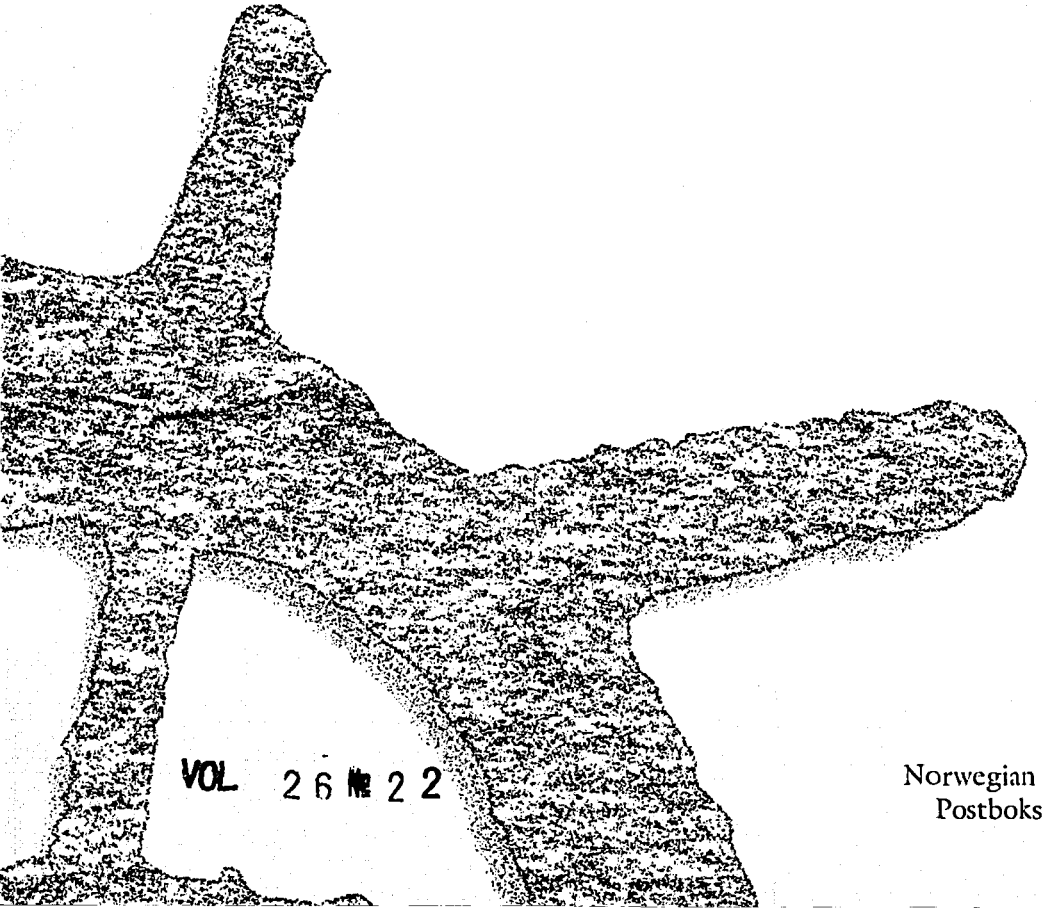
StrålevernRapport 1995:1

Radioactivity in the marine environment

Report from the national surveillance programme

Morten A. K. Sickel, Tone D. Selnæs, Gordon C. Christensen, Bjarne Bøe, Per Strand and Turid Hellstrøm



Statens strålevern

Norwegian Radiation Protection Authority
Postboks 55 · N-1345 Østerås · Norway

NRPA Report 1995:1

Radioactivity in the marine environment

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Morten A.K. Sickel, Norwegian Radiation Protection Authority
Tone D. Selnæs, Institute of Energy Technology
Gordon Christensen, Institute of Energy Technology
Bjarne Bøe, Directorate of Fisheries
Per Strand, Norwegian Radiation Protection Authority
Turid Hellstrøm, Norwegian Food Control Authority

Sickel M. et. al. Radioactivity in the marine environment, report from the national surveillance programme. NRPA Report 1995:1 Østerås, Norwegian Radiation Protection Authority, 1995.

Key words:
Radioactivity in the marine environment, Norwegian surveillance programme.

Abstract:
A large number of samples from the marine environment have been measured. All the samples have confirmed the low levels of radioactivity in the North Atlantic Ocean. All measured levels of radioactivity in foodstuff are by far below the intervention levels for radioactive contamination of food.

Sickel M.et.al. Radioaktivitet i det marine miljøet. Rapport fra det nasjonale overvåkningsprogrammet. Strålevernsrapport 1995:1 Østerås, Statens Strålevern, 1995. Språk: engelsk

Nøkkelord:
Radioaktivitet i det marine miljø, Nasjonalt overvåkningsprogram

Resyme:
Et stort antall prøver fra det marine miljøet er blitt målt. Disse prøvene har bekreftet det lave nivået av radioaktiv forurensning i Nordatlanteren. Alle nivåer som er målt i matvarer ligger langt under tiltaksgrensene for radioaktiv forurensning i matvarer.

The project is funded by the Ministry of Fisheries and the Norwegian Radiation Protection Authority. Samples from the monitoring programme "Radioactivity in Marine Fish" headed and funded by the Norwegian Food Control Authority are also included.

Head of project: Per Strand. Norwegian Radiation Protection Authority,
P.O. Box 55 N-1345 Østerås, Norway.

Approved

Per Strand, Environmental Protection Department

18 pages. Published 1995-02-24 Printed number 450
Cover design: Graf, Oslo. Printed by Grüner & Jebsen, Østerås

Orders to
Norwegian Radiation Protection Authority, P.O. Box 55, N-1345 Østerås, Norway,
telephone +47 67 16 25 00, fax +47 67 14 74 07

ISSN 0804-4910

Summary

During 1994 a large number of samples from the marine environment have been measured. Regarding fish, 22 samples have been measured for all gamma emitting radioisotopes using HPGe detectors, Four pooled samples have been analysed for ^{90}Sr, three pooled and seven single samples have been measured for plutonium. Approximately 900 samples have been analysed for radiocaesium using equipment with higher detection limit. In addition, 21 samples of minke whale, one sample of prawns, ten samples of seaweed, and four samples of sea-water have been analysed for gammaemitters. Three seaweed samples and three seawater samples have been analysed for ^{90}Sr and plutonium.

