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

ASKER AARKROG
Danish Atomic Energy Commission
Research Establishment Risø

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 $239/km^2$, and in the arctic environment the level is estimated at 0.2-0.4 mCi/km^2. Hence in Bylot Sound (approximately 300 km^2), 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 *203*, 568-571 (1964).

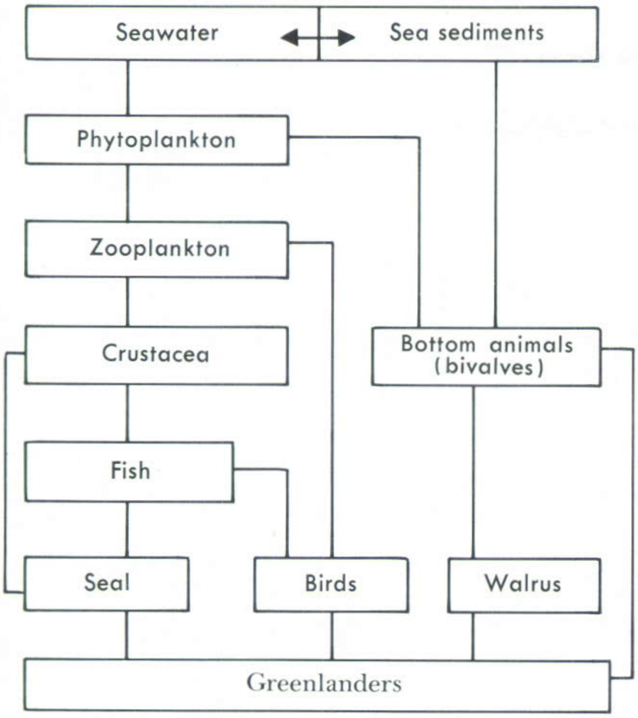


Figure 1 Food chains in an arctic, marine environment.

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

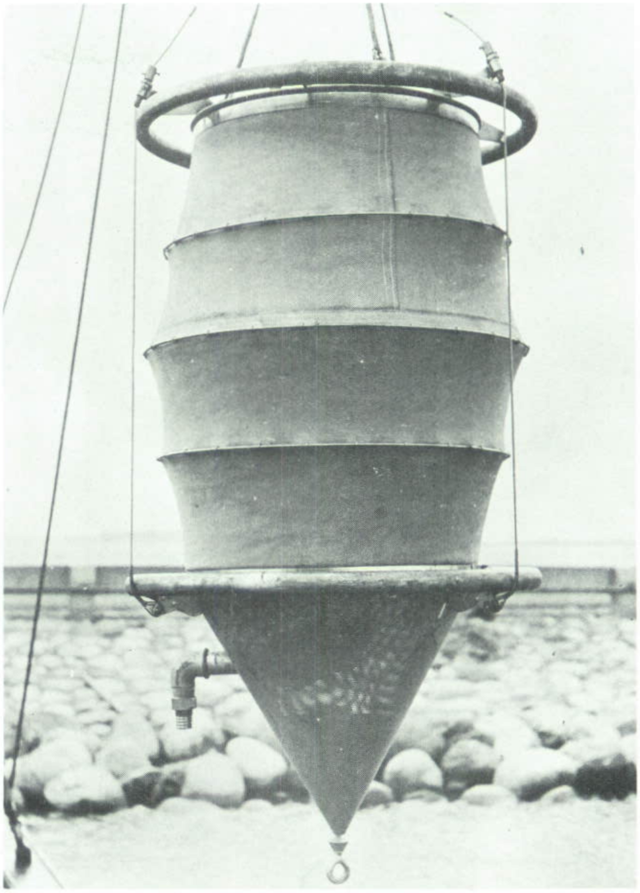


Figure 2 100-litre water sampler.

