

Fol. 41 E

ICES C. M. 1994

/E: 16

Fisneridirektoratets
Bibliotek

Ref. G, H.
Marine Environmental
Quality Committee

**RADIOACTIVE CONTAMINATION IN THE BARENTS SEA,
PAST AND PRESENT STATUS,
UPTAKE OF RADINUCLIDES IN FISH AND ITS IMPACT ON
FISHERIES.**

by

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Abstract

During the atmospheric nuclear bomb test at the end of the fifties and in the beginning of the sixties the Institute of marine research, IMR, monitored the radioactive contamination in commercial landed fish from the Barents Sea. There were indications of an immediate response in uptake of radionuclides depending on the time of the year, probably due to the food situation for the fish. There was also indications of species dependant uptake of radionuclides in fish. Even during the most intensive test period with fall-out directly to the Barents Sea the total beta-activity never exceeded 80 Bq pr kg fish.

The last years media focus on potential radioactive contamination in the Barents Sea have necessitated an establishment of a quite extensive monitoring program, both in fish, water and sediments. The area of interest extends from the site of the sunken former Soviet submarine, "Komsomolets" in the west to Novaya Zemlya in the east of the Barents Sea.

There is at present no significant indication of elevated contamination due to the dumping of radioactive waste by the former Soviet Union. The only present serious concern to the fisheries is the enormous focus from the media on the sunken submarine, "Komsomolets", and the dumped radioactive material in the Kara Sea.

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The Barents Sea

The Barents Sea, Fig. 1, is a shallow sea with an average depth of 230 m, and covers the area between 70°N and 80° N and from the west at the rise of the slope from the depth of more than 2500 m in the Norwegian Sea to the coast of Novaya Zemlya in the east. With an area of 1,4 million km², the Barents Sea represents only about 7% of the total areas of the Arctic ocean. As an extreme

