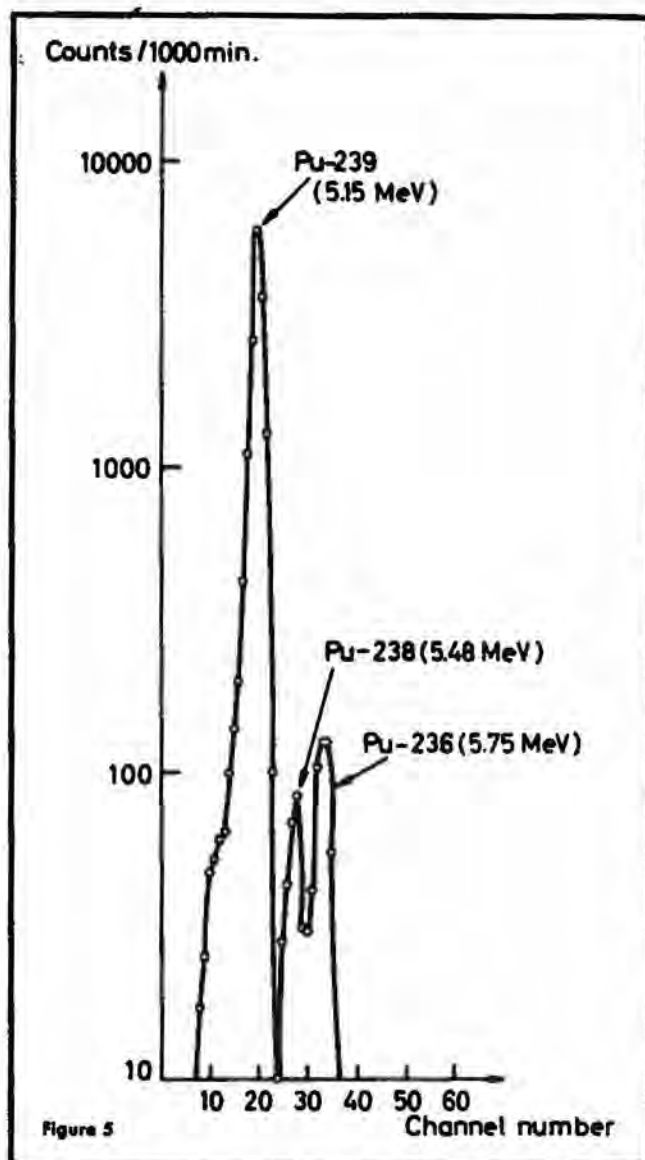


Figure 5 The α -spectrum of a bivalve sample from zone I. The activity ratio $\text{Pu } 238/\text{Pu } 239 = 0.02$. This ratio was nearly the same in all samples from Thule in which Pu 238 was detectable. (Pu 236 is the spike used for the yield determination.)

RESULTS

• *Sea water.* In Figure 6 the results of the seawater analysis are shown. The maximum for water samples was 76 fCi Pu 239/litre found in a sample collected approximately 5 km west of Dundas Mountain. The median fallout background in seawater from five Greenland locations far away from Thule (Danmarkshavn, Angmagssalik, Prins Christians Sund, Godthåb, and Godhavn) was 4 fCi Pu 239/litre as compared with the median level found at Thule: 5 fCi Pu 239/litre. At Qanaq, approximately 100 km north of Thule, the level was 3 fCi Pu 239/litre. In Zone I the seawater samples were collected both at the surface and at the bottom.

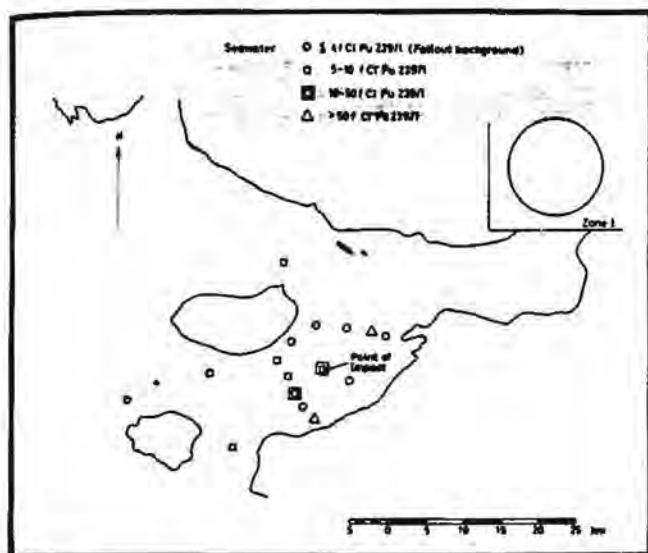


Figure 6 Pu 239 levels in seawater. Thirteen samples were collected in zone I.

From most other locations at Thule they were collected only at the bottom. The samples from Zone I showed that the bottom samples normally had a slightly higher activity than the surface samples. A number of samples were filtered through a 1μ millipore filter before the analysis, and filtrate and filters were analyzed separately. These analyses gave no indications of significant amounts of particulate ($>1\mu$) activity in the water samples. However, we do believe that the few samples that showed relatively high levels ($10\text{ fCi Pu }239/\text{l}$) contained particulate activity, probably particles stirred up from the bottom during the sampling.

It is concluded that the accident caused only a slight

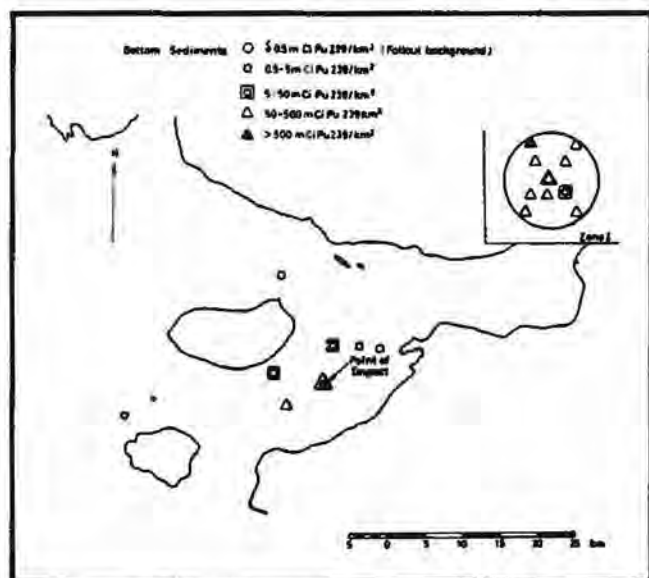


Figure 7 Pu 239 levels in bottom sediments. Ten samples were collected in zone I.

increase in the Pu 239 concentration of the seawater in Bylot Sound.