So far, all the samples have confirmed the low levels of radioactivity in the North Atlantic Ocean. The fish samples which have been measured for all gamma emitting isotopes show activity levels of ^{137}Cs of approximately 1 Bq/kg and up to 3 Bq/kg for one single sample of meat. In addition, selected samples are measured for ^{90}Sr and plutonium isotopes. These radionuclides are found in levels up to 0.5 Bq/kg and 1.3 mBq/kg for ^{90}Sr and $^{239,240}Pu$ respectively. Compared to the intervention levels for foodstuffs, the levels found in marine fish from the Norwegian fishing areas are negligible. Measurements have also been carried out on other kinds of seafood, i.e. prawns and whale meat. These samples showed a maximum value of 0.18 and 5.9 Bq/kg ^{137}Cs respectively. Samples of seaweed and seawater also confirm these low levels of contamination.

Introduction

In recent years, the possible radioactive contamination of the marine environment has received much attention. The information about the dumping of nuclear waste in the Kara and Barents Seas, sunken nuclear submarines, as well as the present handling of nuclear waste on the Kola Peninsula have all further pushed the attention of the public as well as the science community and the authorities towards this issue. The uncertainty regarding the sources and their present and future releases has also led to the speculation that marine fish from the northern areas are radioactively contaminated.

Consequently, a national programme was initiated in 1994 to continuously monitor the levels of artificial radioactivity in the marine environment. In this programme, samples of fish, seaweed, and seawater are collected regularly to be measured for various radioactive substances. By that, it is possible to document the levels of radioactive contamination in such food and to estimate the development of radioactive contamination.

Under this monitoring programme, samples are collected for measurements of all artificial radionuclides: cod samples are collected four times a year, samples of capelin and shrimps are collected occasionally. These fish samples are collected from five different fishing areas; two in the Barents Sea; two in the North Sea and one in Skagerrak. The samples are collected by the Directorate of Fisheries from locations where commercial fishing is taking place. In addition to these samples, samples are collected monthly to be measured for radiocaesium.

Samples of seaweeds and seawater are also collected at selected places along the Norwegian coast. These samples are measured for all gamma emitting isotopes. Selected samples are also measured radiochemically for ^{90}Sr and plutonium isotopes. To the largest possible extent, relevant samples and results from other Norwegian programmes are also included in the monitoring programme.

The work is performed as a cooperation between the Norwegian Radiation Protection Authority (NRPA), Institute of Energy Technology (IFE) and the Directorate of Fisheries. At a later stage, the Institute for Marine Research (IME) is planned to be involved in the sampling of seawater and sediments from the open sea. The work is funded by the Ministry of Fisheries and NRPA.

In addition to the samples and results collected under the national survelliance programme, permission was given by the Norwegian Food Control Authority (SNT) to include samples and results obtained under their monitoring programme "Radioactivity in Marine Fish" under which samples are collected from local food processing plants in the northern parts of Norway and measured for radioceasium by the local food control authorities. Some pooled samples are also measured by NRPA at Svanhovd for all artificial gamma emmitters.

Intervention levels for food

After the Chernobyl accident, derived intervention levels for radioactivity in food were implemented. The levels used in Norway are the same as those which apply in the European Union. The derived intervention levels are 370 Bq/kg for milk and infant food, and 600 Bq/kg for all other foodstuffs concerning the nuclides ^{137}Cs and ^{134}Cs. In Norway national levels which differed from those in the Eurpoean Union were applied for reindeer meat, game and wild freshwater fish and are at present 3000 Bq/kg. The highest uptake of radiocaesium after the Chernobyl accident was observed in the terrestrial environment

and in freshwater fish. The uptake of radionuclides by marine biota shows much lower values.

For future accidents which may include other nuclides in the fallout, a nordic model for respons has been developed. In this model one would after the initial phase implement derived intervention levels which are:

- 1000 Bq/kg for the sum of all low energy beta emitting isotopes such as ^{134}Cs and ^{137}Cs in all foodstuffs exept milk and infant food.
- 100 Bq/kg for the sum of ^{90}Sr and corresponding radionuclides in all foodstuffs.
- 100 Bq/kg for the sum of ^{90}Sr, ^{131}I and corresponding radionuclides in milk and infant food.
- 10 Bq/kg for the sum of ^{239}Pu, ^{241}Am, and corresponding radionuclides (actinides) in all foodstuffs exept milk and infant food in which it is 1 Bq/kg.

Sources of radioactive contamination

Introduction

The marine environment of the North Atlantic Ocean is contamined with radionuclides from three main sources: Fall-out from the atmospheric bomb tests during the fifties and the sixties, fall-out from the Chernobyl accident in 1986, and from radioactivity discharged into the sea from various nuclear installations. The marine environment may also receive radioactive contamination through run off from contaminated land areas.

Of the various contaminants, the most important long lived radionuclides are ^{90}Sr, ^{137}Cs $^{239,240}Pu$. As opposed to strontium and caesium which behave almost conservatively in sea water, plutonium is strongly attached to the sediments (Smith et.al. 1994), thus strontium and caesium will be spread by the ocean currents, whereas plutonium mainly will be found near the source and is spread very slowly.

The two main sources of radiocaesium, strontium and plutonium discharged to the North Atlantic are the reprocessing facilities in Sellafield, UK and La Hague in France. The releases from Sellafield being up to a factor of 40 higher than from La Hague. When disregarding tritium, the releases from Sellafield have steadily decreased after peaking in the mid-seventies.

In 1986, the Chernobyl accident took place and the Northern Seas received contamination, either as direct fall-out, or as run-off from contaminated land areas. As opposed to the bomb tests fall-out and the discharge from nuclear installations, the Chernobyl fall-out mainly occured as one single pulse. The Chernobyl fall-out detectable in the North Sea, the Norwegian Sea and the Barents Sea today, mainly consists of the run-off from contaminated land areas(A. Arkrog, 1989). Approximately 30% of the ^{137}Cs in the surface waters of the southern Barents Sea seems to have originated from the Chernobyl accident (Strand et. al 1994).