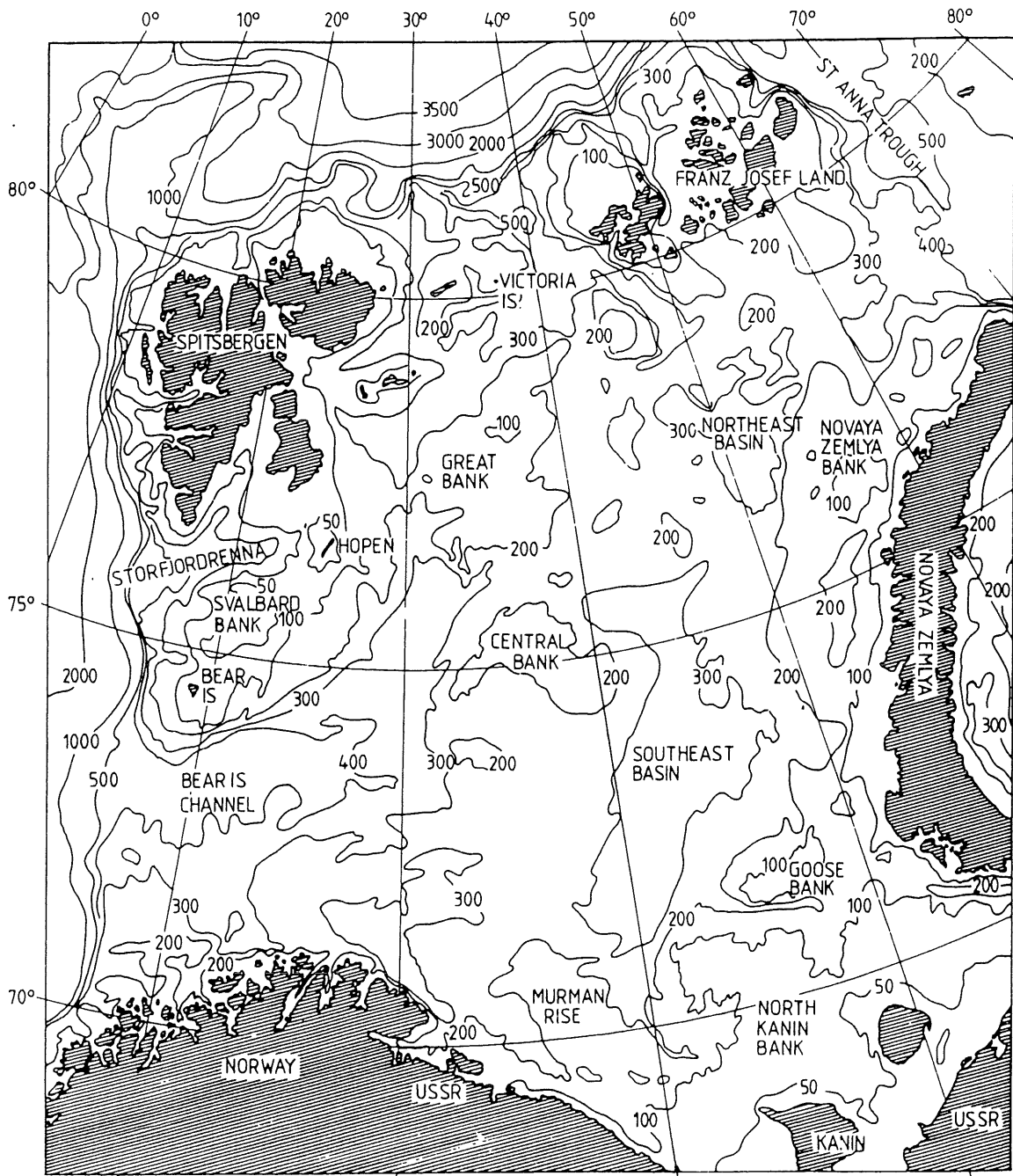


Fig. 1. Bathymetric map of the Barents Sea (Loeng, 1989).

maximum during winter and spring, as much as 75% of the surface can be covered by ice. The annual variation is however considerably. Most of the ice melts during the summer and creates by this process a special hydrographic regime with a rapid developing ice-edge phytoplankton bloom (Skjoldal and Rey, 1989, Sakshaug and Skjoldal, 1989). This highly productive zone follows the ice-edge retreating northwards during the melting. The inflow of warm, nutrient rich Atlantic water to the Barents Sea is another essential factor influencing the conditions for biological production in the area. The Barents Sea is, however, characterized by large fluctuations in the inflow as well as large seasonal and inter-annual variability in the ice cover.

Representing only about 0,4 % of the total surface of the world oceans, this area produces about 4 % of the total world fish catches. The Barents Sea ecosystem contains some of the world largest fish stocks like the capelin, the Northeast Atlantic cod and partly the Norwegian spring spawning herring. There are strong interactions between these stocks, and variations in the year-class strength have a marked influence on other components of the ecosystem (Hamre, 1991).

In addition to the direct harvest of the area the value as feeding grounds for fish populations harvested further south on the Norwegian shelf is considerable. The Norwegian shelf area from 62° N and northwards is spawning grounds for the most important fish populations of the Northeast Atlantic. Fish-egg and larvae are transported via the Norwegian Coastal Current to the Barents Sea.

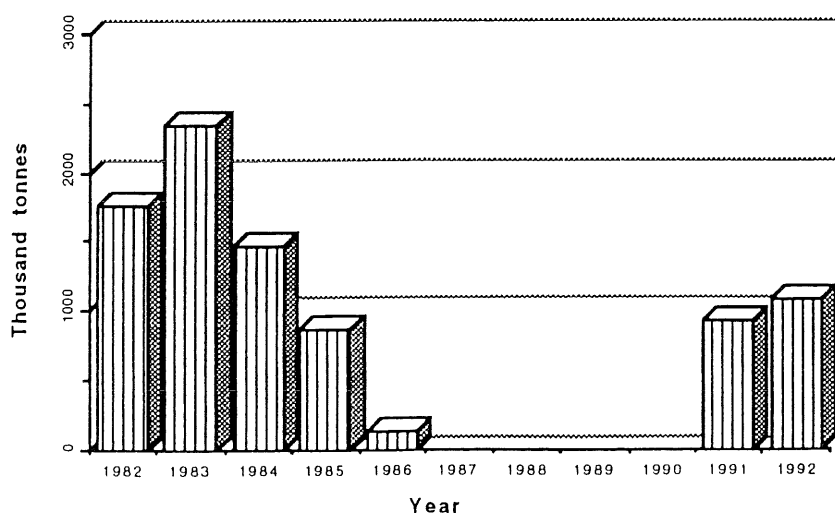


Fig.2. Yearly catches of capelin (*Mallotus villosus*) in the Barents Sea

The annual catches of fish from the Barents Sea have, during the last forty years, been in the order of 2,0 - 3,5 million tonnes. There have been a

considerably variation in the catches due to both overfishing and changing environmental conditions. This variability is illustrated in figs 2 and 3, which summarises the last ten years landings of capelin, cod and haddock.