• **Bottom sediments.** The median level of bottom-sediment samples collected in Zone II was $4\text{ mCi Pu }239/\text{km}^2$, whereas it was $120\text{ mCi Pu }239/\text{km}^2$ in Zone I. The highest level was found 1 km northwest of the point of impact; at that location $1300\text{ mCi Pu }239/\text{km}^2$ was found. From the median level the total deposition of Pu 239 in Zone I (3.1 km^2) was estimated at 0.4 Ci . In the remaining part of Bylot Sound (300 km^2) the Pu 239 level in the bottom sediments was estimated to approximately 1 Ci . These estimates do not include Pu 239 on pieces of debris, which might remain on the sea bottom.

It is concluded that the Pu 239 level in the top layer of bottom sediments in Bylot Sound is approximately 10 times the expected fallout background. In the inner zone around the point of impact the level was more than 100 times as high as the background. This inner zone of high activity might extend as far as a couple of kilometers from the center.

• **Seaweed.** The plutonium level in sea plants (*Fucus* and *Laminaria*) was measured in seven samples collected along the shores of Bylot Sound. The median level was $0.4\text{ pCi Pu }239/\text{g ash}$ ($15\text{ pCi Pu }239/\text{kg wet weight}$) as compared with $0.2\text{ pCi Pu }239/\text{g ash}$ in samples collected in other parts of Greenland (Godthåb, Prins Christians Sund, Danmarkshavn). A sample from Qanaq contained $0.3\text{ pCi Pu }239/\text{g ash}$.

It is concluded that sea plants showed levels of Pu 239 hardly significantly above fallout background.

• **Plankton.** Mixed samples of zooplankton were collected in the surface water layers southwest, northeast, and southeast of Zone I. Furthermore *Gammarus* were collected along the shore at Manussak and north of Dundas Mountain. The median level of the zooplankton was $3\text{ pCi Pu }239/\text{kg fresh weight}$. In *Gammarus* the mean level was $30\text{ pCi Pu }239/\text{kg}$. If the ratio between the plutonium levels in zooplankton and seawater is 2,500 (cf. above), the estimated plutonium level in zooplankton (incl. *Gammarus*) is $2,500 \cdot 0.005\text{ pCi/kg} \sim 10\text{ pCi/kg}$.

It is concluded that the plutonium level in zooplankton (incl. *Gammarus*) was hardly significantly different from the fallout background.

• **Crustacea.** Eight samples of *Crustacea* caught during trawling on the outskirts of Zone I were analyzed. Some samples were divided into flesh and shell. The median level of the total animal samples was $1,900\text{ pCi Pu }239/\text{kg fresh weight}$. The median levels of the flesh and the shell samples were 95 and $330\text{ pCi Pu }239/\text{kg}$ respectively. The maximum level for *Crustacea* samples was $12,000\text{ pCi Pu }239/\text{kg total animal}$. Shells normally contained more Pu 239 than did flesh. As these *Crustacea* are bottom animals, it is believed that most of their plutonium content was particles incorporated from the bottom sediments. Samples of *Crustacea* from southwest Greenland contained $3\text{ pCi Pu }239/\text{kg}$, and samples

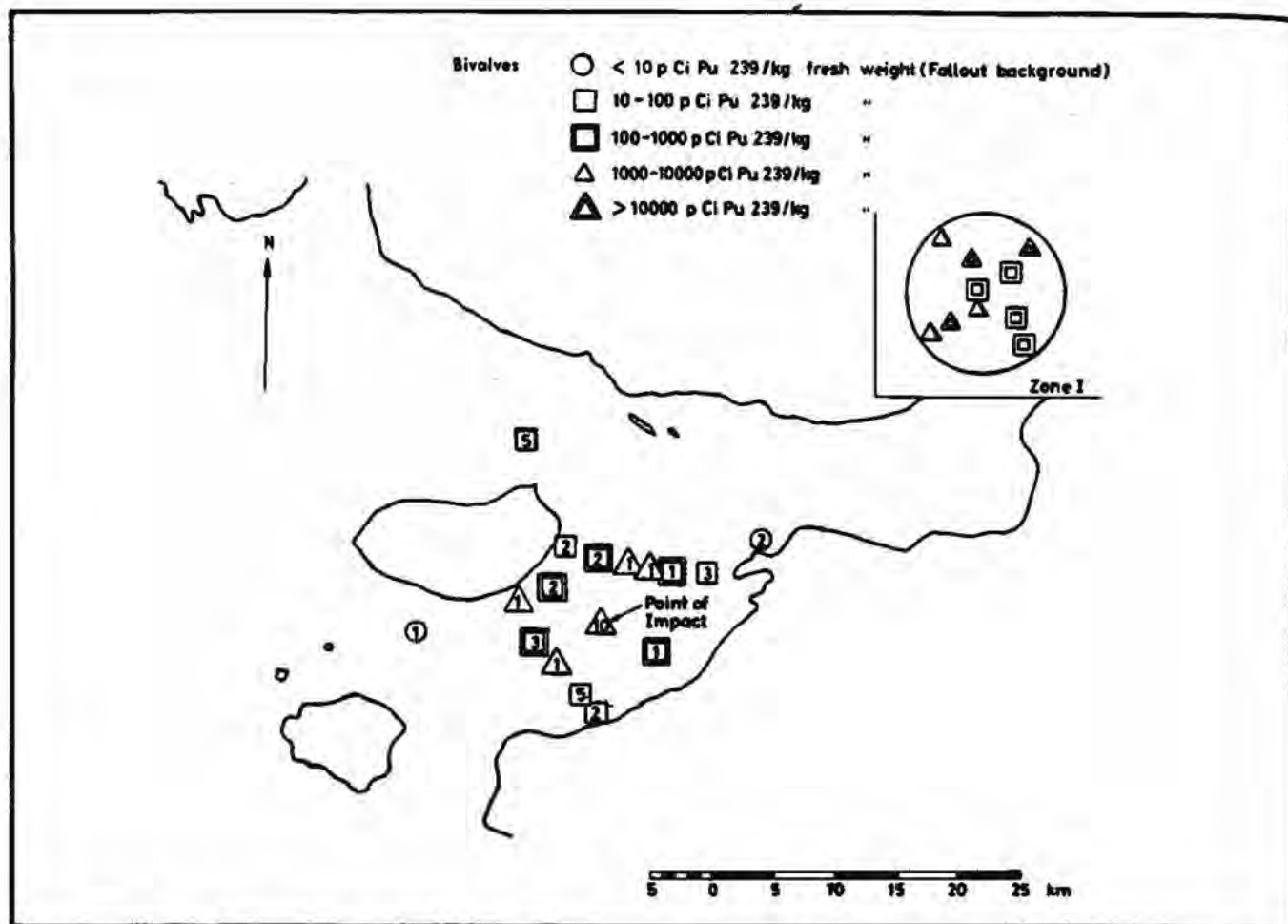


Figure 8 Pu 239 levels in bivalves. The numbers refer to the number of samples analyzed from each location.

from Danish inner waters contained 2 pCi Pu 239/kg.