In 1989, the estimated inventories of radionuclides in the North Atlantic were as follows (A.Aarkrog, 1989):

^{137}Cs:	150 PBq from global fallout (1PBq=10^{15} Bq)
	30 PBq from nuclear reprocessing
	20 PBq from the Chernobyl accident
^{90}Sr	100 PBq from global fallout
	5 PBq from nuclear reprocessing
$^{239,240}Pu$	3 PBq from global fallout

Other sources

In addition to the radioactivity already released in the environment, there are a number of locations where there exist potential risk for radioactive material beeing released to the environment or where lesser amounts of radioactive materials are beeing released to the environment. These releases may take place within a shorter or longer time frame. This is not a complete overview of the potential sources of radioactive contamination to the northern seas, but should give a general picture of the situation.

Dumping of nuclear waste

From 1959 until 1991, the Russian Navy and the Russian ice-breaker fleet dumped nuclear waste in the Northern seas on a number of occations. The dumped waste ranged from low

level liquid waste to highly active spent nuclear fuel. The total activity dumped in the Kara Sea was estimated to be in the order of 90 PBq «^{90}Sr equivalents», the major part being ^{90}Sr and ^{137}Cs. In addition, in the order of 450 TBq (1TBq=10^{12} Bq) of liquid waste and 1,5 TBq solid waste have been dumped in dedicated areas of the Barents Sea (Figure 1) (Yablokov *et.al.* 1993).

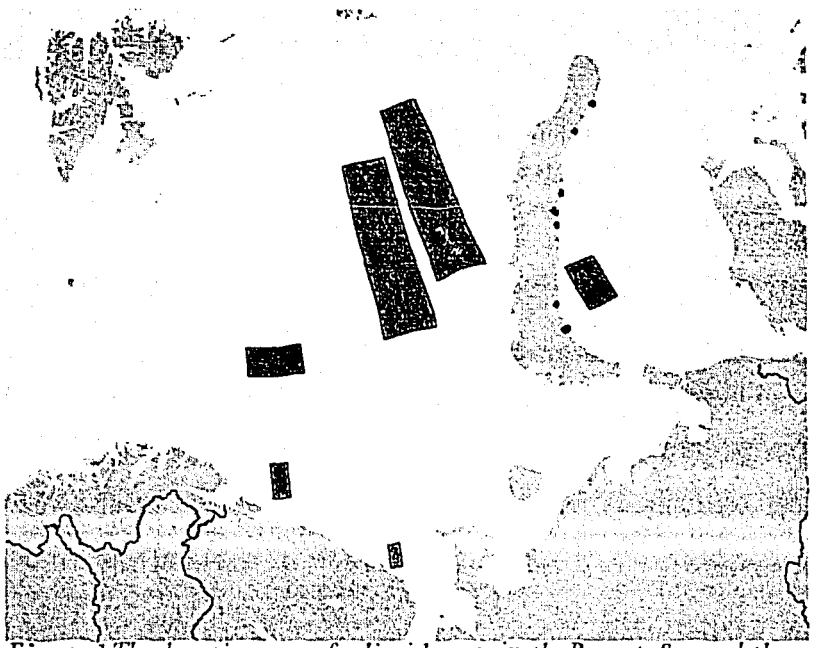

Figure 1 The dumping areas for liquid waste in the Barents Sea and the dumping areas for solid waste in the Kara Sea and along the east coast of Novaja Zemlya are shown.

Under the IAEAs International Arctic Seas Assessment Programme (IASAP) work is being done to more precisely estimate the amounts of different radionuclides in the dumped nuclear fuel and to assess the potential future consequences of the dumping. So far, the estimates of the Yablokov report seem to be too high. This is mainly caused by an overestimation of the burn up of the fuel. This work is still not finished and no better estimates are yet available.