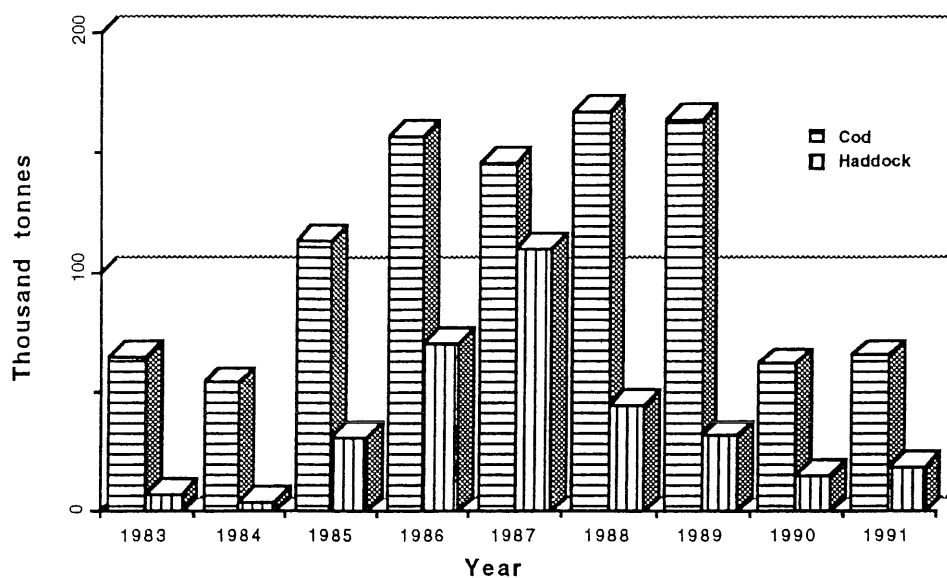


Fig. 3. Yearly catches of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) in the Barents Sea.

Radioactive contamination

a) Observations in the sixties

In the late nineteen-fifties rumours about radioactive contamination of the marine resources of the Barents Sea began to affect the Norwegian fishing industry. The Institute of Marine Research, IMR, Bergen, as an advisory research institute under the Norwegian Ministry of Fisheries, started then, in 1958, a monitoring program on radioactivity in fish meal produced by a fish-fillet factory in Hammerfest. The fish meal was processed of left-over from the fillet fabrication, i.e. skin, bones and other non edible fish tissues. The samples represented an average of the catches from the various fishing areas, and the measurement was aimed to detect possible radioactive contamination in commercial landed fish.

The intense Soviet nuclear bomb tests at Novaya Zemlya in 1961 initiated, in addition to the ongoing monitoring of fish-meal, regular measurements on the most important fish species, i.e. cod and haddock, on an individual basis. A summary of the results of these measurements is presented in fig. 4, (Føyn, 1991). The values at the time of measurement were reported as total beta-

activity minus the activity of potassium - 40, (Berge pers com.), and the potassium-40 values were calculated on the basis of a constant isotope ratio after determination of total potassium content in aliquots of the samples by the use of flame spectrophotometry, 1g K giving 1.740 dpm beta-activity.