It is concluded that *Crustacea* from Thule contained certain amounts of Pu 239 from the accident, the median level being nearly 1,000 times the fallout background.

• *Bivalves.* Figure 8 shows the level of Pu 239 in bivalves. The median level of all samples from Zone II was 64 pCi Pu 239/kg. In Zone I it was 8,000 pCi Pu 239/kg. The maximum level was 76,000 pCi Pu 239/kg; the sample concerned was collected in Zone I, a few hundred meters north of the point of impact. The fallout background in bivalves was estimated to be approximately 5 pCi Pu 239/kg on the basis of measurements of bivalves from Danish waters. Figure 8 shows that nearly all samples from Thule were above this fallout background. Bivalves thus seem to be very sensitive organisms for the detection of plutonium in marine environments. Five different species of bivalves were investigated; it was, however, not possible to see any significant difference between the plutonium levels in the different species. From replicate analysis it was

evident that the plutonium activity was very inhomogeneously distributed within a sample. This was undoubtedly due to the fact that most of the plutonium in the mussels was in particulate form.

It is concluded that bivalves contained plutonium levels significantly higher than background and that the highest concentrations (more than 1,000 times the fallout background) were to be found near the point of impact. Plutonium could, however, be detected in levels significantly above background even as far away as 20 km northwest of the crash area.

• *Bottom animals.* From Zone I a few samples of worms, starfish and sunstars were analyzed. A mixed sample of worms from nine stations in Zone I contained 30,000 pCi Pu 239/kg, and starfish and sunstars contained between 190 and 1,100 pCi Pu 239/kg fresh weight.

It is concluded that not only bivalves, but also other bottom animals, concentrate Pu 239 from the environment and that significant amounts were present especially in the samples collected near the point of impact.

• *Fish.* Sea scorpions were found at the shore

low waters along the southeast coast of Saunders Island. Two samples were analyzed. The plutonium content of the first sample was hardly significantly above the background; the other sample contained 14 pCi Pu 239/kg. The polar cod is the most common fish in the district. Three samples of this species were analyzed and showed levels from 19 to 239 pCi Pu 239/kg. A Greenland halibut caught just north of Zone I contained 470 pCi Pu 239/kg. This was the maximum level found in any fish sample. The medium level of all fish samples (10) was 37 pCi Pu 239/kg.

It is concluded that especially fish living near the sea bottom, as the Greenland halibut, contained Pu levels significantly above fallout background. However, the concentrations were lower in fish than in bivalves and Crustacea.

- *Sea birds.* Five samples of intestinal contents of eider, black guillemots and Brünnicks guillemots were analyzed. The median level was 3.5 pCi Pu 239/kg. Eiderdown collected on the Manson Islands and the Eiderduck Islands contained 130 pCi Pu 239/kg down and dust (adhering to the down).

It was concluded that the sea birds contained plutonium levels which were hardly above the fallout background. The plutonium levels in their intestinal contents were nearly the same as in zooplankton, which is a main constituent of their diet. The down, or rather the dust in the down, from the Eiderduck, however, contained significant levels of plutonium.

- *Seals.* Five samples of intestinal contents of seals killed in Bylot Sound and Wolstenholme Fjord were analyzed. The medium level was 1 pCi/kg fresh weight. The maximum level was 4 pCi/kg found in the stomach contents of a ringed seal shot by the expedition just north of Narssarssuk.

It was concluded that seals contained very low levels of plutonium, and that the levels were hardly significantly different from the fallout background.

- *Walrus.* Intestinal and stomach contents of five walrus killed in late spring west of Saunders Island were analyzed. The median level was 1.3 pCi Pu 239/kg and the maximum was 1.8 pCi Pu 239/kg. It was concluded that walrus did not contain Pu 239 levels significantly above background. On the other hand, this was not unexpected, as the walrus were killed before the ice melted in Bylot Sound.

- *Human urine.* Samples of urine from the Greenlanders at Narssarssuk were collected three times: just after the accident, in September 1968, and in February 1969. A few of the samples from the first two collections showed traces of plutonium 239; however, the possibility that these samples had been contaminated during the sampling could not be excluded. Hence a new set of samples was collected in February 1969, and none of these samples showed any traces of Pu 239.

It was concluded that it was unlikely that any Greenlander in the Thule district had been exposed to signi-

ficant internal levels of plutonium as a result of the accident.

- *Hazard evaluation.* The International Commission on Radiological Protection (ICRP) have not given maximum permissible concentrations (MPC) for marine samples. If food habits and concentration factors in the food chains are known, it is, however, possible to estimate an equivalent to the permissible levels in such samples. In this case, probably the bivalves were the critical sampling object. From the ICRP's recommendations for drinking water it is calculated that the maximum permissible daily intake of Pu 239 with the diet is 0.1 μ Ci. If, for instance, a Greenlander eats 100 g bivalves daily, which undoubtedly is an upper estimate of his consumption, the MPC in bivalves becomes 1 μ Ci Pu/kg. Even the strongest sample of bivalves contained only one tenth of this pessimistically estimated MPC value.

- *Eiderdown.* Eiderdown collected during the summer is cleaned of dust by the Greenlanders. This cleaning might be a matter for concern as an inhalation hazard if the down and dust contained appreciable amounts of plutonium. From the ICRP's recommendations, the daily permissible intake of insoluble Pu 239 into the lungs is calculated at 200 pCi, i.e., the permissible annual intake would be 73,000 pCi. The concentration of Pu 239 in eiderdown was 130 pCi Pu 239/kg; it is thus extremely unlikely that any Greenlander occupied with the cleaning of down might reach the permissible intake of Pu 239 into the lungs.

CONCLUSION

The radio-ecological investigation showed that the plutonium levels in the collected samples in no instances were such that they can be considered harmful to man or to higher animals in the Thule district or in any other part of Greenland. Nonetheless, the B-52 accident in Bylot Sound at Thule in January 1968 measurably raised the plutonium level in the marine environment as far out as approximately 20 kilometers from the point of impact. The highest concentrations were found in bottom sediment, bivalves and Crustacea. The higher animals such as birds, seals, and walrus showed plutonium levels hardly significantly different from the fallout background. Plutonium was not, with certainty, detected in urine from Greenlanders.

ACKNOWLEDGEMENTS

These investigations would have been impossible without the skillful assistance of Lars Bøtter-Jensen, Marianne Christensen, Johs. Jensen, A.P.K. Kristiansen, Birgitte Ladefoged, Jørgen Lippert, Anna Holm Pedersen, Jørn Roed, Else Sørensen, all staff members of the Health Physics Department, and Erik Kjær Markussen, J. Møller Andersen, of the Danish Defense Research Board.