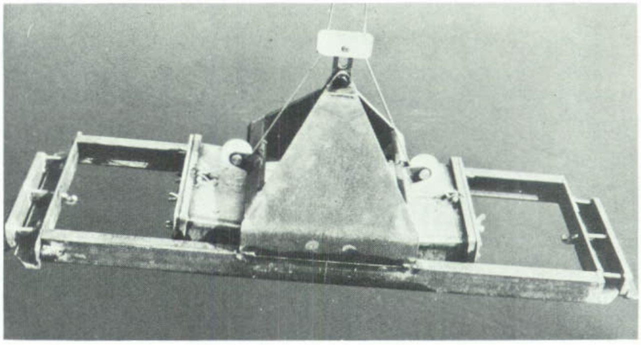


Figure 3 0.1 m^2 sediment sampler.

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 m^2.

• *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.

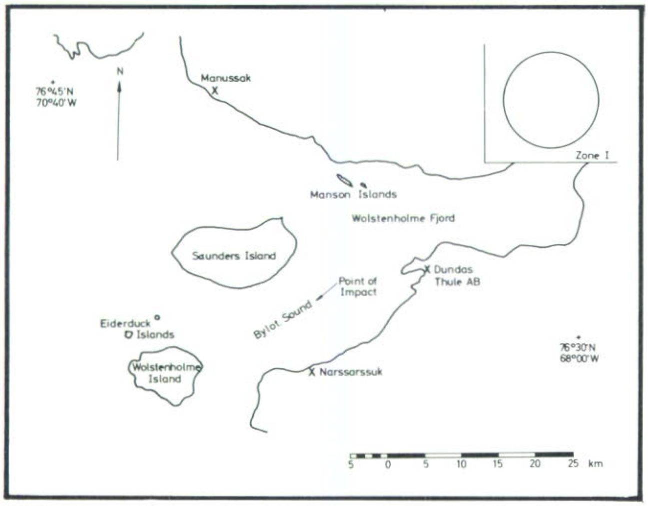


Figure 4 The sampling area at Thule AB, Greenland. Zone I has its centre at the point of impact.

• *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.

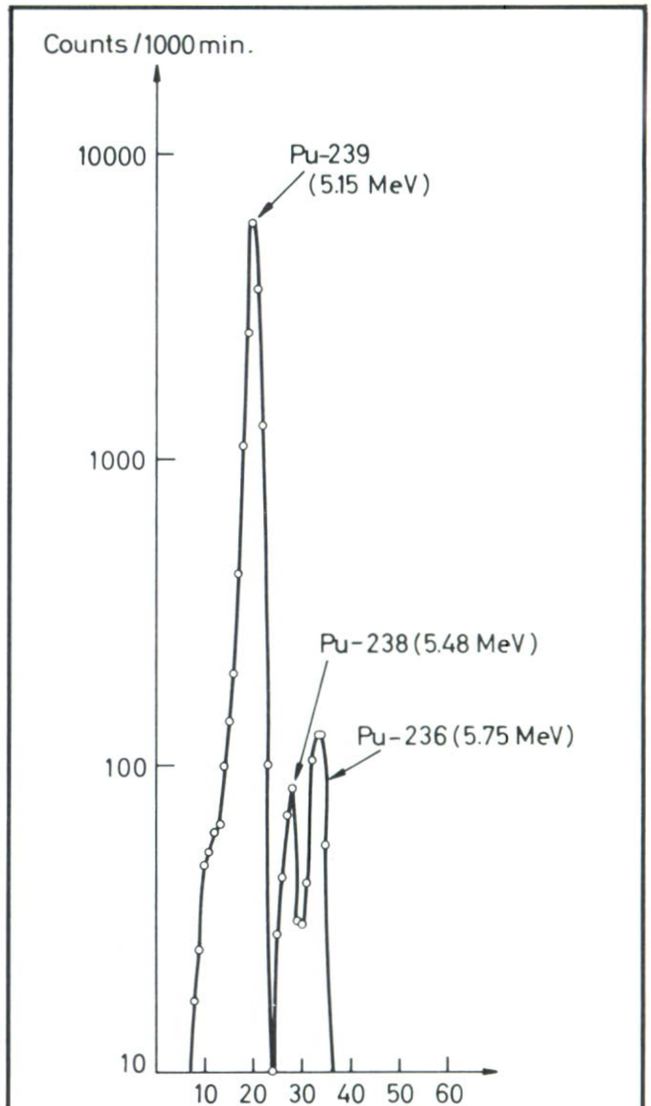


Figure 5

The α-spectrum of a bivalve sample from zone 1. The activity ratio Pu 238/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.