Although the monitoring was not specific regarding determination of radionuclides, the results gave a sufficiently good basis for a continuous assessment of radioactive contamination of fish and fish products from the

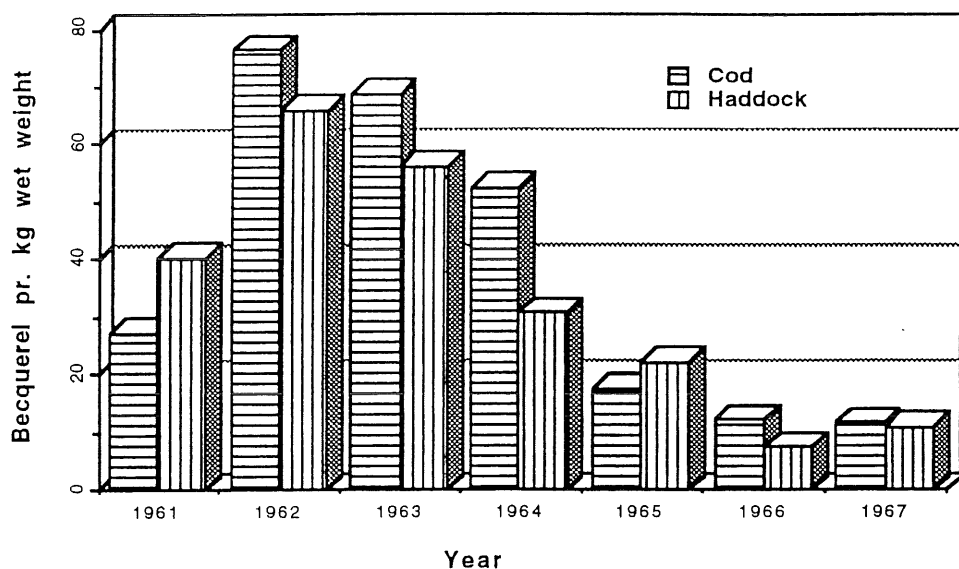


Fig. 4. Yearly mean values of total anthropogenic beta-activity in the edible part of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) from the Barents Sea in the period from 1961 through 1967 (Føyn, 1991).

Barents Sea. The collected data was used in an advisory contexts and unfortunately very few of the results were published outside internal notes. The observed contamination varied from an average maximum value of close to 80 becquerel pr kilogramme wet weight (Bq kg⁻¹ w.w.) to below 10 Bq kg⁻¹ w.w. in 1968, a value believed to be at the anticipated background level.

At the time of closure of the monitoring programme in 1968 it was believed (hoped?) that the problem of radioactive contamination in the fish resources of the Barents Sea was a thing of the past. The Chernobyl accident and more recent events as the wreckage and sinking of the former Soviet nuclear submarine "Komsomolets" and the documentation by the Russian government (Annon, 1993a) of the problem of dumped radioactive material at the east coast of Novaya Zemlya, have proved different.

The measurements undertaken during the monitoring programme increased our knowledge of the behaviour of direct fallout to the ocean. The nuclear bomb tests conducted in the eastern Barents Sea created a considerable direct contamination of this sea area. An example of such direct contamination was experienced by one of our research vessels working close to the test area during a detonation in the late fifties, measurements undertaken more than one month after the visit to the actual area and after several wash-down of the whole ship, showed considerably activity especially in ropes and tarpaulins.

The collected data from the monitoring program showed clearly differences in contamination between the fish-meal samples and the individual samples. (Sampling frequency was in the most intense period twice a week.) While contamination was clearly demonstrated in the individual samples, muscle tissue, the fish-meal which consisted of skin and bone and other non edible parts as the gills, where water flushes through constantly, showed less evidence of contamination. This indicate that the uptake of radionuclides was through the food. The monitoring showed also an "immediate" response of higher contamination following a bomb test.

There was also a pronounced seasonal difference in the radioactive contamination of the fish. In the summer situation with high secondary production following the phytoplankton bloom the radioactive contamination was also at its highest. Indicating that the bio-concentration was through phytoplankton to zooplankton. During the highly productive summer season the various fish species may shift their diet to smaller species.

Berge (pers. com.) observed variation in the composition of radionuclides from one contamination period to another. Cod samples from October 1961 were dominated by rather short-lived radionuclides while in cod samples from October 1962, although a pronounced presence of short-lived, the long-lived radionuclides dominated.

Iodine-131, manganese-54, zinc-65, ruthenium-106 and cesium-137 contributed to the contamination.

Another observation maid by Berge was the species dependent uptake of strontium-90 in fish bones. During the maximum radioactive contamination period in the summer of 1962 strontium-90 was measured in cod, haddock and spotted catfish. While significant levels of strontium-90 was detected in the samples of haddock, only insignificant levels were determined in cod and spotted catfish.