The urine samples were analyzed by Heinz Hansen and Vibeke Jørgensen, The Medical Laboratory of the Danish Atomic Energy Commission.

*Danish health physics activities
at Thule during the clean-up
period.*

DANISH HEALTH PHYS

OLE WALMOD-LARSEN et al *
Danish Atomic Energy Commission
Research Establishment Risø

ABOUT 10 February, Henry L. Gjørup realized that an optimistic conclusion—that very little or no contamination would be found outside the crash area—would in all probability be drawn from the efforts of "Operation Frying Pan." Consequently, he set off for Copenhagen on 14 February in order to take part in the joint U.S.-Danish meeting on 15 February; and to participate in the management of further investigations in Denmark.

Some days after his departure, the "Operation Frying Pan" team concluded that the environmental hazards from Pu 239 outside the crash area were in fact comparable to the accumulated fallout from weapons testing. The team cabled this conclusion to Copenhagen.

On the basis of the team's favorable report it was decided to scale-down the Danish scientific efforts in Thule.

In accordance with the conclusions reached at the February meeting in Copenhagen, namely, to remove as much of the contaminated snow as possible for the sake of good housekeeping, a decision was made to continue the on-scene U.S.-Danish cooperation, mainly on the health physics aspects of the operations to come. This was natural on the part of the Danes, who wanted to ensure that no Danish citizen would be exposed to any hazards in connection with the removal of the contaminated material from Danish territory.

More than a thousand persons assigned to Thule Air Base work for the Danish Construction Corporation (DCC), which with a Danish staff carries out all the civil operations of the base. It was natural, therefore, that from the very start the DCC staff took part in the Crested Ice Operations.

*Asker Aarkrog, Lars Botter-Jensen, Poul Christensen, Henry L. Gjørup, Jørgen Lippert, Jørn Roed and Arne Sørensen, Health Physics Department and Leif Løvborg, Electronics Department.



Danish workers filling the many rows of 25,000-gallon tanks with contaminated snow and ice.

One of the problems facing the Danish health physicist left on his own at the scene after the departure of the Frying Pan Team, was the layman's fear of the unknown: the fear of radiation, of contamination, of atomic weapons, and fear of all the new, unusual phenomena suddenly disturbing the quiet Arctic area at Thule.

Each time Danish participation in the operations escalated, further groups of staff had to be put into the picture, briefed on safety precautions, and made to realize that these precautions were for their own good.

Several briefings were arranged in close cooperation with the DCC safety officer, E. Stubbe Teglbjerg, in order to get things going. Before the removal operations started the DCC key personnel were informed in detail about the radiation-protection measures

laid down in the U.S.-Danish agreement in the Health Physics Program for Snow Removal Operation.

Another briefing was held a few days later in a heated bus, parked at the work site of the Danish workers who were filling the many rows of 25,000-gallon tanks with the contaminated snow coming in from "Camp Hunziker." This briefing gave rise to one of the more diverting events of the Crested Ice Operations. Contrary to the plans laid down by DCC, the briefing caused a delay of slightly more than one hour because of many questions from the workers. This was a highly undesirable delay considering the fine weather and good operational conditions. When the delay became known the smell of brimstone emanating from the SAC headquarters was detectable several miles off until the reasons for the delay were made clear to General Hunziker, who wanted to speed up the clean-up operations. This speedup was necessary due to the shortage of time and the many unknown factors such as weather conditions and the vulnerability of the vast machinery put into action.

The original idea was that the entire removal operation should be carried out by U.S. personnel, if possible. When Danish assistance was required it was to be for work only in noncontaminated areas, or for work on items proved to be free of contamination.

When the heavy, snow-filled containers were emptied into the tanks, minor spills were unavoidable. Even though these spills were collected immediately with shovels and brooms, there was a risk that contamination might spread throughout the base. The original U.S.-Danish agreement was therefore modified to the effect that the tank-filling area was declared a contamination area with corresponding regulations concerning clothing, transportation and decontamination. No contaminated Dane would be allowed to cross the "hot line" in the decontamination building. Nasal swabs were to be taken, records to be kept, and bioassays carried out as deemed necessary by the health physicists.

At the next briefing for the filling teams, numerous questions were raised as to the reasons for these precautions.

One of the most significant problems only appeared after more than a 1½-hour discussion—the problem was fear of sterility and impotence. When it was explained that these fears were groundless, no further questions were asked!

Another briefing was given to the Danish mechanics working at the Base Motor Pool. The strain on facilities for repair and maintenance of vehicles and machinery operating at the crash site and in the tank area gave rise to a minor spread of contamination originating from the engines, where contaminated snow particles stuck on the warm, oily surfaces and finally melted.

This led to the establishment, within a few hours, of an additional vehicle decontamination facility, and to the enforcement of minor restrictions at the Base Motor

Pool which had to be explained to the staff.

Close and frequent contact with union stewards proved useful in ensuring maintenance of good relations with the workers, and also in explaining that the results of nasal swabs and urine samples were found to be negative. This proved that the precautions were entirely adequate and that no Dane had been exposed to any hazards during his work in contaminated areas.

By the middle of April the 140 vehicles and machines were cleared of contamination (except one belt loader which was painted and stored for disposal), and the various areas and buildings used for that purpose at the base were cleaned up.

In April, the crash site was fenced in and marked, and the hunting restrictions were modified, giving Greenlanders access to the rest of the Bylot Sound. After this period the Danish health physics activities in the spring decreased to some visits of a few days' duration.

Later on, when the bay and the harbor were reopened, Danish health physicists were again permanently stationed at Thule until the USS MARINE FIDDLER sailed into international waters carrying on board the last Crested Ice tanks.

The new stevedoring crew coming in from Copenhagen was given a safety briefing. Here, as in the earlier briefings, it proved valuable that qualified persons from an independent authority were present.

Transportation between Thule, in the Polar Region, and Copenhagen, in Denmark, is very infrequent. A regular Scandinavian Airlines (SAS) flight is scheduled for every second Wednesday, and every second Monday an SAS freighter lands at Thule Air Base. Because the flight crews have to return within the same working day, (the flight time being more than 10 hours) the planes must be airborne again in less than 2 hours, which gave little time for briefing and introductions between the incoming and outgoing scientists who took turns at discharging the responsibility for safeguarding the health of the Danes involved in the operation. Nonetheless the team managed to uphold the necessary continuity in this service.

During the entire operation the Danish health physicists had unrestricted access to all data on the measurements made on site and later in the U.S., on bioassays and on all nasal swabs taken. All the measurements proved that during the whole operation no Dane had been exposed to any radiation hazards.

All the items to be transported were cleared in excellent cooperation between U.S. and Danish health physicists. After a thorough survey of the tank farm, the last contamination area at the Thule Air Base, a U.S.-Danish "Final Health Physics Report on Project Crested Ice" drew the conclusion that all areas concerned could be given free with the classification: NDA—No Detectable Activity.

