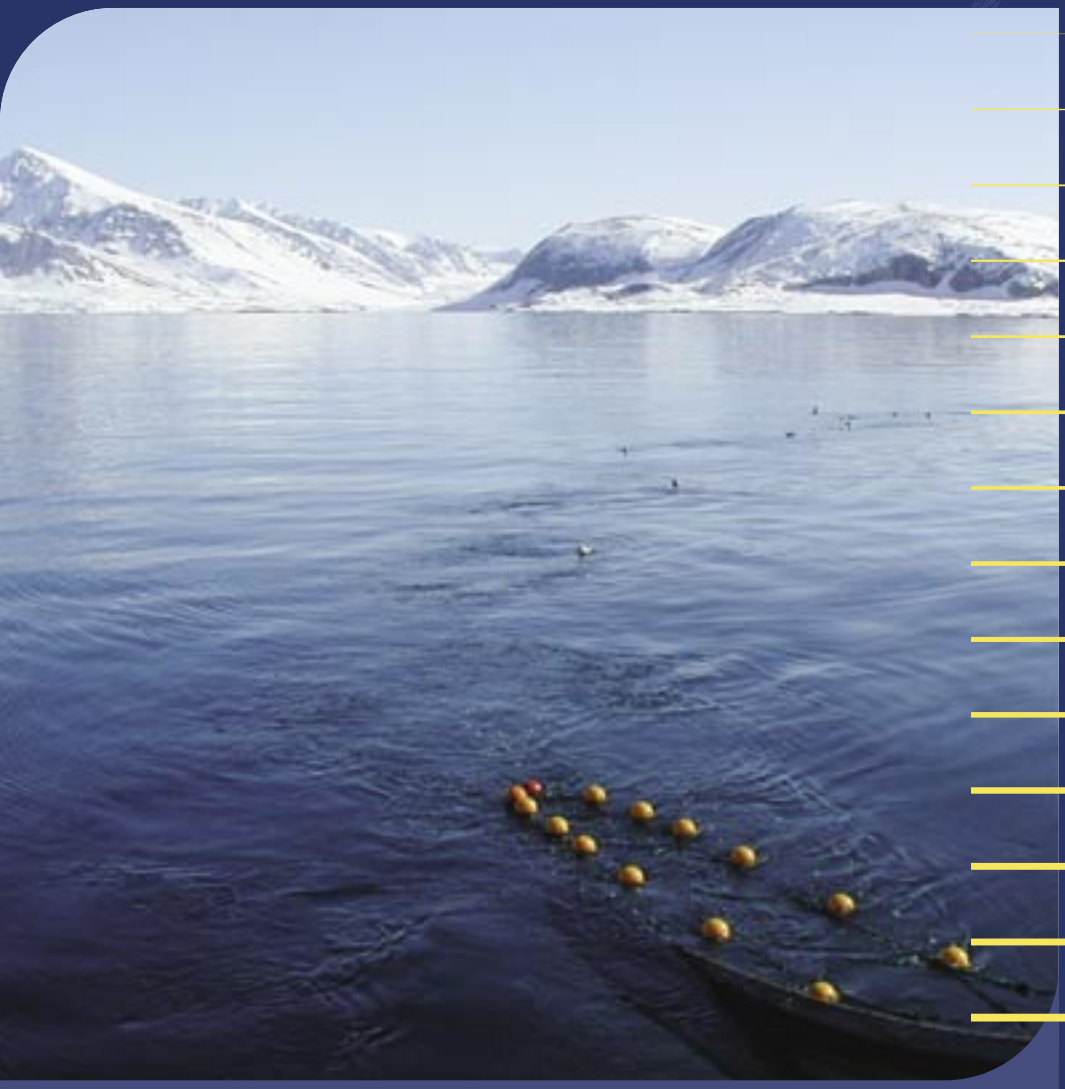
Strålevern Rapport 2003:8

Radioactivity in the Marine Environment 2000 and 2001

Results from the Norwegian National Monitoring Programme (RAME)



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Key words:
Radioactivity, marine environment, RAME, monitoring

Abstract:
This report presents results of monitoring of radioactivity in water, sediment, fish, seaweed and crustacea collected along the Norwegian coast and in the Barents and North Seas in 2000 and 2001. An overview of discharges from Norwegian sources and data concerning the long-range transport of radionuclides from European nuclear facilities is included.

Referanse:
Gäfvert T, Føyn L, Brungot A L, Kolstad A K, Lind B, Christensen G C, Strålberg E, Drefvelin J, Rudjord A L. Radioaktivitet i det marine miljø. Resultater fra det nasjonale overvåkningsprogrammet (RAME) 2000 og 2001. StrålevernRapport 2003:8. Østerås: Statens strålevern, 2003. Språk: engelsk.