The monitoring program was closed in 1968 when the situation concerning radioactive contamination of the marine resources of the Barents Sea, was found to be at the anticipated background level.

b) Present observations

When the Chernobyl accident happened almost two decades had passed without any systematic monitoring of the radioactivity in the Barents Sea. The accident initiated new activity in this field at the Institute of Marine Research, IMR.

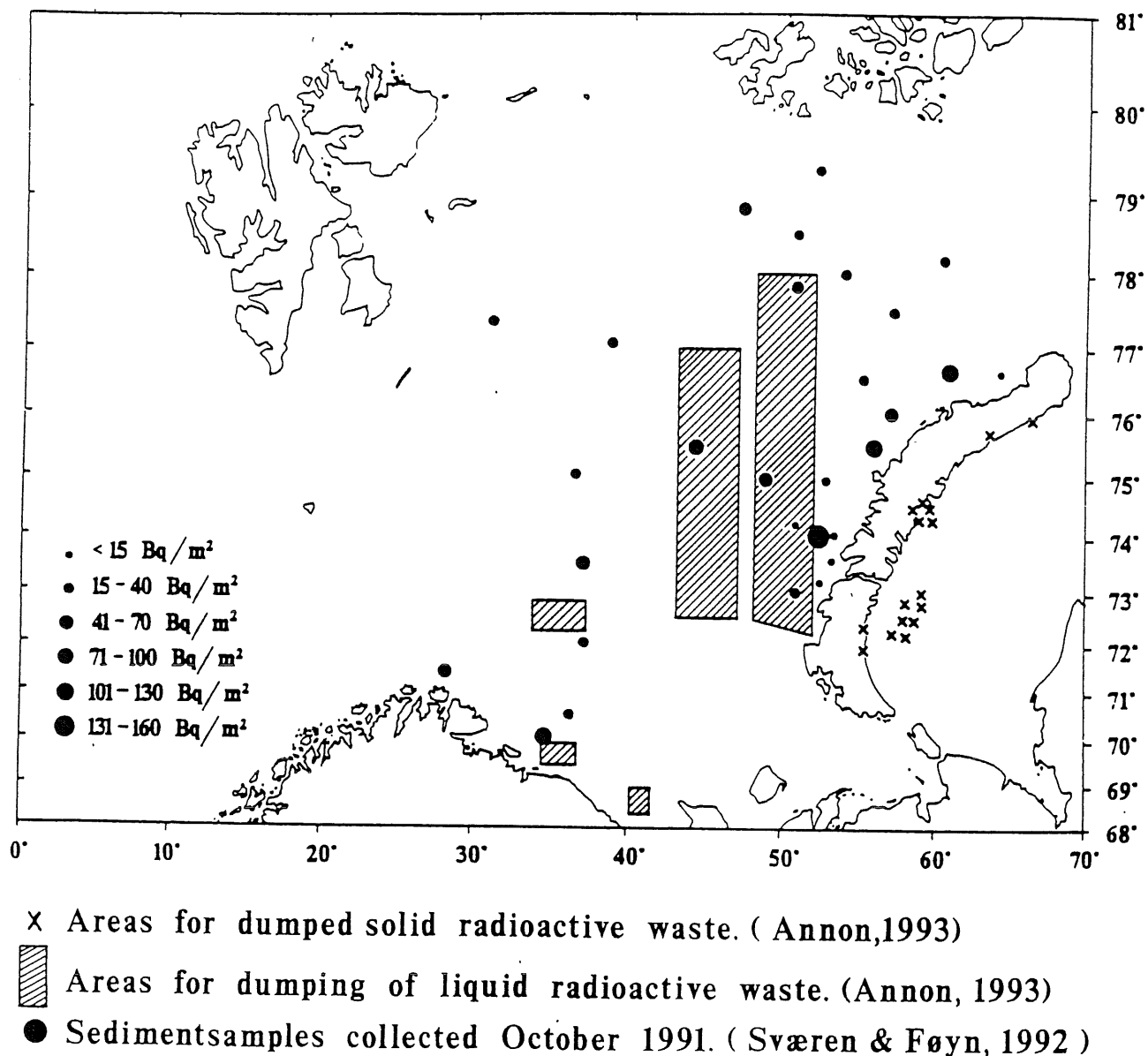


Fig. 5. Cesium-137 values in sediment samples from the Barents Sea and areas and sites of the former Soviet dumping of radioactive waste. Locations for the former Soviet Union dumpsites are according to the official Russian documentation (Anon, 1993a).