ICE OPERATIONS

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PROJECT Created Ice was an example of man's ability to use one of nature's materials to advantage. The material in this case was sea ice. Sea ice, when used as foundation or construction material, has stress or safety limits like any other material. It is necessary to understand these limits—to ignore them could result in the loss of life and equipment.

The first trips from Thule to the Broken Arrow site were made by helicopter and dogsled, thus limiting the number of personnel and the amount of equipment which could be transported to the site. It was therefore obvious that surface transportation, other than dogsled, would be necessary for a successful and speedy recovery mission.

The original ice thickness measured 39" near shore and from 23" to 24" at the site, later named Camp Hunziker. The measurements were taken in the center of the newly plowed road that ran from Delong Pier to Camp Hunziker. Variation in ice thickness is normal for a bay or harbor similar to North Star Bay, for the area near shore freezes first and therefore has a greater ice thickness.

The quality of the ice and its measured thickness indicated that the ice could safely carry distributed loads up to 50,000 lbs. It was decided that future transportation to and from Camp Hunziker would be by automotive equipment.

The original road, called Road No. 1, did not run on a straight line from shore to Camp Hunziker. It crossed several large snowdrift areas which were not desirable because of the difficulty of removing the snow after each windstorm. The road was narrow in places because it became impossible to remove the large snowbanks.

In any operation requiring an ice road, it is advisable to have an alternate road. With two roads, the chance of over-fatigue of the ice is limited. This, plus the difficulties encountered with Road No. 1, justified the construction of a second road.

Road No. 2 was laid out on a straight line from shore to Camp Hunziker. It was also laid out so that the snowdrift problem would be at a minimum. It was decided to close Road No. 1 and lay out a new road parallel to Road No. 2.

The two roads were crossed by a number of tidal and thermal cracks. Tidal cracks are produced when the tide lifts and breaks the ice. These cracks usually refreeze and fill with snow. They normally present no danger once the entire bay is frozen over. Thermal cracks are produced when the ice surface is subjected to extremely



Two main roads leading to Camp Hunziker.



Crack in the ice.

low temperatures and then stressed by a load. These cracks look dangerous because they can open more than several inches. They rarely penetrate the total ice thickness and again are not dangerous if care is taken.

Each day, notations were made of the location of each crack in the road, measurements were made of these cracks as well as of the ice thickness of the roads. This was a safety measure so that any unusual situation could be monitored before there was any chance of danger. Many 3-inch diameter ice cores were taken in the area. The cores were taken from the clean, black, and impact ice zones. The ice in the clean and black areas was identical to undisturbed normal sea ice.

The ice thickness at the camp and parking area varied from 23" to 24". The camp site consisted of a number of plywood buildings placed close together. They presented no problem as far as critical loads on the ice were concerned, but would have presented a

serious snowdrift problem. For this reason, they were repositioned at least 50 feet apart.

Snow is usually a problem when operating on sea ice. Many man-hours of work and "wear and tear" on heavy equipment can be saved if buildings and roads are aligned to take into account the primary problem of excessive snowdrifting. Large piles of snow can be dangerous—their weight can cause the ice to fail. This was almost the case at Camp Hunziker.

A large building, 92 x 18 feet, was assembled as the main building of Camp Hunziker. It was placed approximately 500 feet from the other buildings and a large parking area was laid out a safe distance (500 feet) from the building. During the evening, a front loader operator removed the snow from the parking area and placed it in a large mound close to the building. Being newly assigned, he had not been told of the dangers in placing such a large load near a building. This oversight placed the personnel and contents, as well as the building itself, in great danger. General Hunziker, first to arrive on the scene the following morning, recognized the hazard and took immediate action to have the snow removed. This incident illustrates one factor which must be considered when operating on sea ice.

Project Crested Ice will long be remembered for many reasons, one of which is highly creditable—that of being one of the most efficient operations ever conducted on sea ice. The ice thickness was marginal from the beginning of the operation, yet there were no accidents due to ice failure. This was attributed to rigid adherence to the necessary discipline. A memo titled "Ice Operations" describing the safe procedures for operating on the existing ice of North Star Bay became everyone's way of life and the conformance to its instructions resulted in an accident-free operation. The memorandum follows:

(Editor's Note: The following procedures were based on the climate and ice conditions at that time and place, and are not recommended for use under other conditions.)

ICE OPERATIONS

OPERATING ON AN ICE SHEET SUCH AS THE ICE IN NORTH STAR BAY CAN BE DANGEROUS IF ONE IGNORES THE GROUND RULES AND INSTRUCTIONS ISSUED BY THE COMMANDER. ONE CANNOT AFFORD TO BECOME CARELESS WHILE OPERATING ON AN ICE SHEET. THE FOLLOWING INSTRUCTION SHOULD BE USED AT ALL TIMES.

1. *Driving on ice road:* The vehicles should be spaced 200 feet apart at all times. If a vehicle is stopped it is permissible to pass but never faster than posted speeds. The road is safety inspected each day for cracks and faults. After a phase, no one is authorized to drive on either of the two roads until they have been inspected

by the ice inspection team.

2. *Parking of vehicles:* There are parking signs at the site area which specify the safe parking distance between vehicles. These distances must be maintained.

3. *Foreign material:* It is very important that nothing "dark" be thrown or discarded on the clean ice surface. This includes items such as cigarettes, candy or gum wrappers, waste oil, urine, and wood. Once the sun appears these dark objects will absorb the sunlight at a faster rate than the ice will, therefore causing melting. Once melting begins, a hole or crater will form. These openings can become large enough to lose a large trailer in. It is therefore important to begin "police" practices now. (The clean police habits begun now will insure your safety in a few weeks.)

4. *Cracks:* The existing linear cracks in the roads are caused by thermal expansion. There is no danger associated with them. A failure crack will be a circular crack which will form around the load. Considerable deflection will occur before failure of the ice. If you are in a vehicle or building and a circular crack forms, leave the immediate area of the load. Don't panic but leave the building or vehicle quickly and get 50 feet away. If a "lead" opens (a large crack caused by ice movement) don't panic, but return over the road you have traveled until you can report the "lead" by the best available means. You can then return to base via the other road if possible. Should both roads be cut off by a "lead" you will be picked up by a helicopter pending closure of the opening by natural freezing action.

5. *Driving safety:* Always wear your arctic gear while traveling the two highways. Don't park near vehicles, buildings, or heavy objects on ice. (Park 200 feet apart.) Drive carefully and steadily. The ice will normally afford good traction. Observe the road ahead carefully for unusual cracks or snowdrifts. If any are suspected stay clear at least 50 feet. Report any potential problem areas to the Air Police as soon as possible.