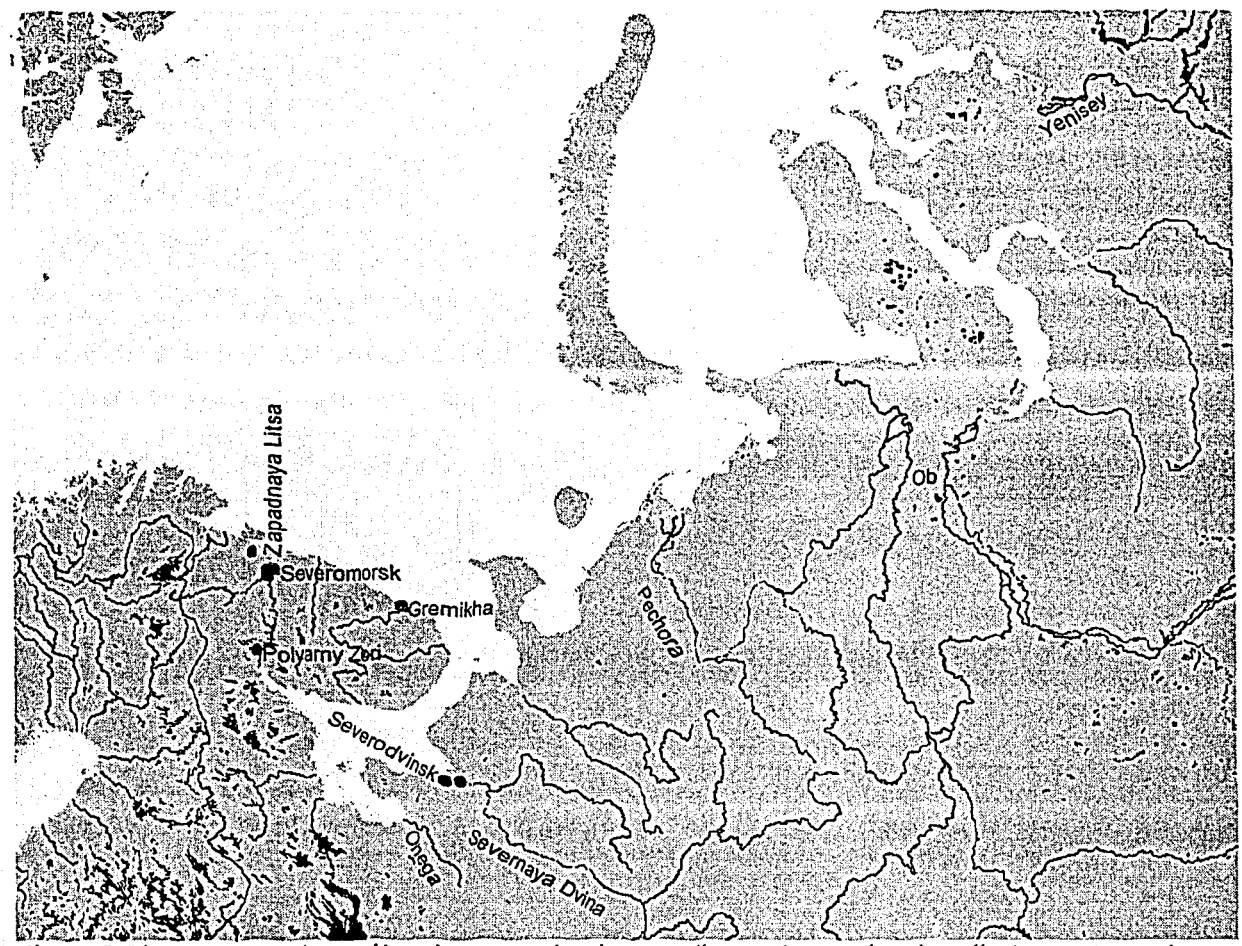

Figure 2 Rivers transporting radioactive contamination as well as various nuclear installations are named

Bases for the nuclear fleets

Along the coast of the Kola Peninsula, the Russian northern fleet, as well as the civilian Russian ice-breaker fleet have their main bases (Figure 2). At some of these sites, nuclear fuel is handled; refilled and stored. Both the actual handling of nuclear devices, and the storage of spent nuclear fuel and other types of radioactive materials pose a potential threat of radioactive contamination of the Arctic environment.

At present, approximately 80 - 90 nuclear powered submarines are operating from the marine bases along the northern coast of the Kola Peninsula. In addition to the submarines, two nuclear powered cruisers, seven nuclear powered ice-breakers and one containership have their bases in Murmansk. As most vessels have two and some have one reactor, the number of reactors in operation is in the order of 200.

In addition to the operating vessels, approximately 70 decommisioned nuclear submarines are laid up at the naval bases in this area. As some vessels have one, but most of them have two reactors, approximately 140 reactors are present in the decommissioned vessels.

River transport

The rivers Ob and Yenisey drain large areas of Northern Russia. Within their drainage areas, several nuclear installations are located. On a number of occasions, radioactivity has been released to the environment within these areas. This includes global fall-out as well as discharges from nuclear installations and accidental releases.

For the Yenisey, the main source is the previous releases from the nuclear installation at Krasnoyarsk. For the Ob, the main sources are discharges and accidental releases from the reprocessing and plutonium production facilities at the Siberian Chemical Plant, Tomsk - 7 and Majak. It is difficult to estimate the impact on the oceans from these sources, especially prior to 1961 as data in the open literature are inconsistent. Based on observations carried out by the Russian organization Roshydromet during 1961 - 1989, in the order of 1 PBq ^{90}Sr and 0.1 PBq ^{137}Cs have been transported to the Kara Sea by these two rivers. As there is a net inflow of water from the Barents to the Kara Sea, one should expect only minor amounts of the activity in the Kara Sea water to be transferred to the Barents Sea.(JRNEG, 1993, Pavlov, 1993, Östlund, 1993)

In addition to the radionuclides transported by the Ob and Yenisey, approximately 200 TBq of ^{90}Sr and 20 TBq of ^{137}Cs have been transported to the Barents Sea by the rivers Pechora, Onega and Severnaya Dvina.(Vakulovsky, 1993)

Komsomolets

In 1989, the Soviet nuclear submarine Komsomolets caught fire and sunk south east of the Bear Island. The submarine contained a nuclear reactor and nuclear warheads. According to Yablokov et al in 1993, the main activity in the reactor consists of approximately 1.6 PBq ^{90}Sr and 2.0 PBq ^{137}Cs. The nuclear warheads contain altogether approximately 15 TBq ^{239}Pu.

The Institute of Marine Research has performed model analyses of the transport of radionuclides from Komsomolets. The conclution of that work is that the mobile radionuclides (i.e. ^{137}Cs and ^{90}Sr) released from Komsomolets are supposed to mix slowly with the water masses of the deeper part of the Norwegian Sea. Due to the ocean currents, the radionuclides will reach the biological active layers in the southern of the Atlantic Ocean in some hundred years. Until then, the radioactive decay of ^{137}Cs and ^{90}Sr will cause a substantial decrease in their activity (JRNEG 1993, Sætre 1994).

Nuclear Power Plants

As the Chernobyl accident clearly demonstrated, accidents in nuclear power plants (NPPs) may influence areas remote from their location. A number of NPPs are situated in north Europe. Anyhow, the NPP situated in Polyarny Zori at Kola is the only one situated within the Arctic areas. An accident at this NPP may cause severe radioactive contamination directly into the Arctic environment.

Thule accident

In 1968 an US B-52 bomber crashed on the ice near Thule airport in Greenland. During the crash, four nuclear weapons carried aboard were ruptured causing the release of ^{239,240}Pu. When disregarding the plutonium recovered immediately after the accident, approximately 1 TBq of ^{239,240}Pu was released to the environment. Anyhow, this plutonium has only undergone a minimal disperson and does not represent any significant source of radioactivity (Smith et. al. 1994).

Lighthouses

Since the middle of the sixties, approximately 130 lighthouses powered by a strong ^{90}Sr source have been built along the coast of the Kola Peninsula and Novaja Zemlya. Each source contains between 2000 and 10000 TBq ^{90}Sr. There is not much information available on the state of these lighthouses or the handling of the sources (JRNEG, 1993).

Methods

Collection and treatment of samples

Samples of fish and seafood

The fish and prawn samples in the surveillance program are collected by the Directorate of Fisheries at locations where commersial fishing is going on. The Norwegian Food Control Authority have bought fillets from local fish processing factories as these would best represent what is actually consumed by the public. From the fillets, the thickest parts were used for the measurements. Minke whale samples were taken from the research hunt in 1992. For all samples, the date and location of the catch were registered.