New instrumentation was provided through a special governmental funding and by 1990 we started the sampling of sediments and water in the Barents Sea for, in the first hand for determination of radiocesium.

Sediments

Figure 5 presents the results of the measurement of cesium-137 in sediment as becquerel pr square meter from the upper 1 cm. Highest values, amounting to about 150 Bq m², are found in the eastern part of the Barents Sea. As can be seen from the figure the highest values are also found in the vicinity of areas where there have been discharges of low-level liquid waste (Annon,1993).

Biota

Some fish samples (5) from the Barents Sea have been measured by the Norwegian Radiation Authority, values between 1,6 - 3,3 Bq kg⁻¹ w.w. for ¹³⁴Cs + ¹³⁷Cs were found (Selnæs pers. com. 1993). The Directorate of Fisheries is monitoring fish from commercial landings and so far no values have exceed their detection limit of 20 Bq kg⁻¹ radiocesium.

The russian fisheries institute, PINRO, in Murmansk, measured radioactive contamination in seaweed from the eastern part of the Barents Sea in 1991, they reported values from 4 - 10 Bq kg⁻¹ dry weight. Earlier measurements reported, 1980 - 1983, from the western Barents Sea and the Norwegian coast are within the same range.

Water

Our measurements in surface samples collected in 1991 showed values of cesium-137 between 5 and 15 Bq m⁻³. This values are within the same range as the values determined on board the Russian research vessel "Akademik Boris Petrov" on a cruise along the Norwegian coast and in the Barents Sea in June 1991. The results from these measurements showed a distinct reduction in cesium-137 levels in the surface water as the ship moved northwards, from about 50 Bq m⁻³ in the Skagerrak at the southern border of Norway, to values around 10 Bq m⁻³ in the Barents Sea.

The dumping of radioactive material in the Kara Sea

According to official Russian information, (Anon, 1993a) 576 TBq of low and medium level solid waste and 85 PBq from reactors, of which seven are with spent fuel and ten without fuel, have been dumped in the Kara Sea and in fjords at the east coast of Novaya Zemlya.

At the time of this presentation, there have been three joint Norwegian -

Russian expeditions to the area. The third cruise ended on September 19 of this year. The first expedition took place in August - September 1992. Preliminary results from this cruise were presented to the London Commission in November 1992, (Føyn and Semenov, 1992), and showed values for Cs-137 around 5 Bq m⁻³ for the surface water of the Kara Sea. The final results presented in (Anon, 1993b) showed Cs-137 values in the water in the range 3,3 - 20,4 Bq m⁻³, with the highest values close to the bottom in the deepest part of the Kara Sea. The corresponding Sr-90 values were in the range 3,0 - 12,1 Bq m⁻³ (Anon, 1993b).

Sediment samples were collected as part of the programme and values from the upper 10 cm showed values of Cs-137 in the range 90 - 500 Bq m⁻², and Pu-239,240 values in the range 2,5 - 18 Bq m⁻², (Anon, 1993b). The highest plutonium value was found at a station in the entrance to the Kara Sea, which was close to an on shore nuclear testing ground.

Samples of biota were also measured. Only a few gammarides and ophiurides were collected with measured mean values in gammarides of Cs-137 of 1,51 Bq kg⁻¹ DW and of Pu-239,240 of 0,011 Bq kg⁻¹ DW. In the ophiurides the values were at the detection limit in the gammarides for Cs-137 and a mean value for Pu-239,240 of 0,118 Bq kg⁻¹ DW (Anon, 1993b).

Preliminary results from the second expedition, which took place in September - October 1993 showed similar small values (Føyn and Nikitin, 1993). At the second expedition we had the information presented by the Russians (Anon, 1993a) about positions of the dumpsites with fairly good coordinates. We were able to locate dumped material and we inspected the various obstacles with an ROV on which we had mounted video camera and a gamma-detector. There was also a device for sediment collection mounted to the ROV.