Project Crested Ice, as well as previous projects involving ice operations, demonstrated the importance of having previous experience and knowledge of the safety of using ice as a load-bearing material. For this reason, the U.S. Army Terrestrial Sciences Center was requested to conduct the ice measurements and to advise on the overall ice operations.

(Editor's Note: For the information of Air Force officers and civilians who are scheduled for cold regions duty, there is a USAF Civil Engineering sponsored course at the U.S. Army Terrestrial Sciences Center. This course, a 1-week segment of a Cold Regions Engineering Course, discusses the landing of aircraft on ice and approaches, to dealing with engineering problems relating to occupation of, and operations within the cold regions.)

ICE INVESTIGATIONS

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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.

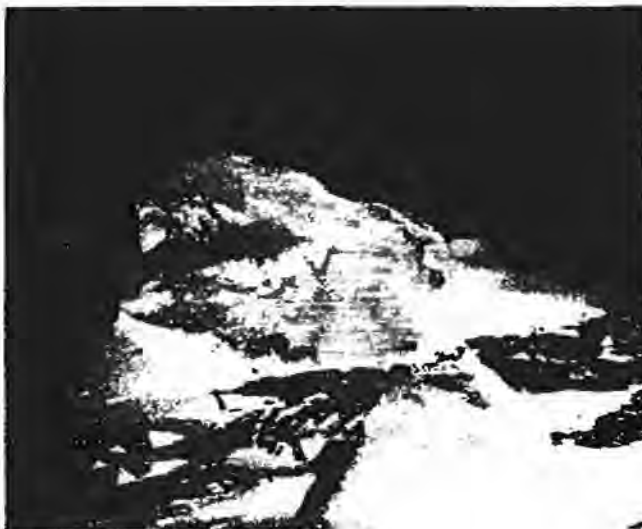
The rate of growth depends to a great extent on the temperature of the air and the snow covering. A thick layer of snow serves as insulation and the ice will grow slowly, whereas no snow or only a thin covering produces a faster rate of growth. At the beginning of May the ice will crack under the spring 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



Ice floe from the crushed spots.



Figure 1. Ice conditions north of Baffin 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.

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.

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 $\frac{1}{2}$ 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 occurred 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



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. Carlin, 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

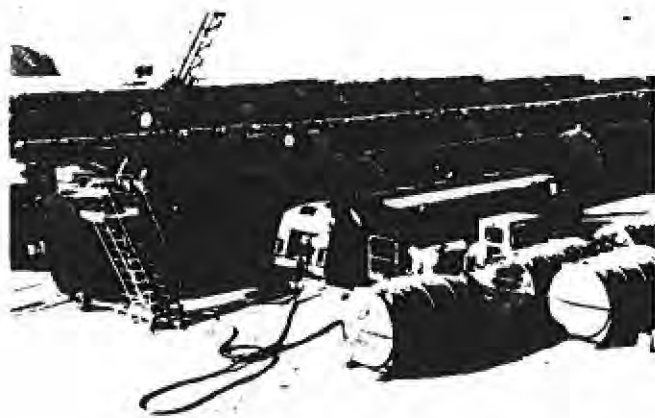
the United States for disposal. However, the health physicists did not fully agree with this concept due to the high degree of purification required to meet international drinking water standards.

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.

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.



Decontamination personnel unloaded forklift inside designated bunker.

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?

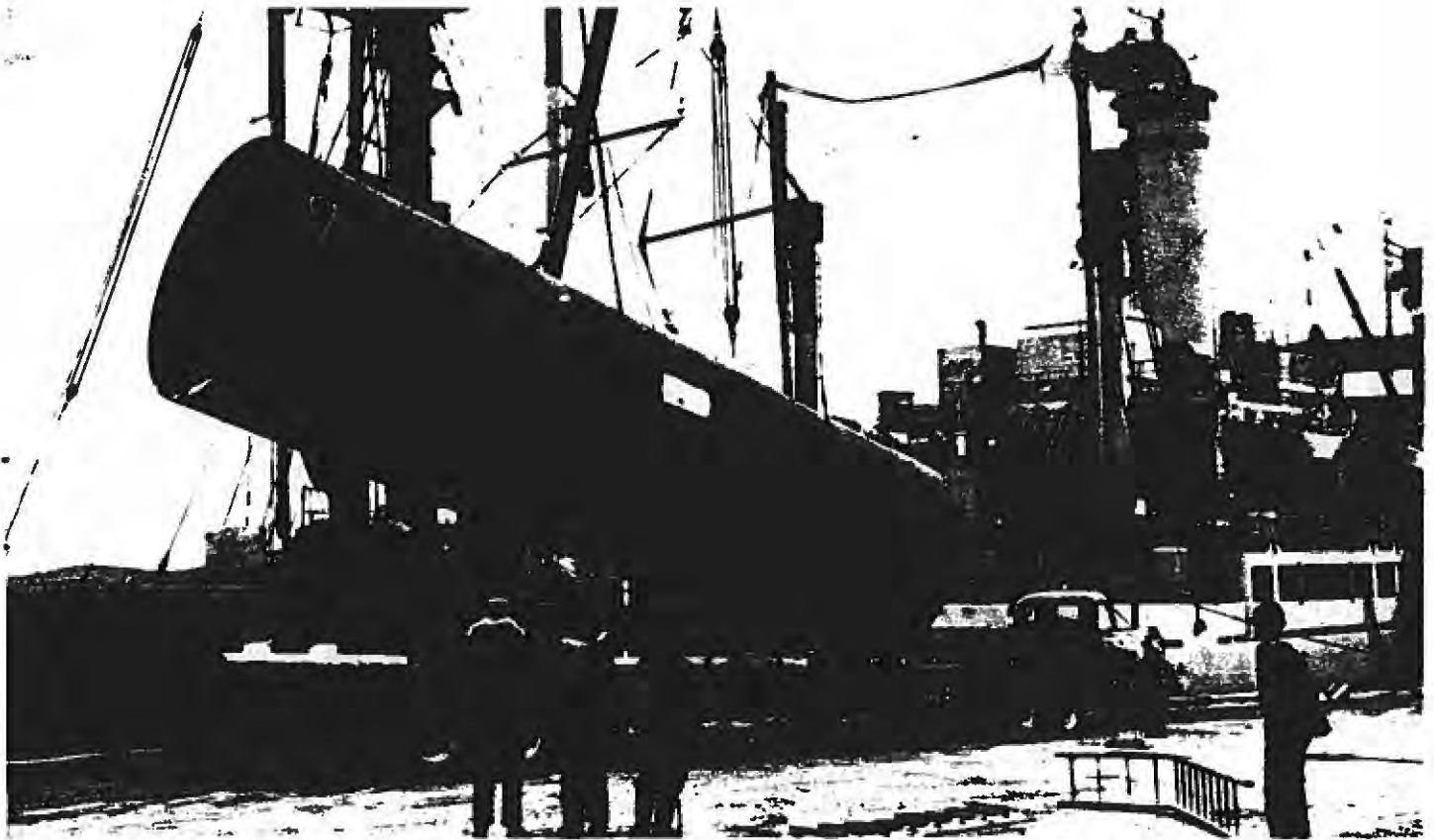
These and all other questions were answered during a comprehensive briefing concerning the mission, constraints and time schedules, international interests and relationships. Individual crew assignments were made in the major areas of effort: melting, pump transfer, radiological monitoring, packaging 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 "Dumb Commuter's Special."