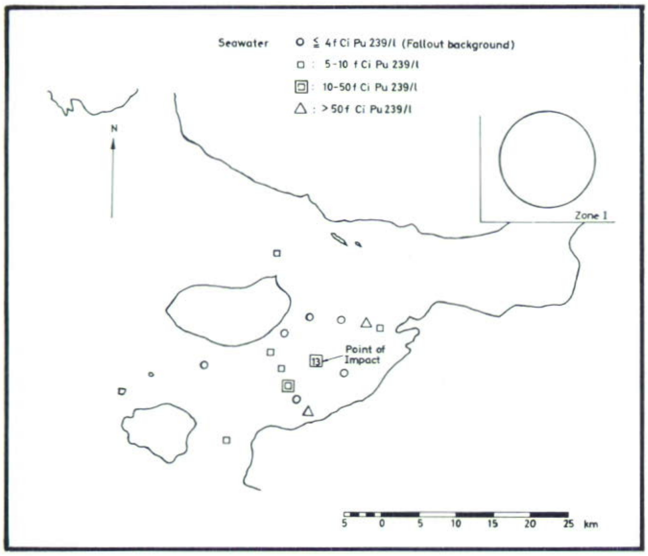


Figure 6 Pu 239 levels in seawater. Thirteen samples were collected in zone I.

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 1 μ millipore filter before the analysis, and filtrate and filters were analyzed separately. These analyses gave no indications of significant amounts of particulate (〉1 u) activity in the water samples. However, we do believe that the few samples that showed relatively high levels (10 fCi Pu 239/1) contained particulate activity, probably particles stirred up from the bottom during the sampling.

It is concluded that the accident caused only a slight 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 mCi Pu 239/km^2, whereas it was 120 mCi Pu 239/km^2 in Zone I. The highest level was found 1 km northwest of the point of impact; at that location 1300 mCi Pu 239/km^2 was found. From the median level the total deposition of Pu 239 in Zone I (3.14 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 pCi Pu 239/g ash (15 pCi Pu 239/kg wet weight) as compared with 0.2 pCi Pu 239/g ash in samples collected in other parts of Greenland (Godthåb, Prins Christians Sund, Danmarkshavn). A sample from Qanaq contained 0.3 pCi Pu 239/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 pCi Pu 239/kg fresh weight. In *Gammarus* the mean level was 30 pCi Pu 239/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 • 0.005 pCi/kg ~10 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 pCi Pu 239/kg fresh weight. The median levels of the flesh and the shell samples were 95 and 330 pCi Pu 239/kg respectively. The maximum level for *Crustacea* samples was 12,000 pCi Pu 239/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 pCi Pu 239/kg, and samples

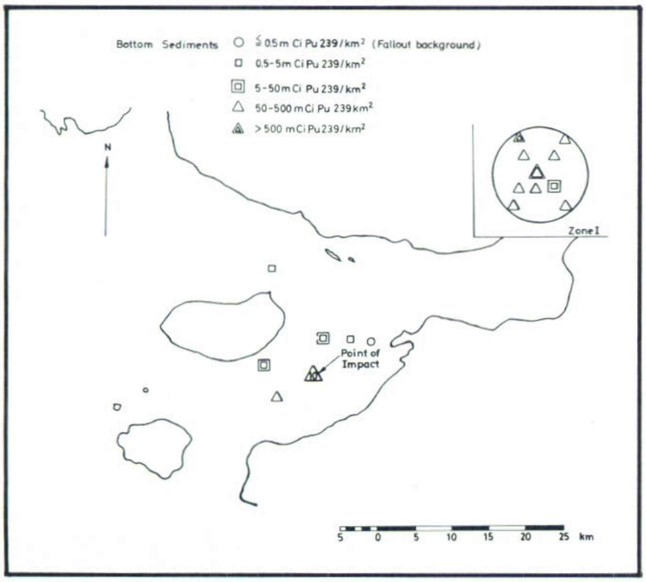


Figure 7 Pu 239 levels in bottom sediments. Ten samples were collected in zone I.