In the Stepovogo fjord we inspected a sunken nuclear submarine which was sunk at a depth of 30 meters. Sediment samples collected close to the compartment in the submarine where the reactor with fuel was located showed no indication of contamination according to the preliminary measurements undertaken on board (Føyn and Nikitin, 1993).

Only at one position in the inner part of the Stepovogo fjord were elevated levels of Cs-137 detected in the sediments, in this sample Co-60 was also detected. Table 1 presents the preliminary results from measurement on our HpGe-detector performed on board.

<i>St. 1 Tsivolki Cs-137</i>	<i>St. 4 Tsivolki Cs-137</i>	<i>St. 5 Stepovogo Cs-137</i>	<i>St. 6 Stepovogo Cs-137</i>	<i>St. 6 Stepovogo Co-60</i>	<i>St. 9 Kara Sea Cs-137</i>
6 Bq kg ⁻¹	8 Bq kg ⁻¹	5 Bq kg ⁻¹ *	25 Bq kg ⁻¹ *		6 Bq kg ⁻¹
7 Bq kg ⁻¹	6 Bq kg ⁻¹	10 Bq kg ⁻¹ *	40 Bq kg ⁻¹		
6 Bq kg ⁻¹		6 Bq**	90 Bq kg ⁻¹	5 Bq kg ⁻¹	
4 Bq kg ⁻¹			68 Bq kg ⁻¹	3 Bq kg ⁻¹	
4 Bq kg ⁻¹					
4 Bq kg ⁻¹					
5 Bq kg ⁻¹					

Table 1

Preliminary measurements of Cs-137 and Co-60 (detected only at St. 6) in sediments. Values in becquerel per kg wet weight.

* Sediment samples collected with the ROV.

** Sediment sample collected with the ROV close to the submarine.

After (Føyn and Nikitin, 1993).

The final report of the 1993 expedition is in preparation, but this more detailed measurements confirm the preliminary results obtained on board during the cruise. Except for the values from St. 6 there is no indication of any leakage from the dumped radioactive material in the areas inspected during the expeditions in 1992 and 1993.

The "Komsomolets" - situation

The media focus on the sunken former Soviet submarine is continuing in an astonishing force. The submarine has found its rest at the depth of 1658 m in the position 73° 43,49' N and 13° 15,96' E. The water masses at this depth are more or less closed off from the upper layers due to the hydrographic conditions. Any release from the wreck of radionuclides will slowly be mixed with the deep water masses in the Norwegian Sea. This water will only surface to biological active layers in some hundred years, and then in the southern part of the Atlantic Ocean. The enormous water masses available for dilution secure the potential radioactive contamination in the ocean, due to leakage from the "Komsomolets" to be insignificant.

There have been three extensive Russian expeditions to the wreck. By the use of manned mini-submarines, the "Mir 1" and "Mir 2", inspections have taken place. From the inspections in 1992 and 93, it is clear that the "Komsomolets" has more severe damage to its hull than what was observed in 1990 when plans for a salvage operation were made. At present it seems not possible to salvage the submarine as such. There are, however, Russian considerations to rescue the front part with the nuclear missile-torpedoes or to seal this part off from the environment.

The purpose of such operations is said to be due to the environment, and it is especially underlined that release of plutonium will be a tremendous threat to marine life and the fisheries in particular. In the official Russian documentation of the dumping of radioactive waste from the Soviet Union, it is estimated an economic loss of 2,5 billion rubles (1991 values) for the fisheries, due to a release of plutonium from the wreck of "Komsomolets", (Anon, 1993a).

The plutonium present in the nuclear warheads is about 8 to 10 kg, it is in a metallic form and will disintegrate slowly into the seawater when the enclosure of the warheads is corroded. Some Russian experts claim that the release of plutonium will start in 1995-96, (Anon, 1993a). Other Russian experts are more in line with western estimates that it may take hundreds of years, before plutonium is released to the water masses around the wreck.

The ecological importance of a plutonium release at the depth of more than 1600 meters is rather insignificant. The amount of plutonium is estimated to be a maximum of 8-10 kg. As a comparison there has been a discharge from Sellafield, into the Irish Sea, throughout the last 30 years in an amount of 200 - 400 kg Pu. Ninety percent of this is found in the sediments close to the discharge point (Williams et al., 1988), and there does not seem to be any real problems regarding the regular fishing industry in the Irish Sea.