Seaweed and seawater samples

Samples of the brown seaweed bladder wrack (*Fucus vesiculosus*) have been collected from 10 locations along the Norwegian coast from the Russian border in the north to the Swedish border in the south. The sampling has taken place in August or September. All the seaweed plants taken were firmly rooted to the rock or large stones in the middle of their zone of growth in the tidal area. Simultaneously, 0.5 litres of seawater was collected to determine the salinity of the water. The plants were well shaken to get rid of sea water and shells.

At the same time and location, a larger sample of water was taken for measurement of radionuclides.

Analytical procedures

Analysis of gamma emitters

The samples of fish and seaweed measured at IFE were dried at 105°C and homogenised prior to gamma measurements. Fish bones and fish meat measured at NRPA were ashed at 750°C. Whale meat was not dried before measurements. Samples of 25 litres of seawater were evaporated at low temperature for measurements in 1 litre Marinelli beakers.

All samples were subjected to gamma spectrometry using various high resolution HPGe (high purity germanium) detectors (resolution in the range of 1.7-2.0 keV, relative efficiencies in the range of 30-55%). The counting times varied from two to several days. This method gives a limit of detection of approximately 0.05 Bq/kg wet weight.

Analysis of radiocaesium using NaI detectors

The laboratory of the Directorate of Fisheries in Tromsø and a number of local food control authorities are equipped with Canberra series 10 portable multichannel analysers with 3" NaI-detectors (resolution of approximately 7%, efficiency of approximately 5%). This equipment is used for routine analyses of food. During this investigation, fresh fish fillets were measured. Approximately 200 g is cut to small pieces and transferred to the measuring beaker. The measuring procedure gives a detection limit of approximately 20 Bq/kg wet weight. The counting time was in the order of 2-3 hours. Due to the efficiency and theoretical detection limit, longer counting times are not adequate.

Analysis of beta emitters

For analysis of ^{90}Sr, ^{85}Sr spike and Sr-carrier were added to the samples. Then the carbonate precipitate from 50 litres of water or the solution after acid leaching of ashed samples were subjected to radiochemical separation. Radionuclides interfering with the ^{90}Sr deter-

mination were removed with hydroxides and chromate precipitations. After the ^{90}Sr - ^{90}Y equilibrium was attained, yttriumcarrier was added and the ^{90}Y was precipitated as hydroxide and converted to oxalate for counting.

The counting samples were measured by low background anticoincidence beta counters (Risø type, background 15 pulses/hour, efficiency 55%). The chemical yields were determined by ^{85}Sr spike and titration with EDTA.

Analysis of alpha emitters

The precipitate from 50 litres of water samples, or aqua regia extracts from 10 g of ashed seaweed or fish were subjected to alpha analysis. After addition of ^{242}Pu, plutonium was separated by extraction with a 10% TIOA/Xylene solution. Then, plutonium was backextracted from the organic phase into 8N HCl, and separated by ion exchange chromatography. After electrodeposition on stainless steel discs, ^{238}Pu, $^{239,240}Pu$ and ^{242}Pu were measured by semiconductor silicon detectors (Chen et al., 1991).

Results

Measurements

During 1993 and 1994, a large number of fish samples have been measured. Five different series of analyses have been performed. The laboratory of the Directorate of Fisheries in Tromsø have performed measurements using NaI detectors. This equipment allows measurements of ^{137}Cs with a minimal preparation of the sample but a relatively high limit of detection. Under the monitoring programme "Radioactivity in marine fish" by SNT, local food control authorities in Hammerfest, Tromsø and Bodø have performed the same type of measurements. At NRPA in Bærum and Svanvik, and at IFE, measurements of ^{137}Cs are performed using HPGe detectors. With a more elaborate preparation of the sample, a limit of detection for this nuclide of approximately 0.05 Bq/kg wet weight is reached. Both IFE and NRPA have performed radiochemical analyses of plutonium. IFE has also performed radiochemical analyses of ^{90}Sr under this programme.

Radioactivity levels in fish and seafood

Fish

Samples have been measured for ^{137}Cs and other artificial gamma emitting nuclides using HPGe detectors. In one single sample from Skagerrak, some ^{134}Cs was found, in all other samples, ^{137}Cs was the only artificial radionuclide detected. The levels of ^{137}Cs for single samples varied from 0.2 to 3.2 Bq/kg wet weight. Compared to levels of ^{137}Cs in sea fish from some of the other North European fishing areas, these levels are low. (Figure 6 and Table 5) See figure 3 for catchment locations of the samples.

In 1993 50 samples and in 1994 300 samples of single cod from the Barents and Norwegian Sea were measured at the Directorate of Fisheries using NaI detectors. Approximately 130 samples of various fish species and were also measured. The local food control