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

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



Fuel tank being lifted onto flatbed by crane.

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

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.

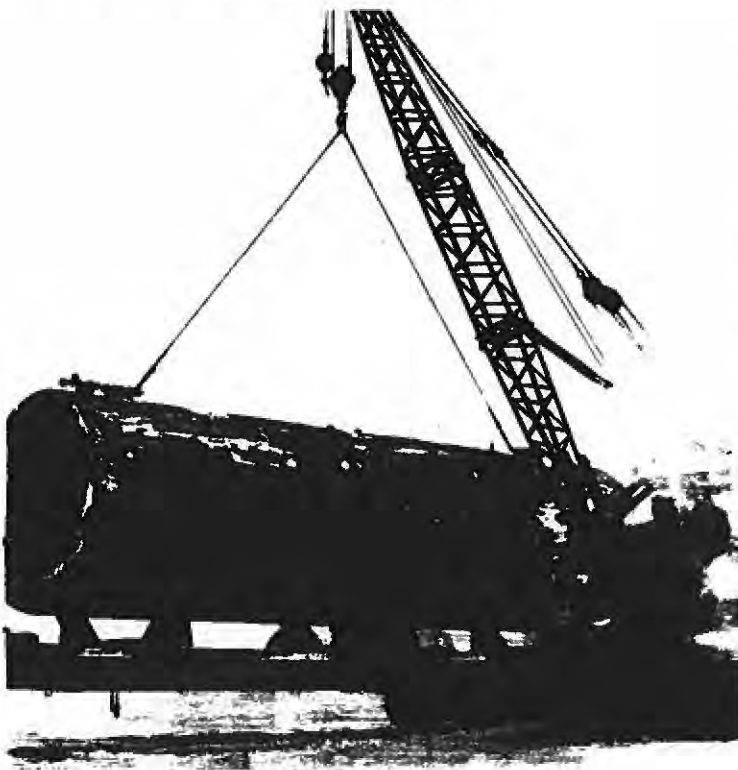
All preparatory efforts of the pump-transfer operations were completed by 22 July.

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



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-15 scintillator detector.

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.

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

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;

*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.

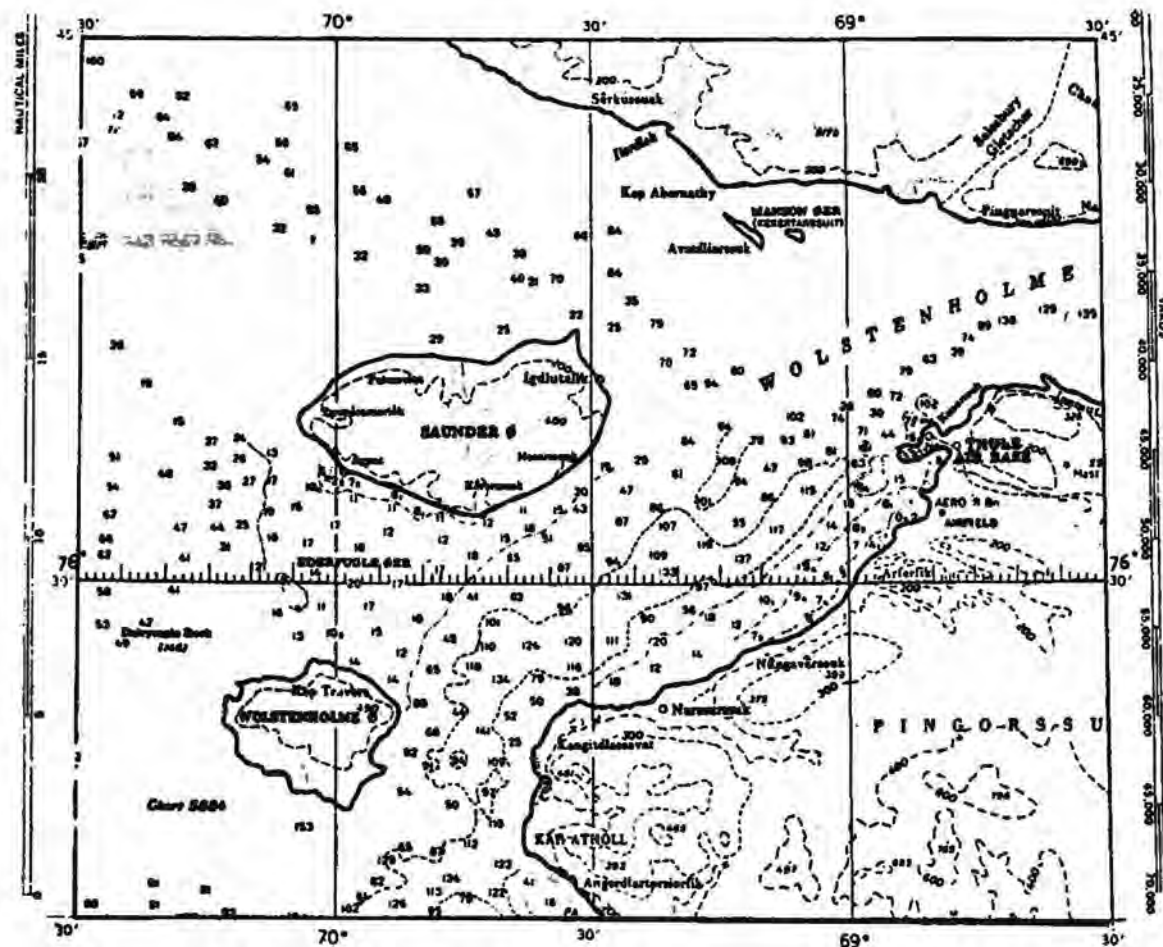


Figure 1. General Operational Locale.