Emneord:
Radioaktivitet, marin miljø, RAME, overvåking

Resymé:
Rapporten inneholder resultater fra overvåkningen av radioaktivitet i sjøvann, sedimenter, fisk og skalldyr i 2000 og 2001 langs norskekysten, i Barentshavet og i Nordsjøen. En oversikt over utslipp fra norske kilder og utslippsdata fra europeiske nukleære anlegg som er relevante for langtransport av radioaktivitet til norske havområder er inkludert i rapporten.

Head of project: Anne Liv Rudjord
Approved:

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1. Introduction

The issue of present and potential radioactive contamination in the marine environment has received considerable attention in Norway in recent years. In the late 1980s several accidents and incidents involving nuclear powered submarines, demonstrated that the risk of the release of radionuclides into the Barents Sea should be considered more carefully. In particular, it became evident that better documentation concerning the radioactivity levels in fish and other seafood was important for the seafood export industries. Furthermore, in the early 1990s, information concerning the dumping of nuclear waste emerged through bilateral environmental cooperation between Norway and Russia. In the years that followed, concern grew regarding the safety of military and civil nuclear installations in the northwest of Russia. This concern was associated not only with possible reactor accidents, but also with the prolonged or sudden release of radionuclides from radioactive waste facilities.

In addition to the potential threats outlined above radionuclides originating from nuclear weapons fallout, the Chernobyl accident and waste discharged from European reprocessing facilities have been detected in the Norwegian marine environment. In 1994 and 1995, the discharge of ^{99}Tc from the reprocessing facilitiy at Sellafield in the UK increased sharply, and although this discharge has been reduced slightly, it has continued at a high level up to date. There has been much public concern about the consequences of such kinds of release, as the radionuclides discharged to the Irish Sea are transported by ocean currents via the North Sea into the Norwegian coastal current and the Barents Sea. In response to this concern, programmes for the monitoring of radioactivity in the marine environment have been established. Due to the economic importance of the fishing industry and its vulnerability to contamination as well as any rumours of radioactive contamination, one of the main objectives of these programmes is to document levels and trends of radionuclides in the Norwegian marine environment.

Other human activities, such as mining and oil production, may change the distribution of natural radionuclides in the environment. The discharge of radium from water produced by oil installations is one area that has recently received special attention, and one of the tasks for the marine monitoring programme will be to look closer at this in the near future.

In Norway there are currently two monitoring programmes concerned with radioactivity in the marine environment, both coordinated by the Norwegian Radiation Protection Authority (NRPA). One is funded by the Ministry of the Environment and focuses of monitoring of radioactivity in the marine environment both in coastal areas and in the open seas, the other by the Ministry of Fisheries which focus on monitoring of radioactivity in commerically important fish species. Results of both these programmes are presented in this report. In addition, data from the Food Control Authoritiy´s monitoring programme, which is concerned with radioactivity in marine fish, have been included.

The marine monitoring programmes include the collection of discharge data from Norwegian sources, in addition to the collection of discharge data relevant for the long-range transport of radionuclides from various sources. Liquid discharge data for 2000 and 2001 from nuclear installations and recent trends in such discharges are summarised in Chapter 2, together with the available information concerning historical nuclear weapons fallout and outflow of ^{137}Cs from the Baltic Sea originating from the Chernobyl accident.

During 2000 and 2001, samples for the monitoring programmes for radioactivity in the marine environment were collected in the Barents Sea, the Norwegian Sea, the North Sea and the Skagerrak, in selected fjords and at coastal stations including the islands of Svalbard, Bjørnøya, Hopen and Jan-

Mayen. In addition to this, samples were collected in the River Nitelva, close to a former outlet for liquid discharge at the Institute for Energy Technology (IFE) Kjeller. Results from the analysis of these samples are presented in Chapters 4, 5 and 6.

An extraordinary event that took place in the time period covered by this work was the explosion and loss, and later salvage, of the Russian submarine the Kursk in the Barents Sea. In connection with this the NRPA participated in monitoring radioactivity in sea water, sediments and fish during both the initial phase of the accident and in connection with the salvage of the submarine. A description of the accident and the results of radioactive monitoring are presented in Chapter 5.

In Chapter 8, a summary of the findings and the conclusions are given. In the Appendix, technical information regarding sample preparation techniques and analytical methods employed in the laboratories are presented.

2. Sources of radionuclides in the marine environment

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This chapter provides updated information and an overview of radionuclide discharges and other sources that are relevant to the Norwegian marine environment. The collection and updating of this information is an integral part of the marine monitoring programme RAME (Radioactivity in the Marine Environment), the main purpose of which is to present recent trends in radionuclide discharges and other sources of radioactivity in the marine environment. Information on discharges from Norwegian sources and on long-range transport of radionuclides from various sources is included. Anthropogenic radionuclides are discharged from the nuclear facilities of the Institute for Energy Technology, IFE Kjeller and IFE Halden. These facilities are authorised by the Norwegian Radiation Protection Authority (NRPA) to make certain discharges. Unsealed radioactive materials used in medicine and science will primarily be released to the marine environment via sewage treatment plants. The utilisation of such unsealed sources is regulated through guidelines issued by the NRPA.