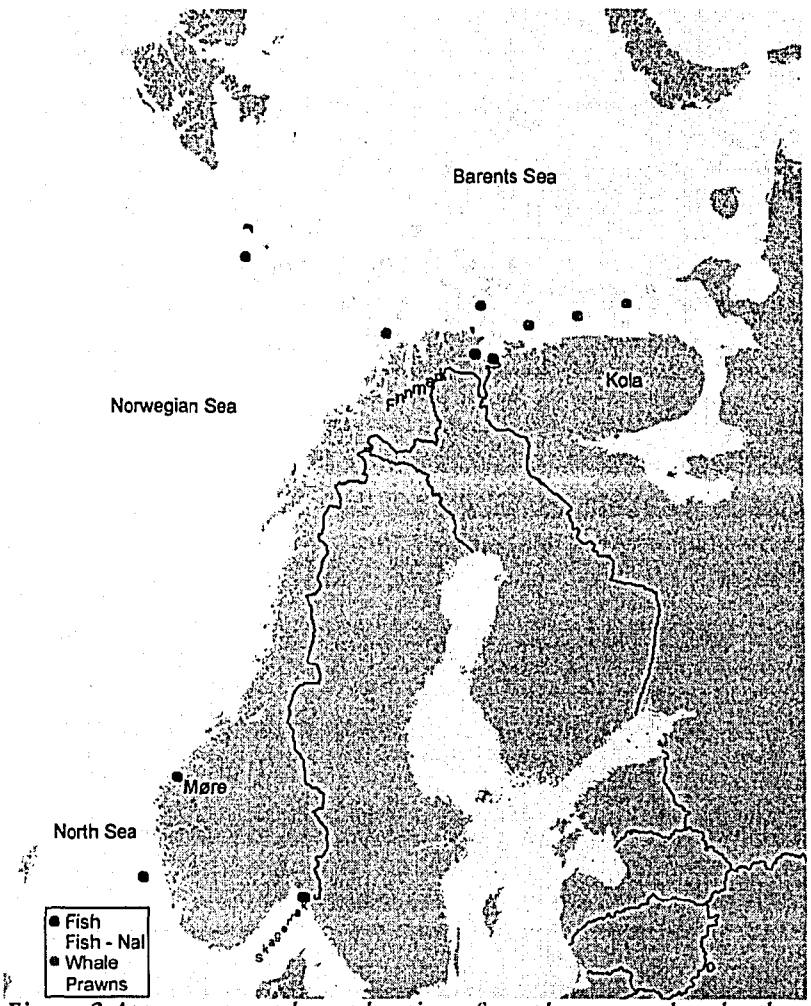

Figure 3 Approximate catchment locations of samples measured under the national surveillance programme

Table 1 Measured wet weight concentrations of various artificial radioisotopes in marine fish. All measurements are in Bq/kg wet weight

Species	Location	Year	^{137}Cs	^{90}Sr	$^{239,240}Pu$[1]
Cod	Barents Sea	Nov - 92	0.7±0.3	0.11±0.05	0.0013±0.0004
Cod	Møre	Nov - 92	1.7±0.3	0.28±0.07	0.0012±0.0004
Cod	Skagerrak	Nov - 92	1.6±0.2	0.06±0.03	0.0010±0.0002
Cod	North Sea	Nov - 93	0.30±0.02	n.m	n.m
Cod	Norwegian Sea	Nov - 93	0.23±0.01	n.m	n.m
Cod	Barents Sea	Nov - 93	0.45±0.02	n.m	n.m
Fish bones	various locations	Nov - 93	0.28±0.01	0.5±0.1	n.m
Cod [2]	Barents Sea	Nov - 93	0.8±0.7	n.m	<0.0002[3]
Cod	Skagerrak	Jan - 94	1.09±0.04	n.m	n.m
Herring[4]	Saltfjorden	April -94	0.6±0.08	n.m	n.m
Halibut[4]	Andøya	June - 94	0.70±0.06	n.m	n.m
Cod	Norwegian Sea	Sept - 94	0.23±0.06	n.m	n.m
Cod	Barents Sea	Sept - 94	0.51±0.06	n.m	n.m
Haddock[4]	Finnmark	Oct - 94	0.3±0.06	n.m	n.m
Haddock[4]	Saltfjorden	Oct - 94	0.7±0.1	n.m	n.m
Cod[4]	Finnmark	Oct - 94	0.7±0.07	n.m	n.m

n.m.: Not measured

[1] In all the samples measured for plutonium, the level of ^{238}Pu fell below the detection limit

[2] The result given for this sample is the average of measurements of 11 measurements on single fish. The uncertanity given is the standard devation of the measurements. All other samples are pooled samples and the uncertanity given is the uncertainty in the measurement

[3] For all the fish, the measured level of all plutonium isotopes fell belov the detection level. The highest detection limit was 0.2 mBq/kg for $^{239,240}Pu$

[4] These samples are collected and measured under the SNT monitoring programme "Radioactivity in Marine Fish"

authorities have measured approximately 75 samples of various fish species in 1993 and 600 sanples in 1994 using this equipment. All these samples fell below the detection limit of the equipment, 20 Bq/kg. These results confirm the results obtained using HPGe, but due to the high limit of detection, no further information is obtained about the distribution of ^{137}Cs in the areas where the samples are collecteted.

Some mixed fish samples have been analysed for ^{90}Sr and $^{239,240}Pu$. Levels of ^{90}Sr between 0.06 and 0.28 Bq/kg were found in fish meat. A bone sample was measured to 0.5 Bq ^{90}Sr/kg. The plutonium levels were found to be down to the mBq/kg level; the highest value being found in fish from the Barents Sea with 1.3 mBq/kg of $^{239,240}Pu$.

Other seafood

Twenty-one samples of minke whales caught along the coasts of Finnmark and the Kola Peninsula (figure 3) were measured for gamma emitting isotopes using HPGe detectors. The samples were measured to values ranging from 0.90 to 5.93 Bq/kg of ^{137}Cs. See Table 2 for average values at each location. No other artificial radioisotopes were identified.

One single sample of meat of prawns from the Norwegian Sew was measured for gamma emitting isotopes using HPGe detector. The only artificial radioisotope found, was ^{137}Cs: 0.18±0.01 Bq/kg wet weight. The Directorate of Fisheries and the Food Control

Table 2 Levels of ^{137}Cs found in whale meat, 1992. All numbers in Bq/kg wet weight

Location	^{137}Cs	*No. of samples*	*Location*	^{137}Cs	*No of samples*
Finnmark West	3.4±2,5	4	Kola West	1.4±0.2	2
Finnmark East	0.9±0.3	3	Kola East	1.3±0.2	9
Kola	1.0±0.2	3			

The numbers given are average values for each catchment location. The uncertanity is much lower for single samples.

Authorities in Bodø have measured respectively 19 and 13 samples of prawns using NaI detectors. None of these samples contained amounts of ^{137}Cs above the detection limit.

Levels of radioactivity in seawater and seaweed

Seaweed along the Norwegian coast has been collected every year since 1980. The collection locations are shown in Figure 5. Grense Jakobselv, Vadsø, Senja and Vågsøy have not been parts of the routine collection. The concentration of radiocaesium and ^{60}Co has decreased steadily since 1981, with the exception of the input from fallout from the Chernobyl accident in 1986 (Figure 4).