There is also experiences from other plutonium releases. For example the crash of an US B-52 aircraft, carrying four nuclear bombs, on the ice off Thule air base at the Northwest coast of Greenland in January 1968. The bombs were destroyed in the crash but no nuclear explosion took place. Both the ice and the bottom sediments were contaminated by plutonium as a result of the accident. About 0,4 kg plutonium ended up at the bottom and is distributed at the sea-floor which has a depth of from 100 to 300 meter. The transfer of plutonium in the actual marine ecosystem have been studied since the accident in 1968, There is observed plutonium contamination in bottom living biota, but there is a distinct discrimination against plutonium when we move to higher trophic levels in the food-chain (Aarkrog, 1993).

The movement of the plutonium at the bottom and in the sediment, is described by the median distance, i.e. the distance from the place of accident to where half of the activity is found. The median distance increases by about 400 meters a year, (Anon, 1990a).

Both the experience from the Sellafield discharge as well as the Thule accident with plutonium releases to the marine environment, show that the threat, as expressed by some Russian and other sources, to the marine life and in particular to the marine fisheries from the plutonium of "Komsomolets" is exaggerated.

For the assessment of the potential pollution from "Komsomolets" it can be concluded that due to;

- the great depth where the release of radioactive material will take place,
- the actual and relatively small amount of radioactive material available for release,
- the enormous water masses available for dilution,
- the additional "chemical dilution"
(derived from the fact that the radioactive isotopes of strontium and cesium are only a very small fraction of the total amount of strontium and cesium in sea water, and their biological uptake depends on the chemical behaviour of the element and not whether it is a radioactive or a non radioactive isotope),
- the relatively biologically inactive plutonium which will be found in particulate form in the sediments close to the release point,

the sunken nuclear submarine represents a minor radioactive pollution problem.

Concluding remarks

The fish resources as such of the Barents Sea have not yet been affected by anthropogenic radioactivity. Neither during the nuclear bomb tests in the fifties and sixties, nor during recent years due to accidental releases. The fisheries may however, be dramatically affected by the fact that the focus of the media on radioactive contamination frightens people from eating fish. Television programmes with "nice" pictures of nuclear explosions combined with pictures of fishing activities and further a dish with fish with a question-mark of the edibility of the food are not especially in favour for the fisherman and the fishing industry.

The uptake of radionuclides in marine fish is not as significant as in fresh water fish. This may be due to the fact that an organism do not distinguish between a radioactive isotope and a non-radioactive isotope of the same element. It is the chemical properties of the actual element that govern the uptake in an organism. In sea water where all the elements are present there is therefore a potential of a chemical dilution in addition to the dilution which the enormous water masses represent.

As was observed during the nuclear bomb tests in the late fifties and the early sixties, there were also seasonal variations in the uptake (Berge, pers.com.). The great variations in the fish stocks as shown in figs. 2 and 3, and thereby a change in the feeding conditions at higher trophic levels, will add to the complexity of making estimates of a potential dose to man of radioactivity from

observed concentrations in water and sediments.

The problem of radioactive contamination in the marine environment is to this day far less than the problem of contamination by organic micro pollutants. Sætre et. al., 1992, in summarizing the situation in the Barents Sea, points to the fact that persistent organic pollutants as PCBs, are found in all marine species of the area. These pollutants are concentrated through the food-web and create a potential threat to animals as seal and polar bear.

For the concern of the radioactive contamination of the Barents Sea we will continue the monitoring,

- a) to detect possible changes in the presence of radionuclides in Norwegian waters, and to develop a base for assessing, in a readiness situation, the impact of potential accidental releases, and
- b) to document the potential of contamination both in marine fish and in the marine environment for the purpose of avoiding speculations about the quality of fish products from Norwegian waters.

Acknowledgment.

The documents dealing with the problem of radioactive contamination in the fifties and sixties, both hand written and data sets not published have been made available from the personal files of former research director at the IMR, Dr. Grim Berge. I would like to use this opportunity to thank him for valuable information and inspiring discussions about marine radioactivity.

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