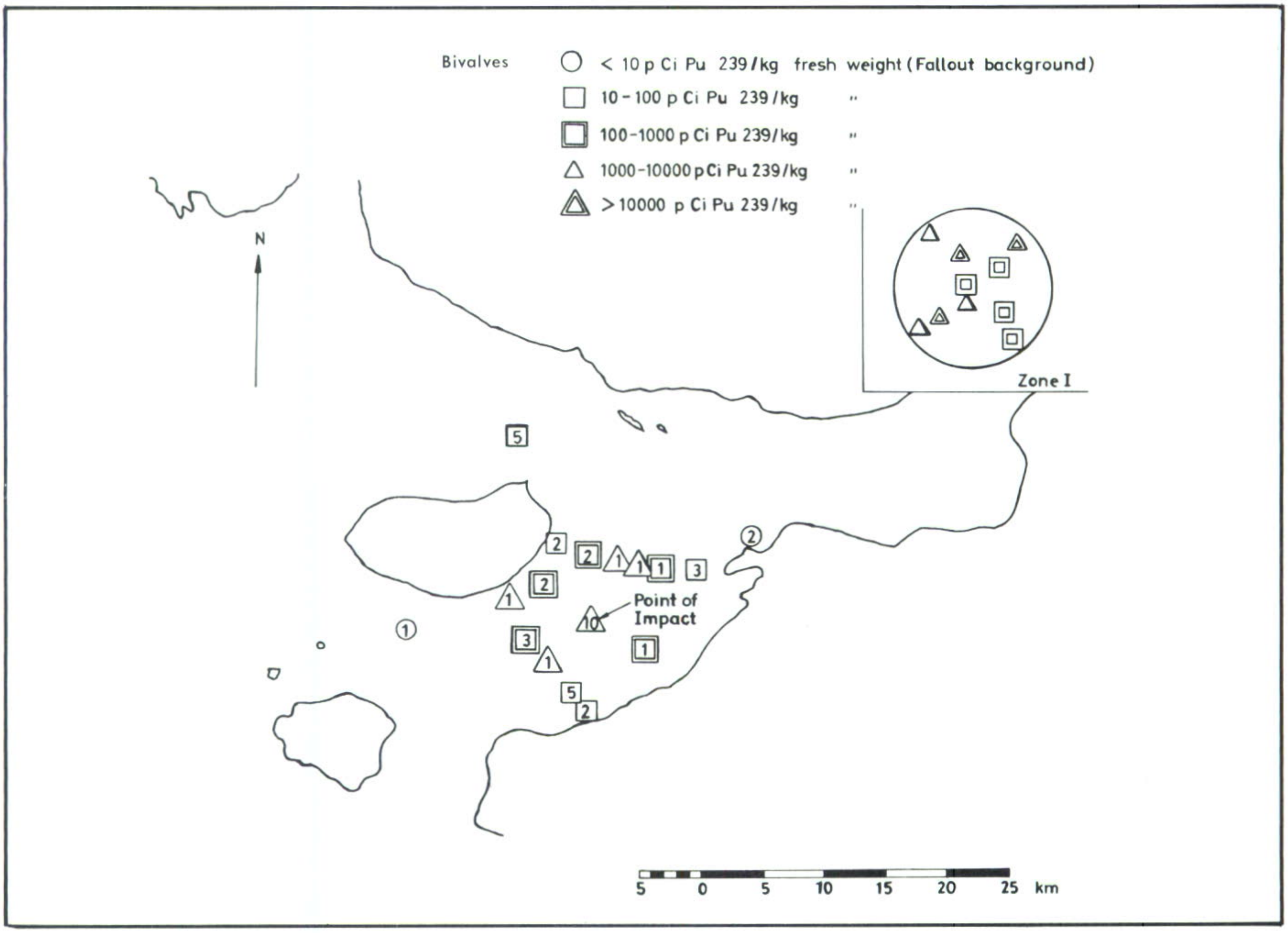


Figure 8 Pu 239 levels in bivalves. The numbers refer to the number of samples analyzed from each location.