The samples have been analysed for all artificial gammaemitting radionuclides. On some selected samples, radiochemical analyses of ^{90}Sr and plutoniumisotopes have been performed.

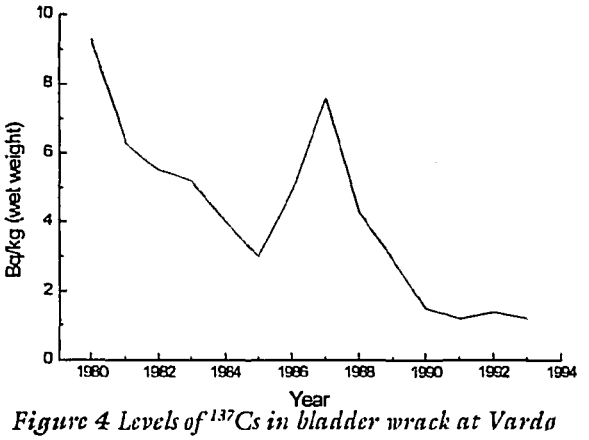

Figure 4 Levels of ^{137}Cs in bladder wrack at Vardø

Seaweed

When measuring the seaweed samples using HPGe detectors, ^{137}Cs and to lesser extent, ^{60}Co and ^{134}Cs are the artificial radionuclides detected. The concentration of ^{137}Cs varied in 1993 between 0.78 Bq/kg at Ingøy and 9.39 Bq/kg at Hvaler. The Hvaler sample was also the only sample with ^{134}Cs levels above the detection limit. In 1993 the maximum concentration of ^{60}Co found was 0.8 Bq/kg at Tjøme. In all the three samples analysed, ^{90}Sr was detected. The concentrations varied between 1 and 2 Bq/kg. The concentration of $^{239,240}Pu$ varied between 0.08 and 0.15 Bq/kg with the highest values along the southern coast of Norway and the lowest value along the coast of Finnmark. In none of the samples analysed for plutonium was ^{238}Pu found. The results are presented in Table 3 and Figure 5.

Table 3 Levels of various artificial radionuclides in bladder wrack, dry weight

	Salinity (‰)	^{60}Co	^{134}Cs	^{137}Cs	^{90}Sr	$^{239,240}Pu$
Vardø	33.9	<0.3	<0.09	1.20±0.07	n.m	n.m
Ingøy	34.5	0.4±0.1	<0.16	0.78±0.06	1.4±0.2	0.08±0.02
Vestvågøy	33.8	0.5±0.1	<0.13	0.78±0.08	n.m	n.m
Vikna	30.8	<0.5	<0.17	1.95±0.17	n.m	n.m
Bud	28.8	0.3±0.1	<0.11	1.39±0.07	1.0±0.1	0.14±0.04
Utsira	30.7	0.5±0.1	<0.25	2.47±0.10	n.m	n.m
Lista	32.5	0.4±0.2	<0.16	1.93±0.09	n.m	n.m
Tromøya	27.3	0.5±0.3	<0.44	2.66±0.21	n.m	n.m
Tjøme	22.7	0.8±0.2	<0.33	3.72±0.21	2.1±0.3	0.15±0.04
Hvaler	15.0	<0.5	1.11±0.29	9.39±0.25	n.m	n.m

n.m.: not measured

Table 4 Levels of artificial radionuclides found in seawater

	$^{239,240}Pu$	^{60}Co	^{134}Cs	^{137}Cs
Ingøy	0,0008±0,0002	< 0,006	< 0,001	0,0078±0,0017
Vestvågøy	b.l.d	< 0,003	< 0,002	0,0076±0,0013
Vikna	b.l.d	< 0,004	< 0,002	0,0079±0,0011
Hvaler	n.m	n.m	n.m	0,036±0,008

n.m: not measured; b.l.d: below limit of detection

Seawater

Seawater samples from Ingøy, Vestvågøy and Vikna (Figure 5) have been analysed for gamma emitters using HPGe and radiochemically for ^{90}Sr and plutoniumisotopes. The only artificial gamma emitting isotope found was ^{137}Cs at values of approximately 8 mBq/l. There was no significant difference between these sampling locations. In addition, Oceanographic Company of Norway (OCEANOR) has collected samples outside Hvaler in the Oslo Fjord. These samples are analysed by IFE for ^{137}Cs, and significantly higher levels were found compared to the samples from Ingøy, Vestvågøy and Vikna (Table 4).

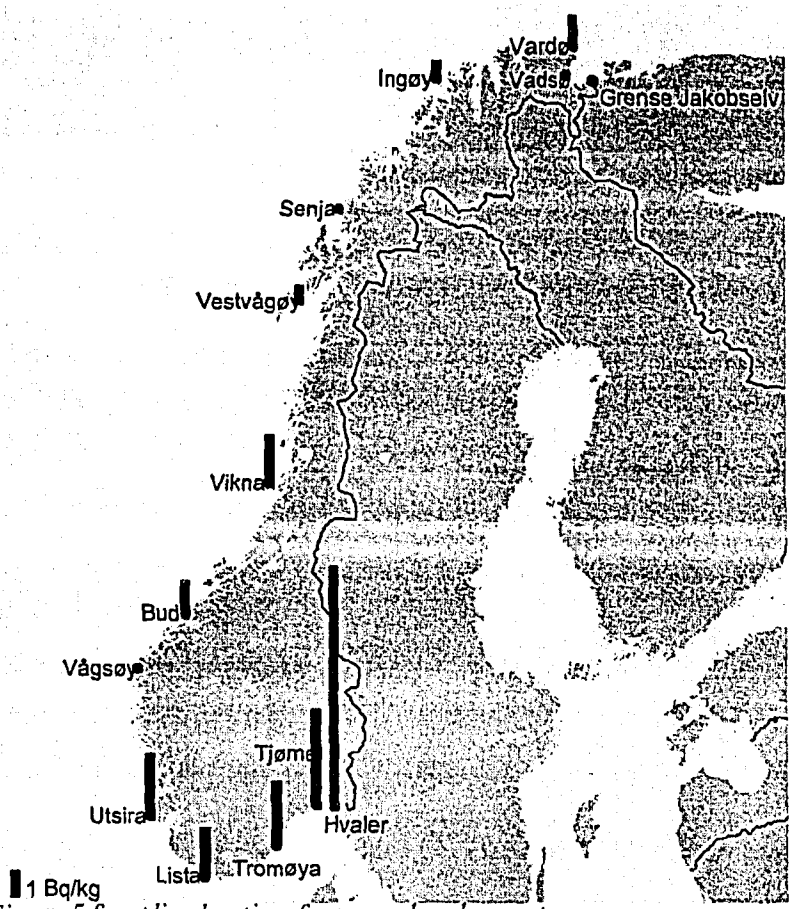

Figure 5 Sampling locations for seaweed and seawater. The levels of ^{137}Cs in seaweed are indicated