- Between Saunder and Wolstenholme Islands;
- Between Wolstenholme Island and Kap Atholli 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 Sites 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 the 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-

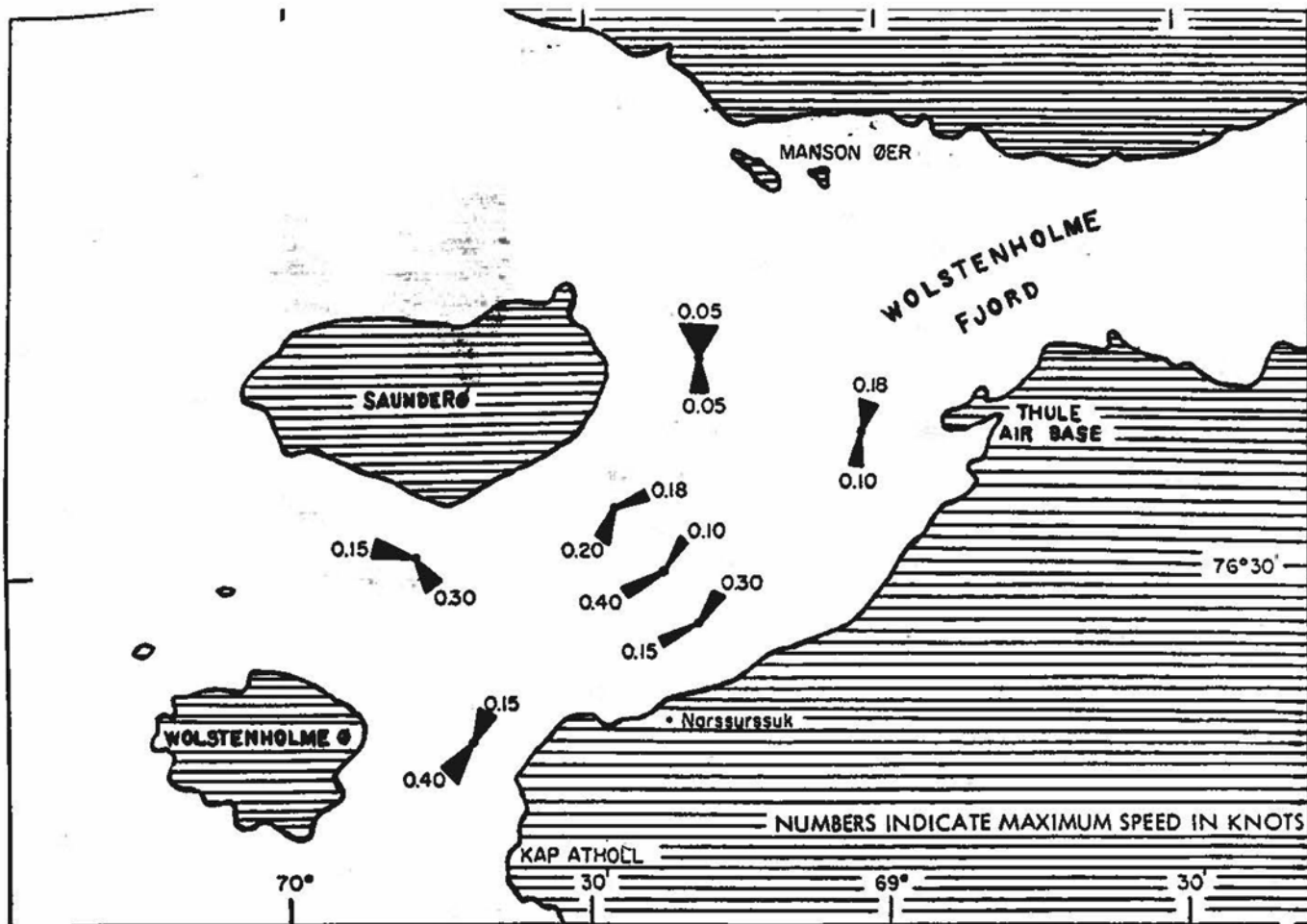
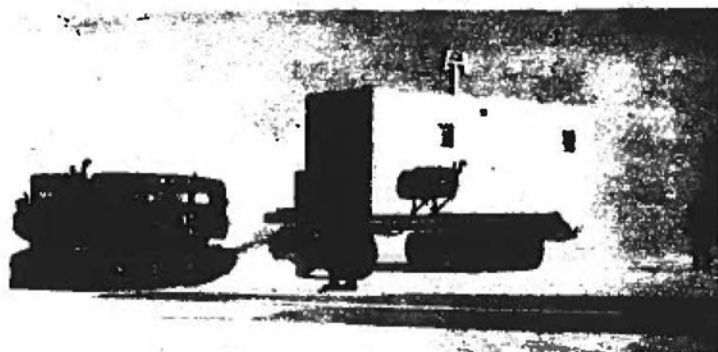


Figure 2. Summary of current data.



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.

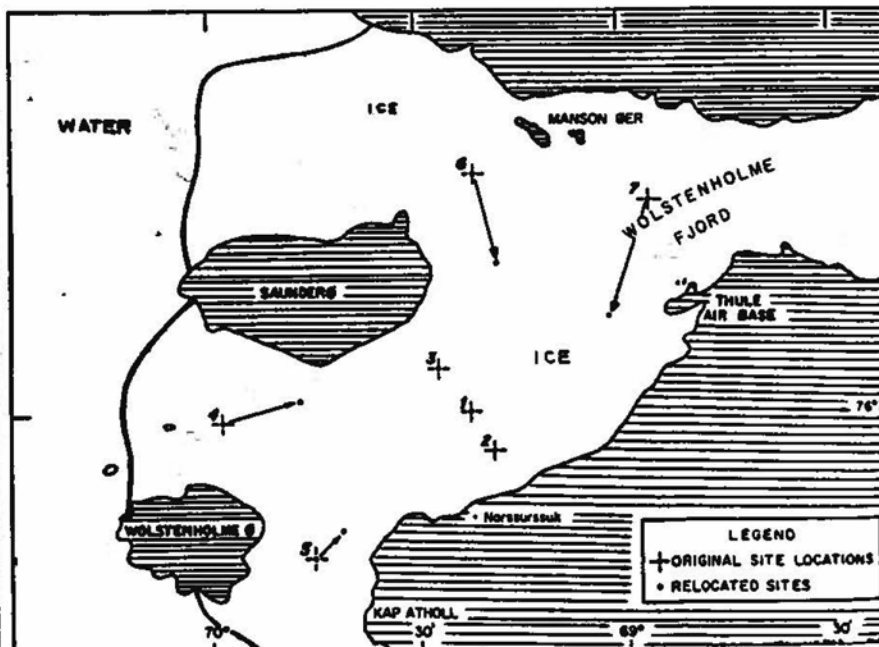
Most diving operations during Crested Ice were con-

† 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 Saunderson 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 Calcareo 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.



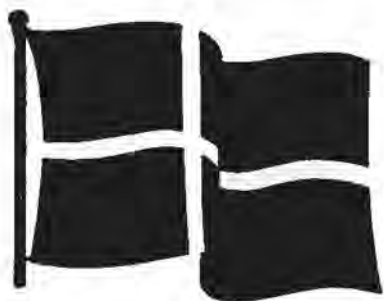
EPILOGUE

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)