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 shallow 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 230 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 walruses 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 significant 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 μCi. 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 μCi 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 PHYSICISTS' ACTIVITIES

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

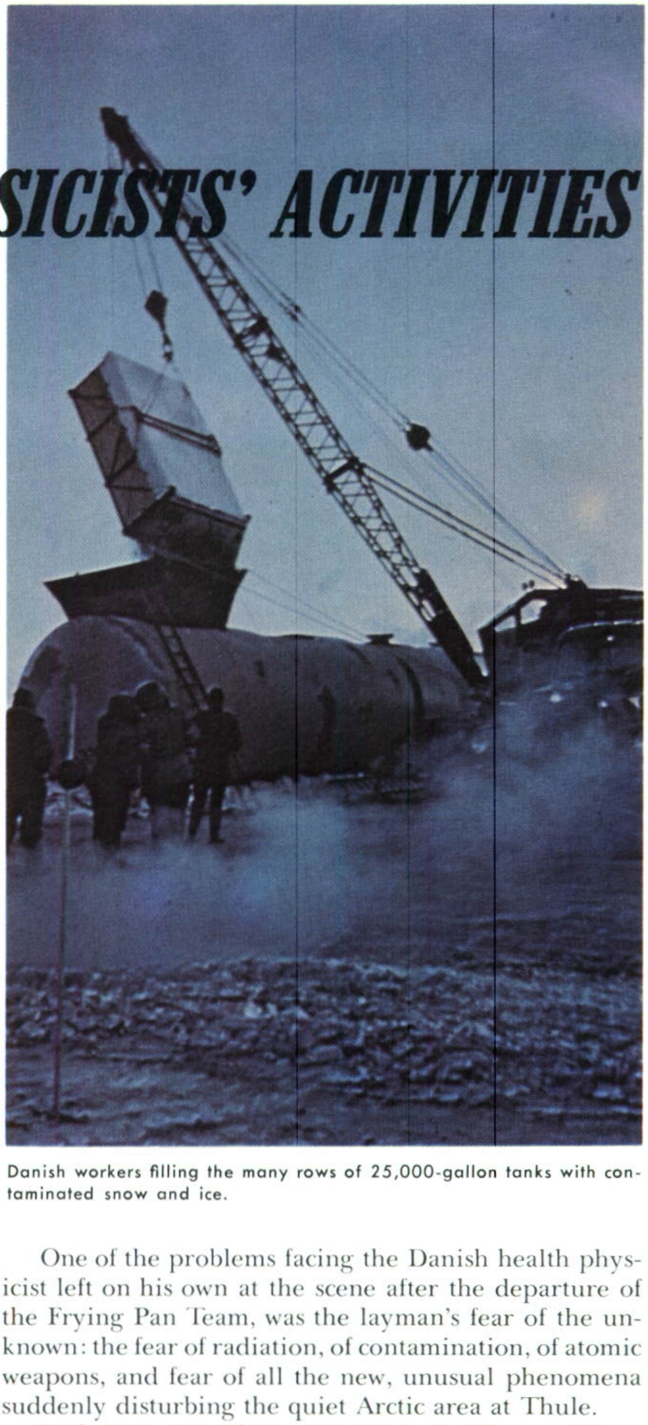
ABOUT 10 February, Henry L. Gjørup realized that an optimistic conclusion—that very little or no contamination would be found outside the crash area—would in all probability be drawn from the efforts of "Operation Frying Pan." Consequently, he set off for Copenhagen on 14 February in order to take part 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.



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

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

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

GUNTER E. FRANKENSTEIN
US Army Terrestrial Sciences Center
Hanover, New Hampshire

PROJECT Crested 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 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.

Two main roads leading to Camp Hunziker.

Crack in the ice.

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.)