Comparison to other areas

When the radioactive contamination in marine food from the North-European waters is considered, two different situations are seen. In the Irish and the Baltic Seas, high levels are found. These two areas are directly influenced by two of the most important sources of radioactive contamination to the Northern Seas, the Sellafield reprocessing plant and run-off from areas contaminated during the Chernobyl accident, respectively. In more open areas, dilution with water from the Atlantic Ocean gives lower levels. When comparing ^{137}Cs in cod samples from the two different areas, levels up to approximately 20 Bq/kg are found in the Irish and Baltic Seas. In the open seas, such as the North Sea and the Barents Sea, levels of around 1 Bq/kg or less are found (Table 5 and Figure 6). (MAFF, 1993; This paper)

It has been difficult to find comparable data for the concentration of radionuclides in seawater from different areas. The concentrations in marine biota does is not just propor-

Table 5 Wet weight Levels of ^{137}Cs in cod from different areas

Location	^{137}Cs (Bq/kg)	Reference
Barents Sea	0.7	This paper
Norwegian Sea	0.5	This paper
North Sea	0.3	This paper
Icelandic area	0.3	MAFF, 1993
Skagerak	1.1	This paper
Baltic Sea	21	MAFF, 1993
Irish Sea, Sellafield	19	MAFF, 1993
Irish Sea	6.4	MAFF, 1993

tional to the concentration in the water, as the uptake of different species depends on the properties of the water, especially the salinity. For seaweed, the concentration factor ($Bq \cdot kg^{-1}_{seaweed}/Bq \cdot m^{-3}_{seawater}$) is known to vary as much as a factor of 10 in different areas in the North Atlantic Ocean. The trend is for higher concentration factors at lower salinities and lower temperatures (Jones, 1989).

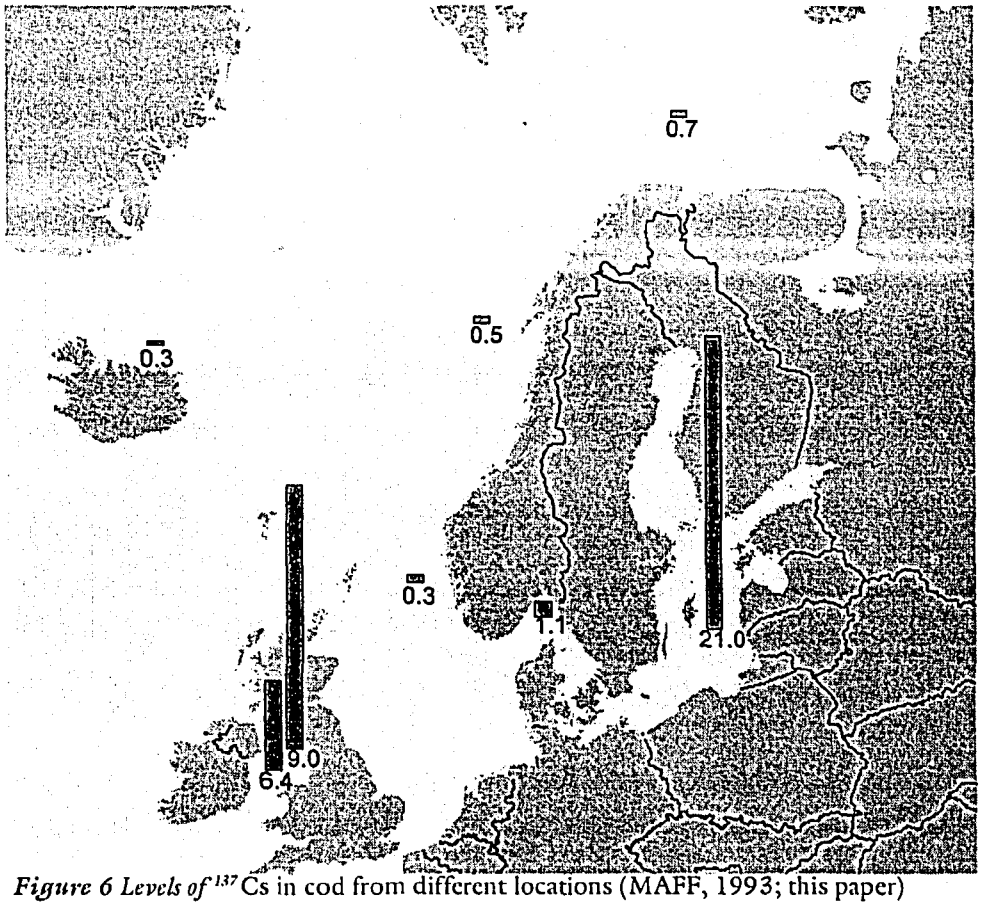

Figure 6 Levels of ^{137}Cs in cod from different locations (MAFF, 1993; this paper)

Conclusions

The levels of radioactive contamination in food from the marine ecosystem are low and pose an insignificant risk for the health of the consumers. Compared to the international general limits of intervention for food products, the levels of approximately 1 Bq/kg found in marine food from the Norwegian fishing areas are negligible.

The present level of radioactive contamination in the marine ecosystem is low, and the general levels of ^{137}Cs and ^{90}Sr in seawater are decreasing due to reduced discharges from Sellafield and La Hague. Even so, it is important to continuously monitor the situation to be able to demonstrate the actual levels of the marine environment and to be able to early observe any increases in the contamination level from new sources or increased releases from the known sources, so that the appropriate countermeasures may be taken.

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ISSN 0804-4910