In recent years, increased attention has been devoted to releases containing elevated levels of naturally occurring radionuclides. Such releases occur due to offshore oil production and, probably, due to the leaching of mine tailings.

The discharge of radionuclides from Norwegian sources is only detectable in the local environment, near the discharge point. The long-range transport of radionuclides originating from fallout from atmospheric nuclear weapons tests (conducted mainly in the 1950s and 1960s), reprocessing of nuclear fuel and from the Chernobyl accident in 1986 are still the main contributors to the general levels of anthropogenic radionuclides found in Norwegian waters. In some areas of the River Nitelva, the main source of radionuclide contamination has been previous discharges from IFE Kjeller. Removal of the most contaminated sediment in 2000 has however reduced the concentration of transuranic elements in the sediment considerably near the former discharge point.

2.1 Discharges of anthropogenic radionuclides from Norwegian sources

2.1.1 IFE Kjeller and Isopharma A/S

The IFE Kjeller nuclear site is located about 20 km east of Oslo. The facilities include a heavy water cooled and moderated research reactor with a thermal effect of 2 MW, called JEEP II, a metallurgical laboratory, production facilities for medical radioactive isotopes, and a radioactive waste treatment plant for low-level and intermediate-level waste (LLW and ILW). The liquid LLW originates from these facilities.

Liquid effluent is discharged through a designated pipeline to the River Nitelva about 100 km from the sea. The river empties into Lake Øyeren where the water is mixed with the water from the Glomma River. The River Glomma empties into the Oslofjord at the city of Fredrikstad.

A plant manufacturing radiopharmaceutical products, managed by the private company Isopharma A/S, operates in close collaboration with IFE Kjeller. Authorisation for IFE Kjeller releases also includes the releases from this production facility.

Table 2.1. *Liquid discharges (MBq) from IFE, Kjeller, 1996-2001 (including Isopharma A/S).*

Radionuclide	1996	1997	1998	1999	2000	2001
^{137}Cs	80	21	110	30	6.7	25.7
^{134}Cs	1.7	2.7	5.0	1.9	0.43	2.5
^{131}I	$1.41 \cdot 10^3$	74	350	$1.35 \cdot 10^3$	6.28	107
^{125}I	760	117	190	182	91	310
^{65}Zn	273	15	0.87	0.75	0.9	3.8
^{60}Co	106	16	11	6.9	8.67	74
^{35}S	695	820	280	18.5	142	0
^{90}Sr	12.2	4.6	81	161	6.5	0.96
$^{239+240}Pu$	0.782	0.15	0.11	0.016	0.17	0.04
^{3}H	$7.23 \cdot 10^5$	$0.11 \cdot 10^5$	$1.52 \cdot 10^5$	$0.85 \cdot 10^5$	$4.0 \cdot 10^5$	$1.5 \cdot 10^6$

The discharge limit authorised by the NRPA is based on the annual dose to any member of a critical group of the population along the River Nitelva, and shall not exceed 1 μSv. Each year, IFE Kjeller reports discharge data, the results of their environmental monitoring programme and calculations of effective doses resulting from discharges, to the NRPA (IFE 2000a; IFE, 2001). The reported discharges for the period 1996-2001 are summarised in Table 2.1.

Table 2.2. *Effective doses (μSv) to the critical group from river water exposure pathways as reported by IFE Kjeller.*

Effective dose (μSv)					
1996	**1997**	**1998**	**1999**	**2000**	**2001**
0.71	0.06	0.24	0.53	0.04	0.21

Effective doses have been calculated by the IFE for a hypothetical critical group exposed through the annual consumption of 20 kg of fish from the river and 100 hours per year presence on the riverbanks. In 2001, the calculated effective dose to this critical group was 0.21 μSv, corresponding to 21 % of the annual dose limit of 1 μSv. The effective dose to the critical group varies, as can be seen in Table 2.2, corresponding to between 4 and 71 % of the dose limit, with an average of about 30 % for the years 1996-2001.

2.1.2 Contamination of Nitelva sediments due to previous discharges from IFE Kjeller

Nuclear activities began at IFE in Kjeller in 1951 with the start-up of the first research reactor, JEEP I. Radionuclides have been produced since 1952 and this has been the main source of discharge of the short-lived radionuclide ^{131}I. Another reactor (NORA) was in operation between 1961 and 1968. At the same time, an experimental plant for the purification of uranium was in operation. The available information regarding earlier discharges has been collected in a report in Norwegian (NRPA, 1999). Discharge data can be found in reports from 1964 onwards, when the first discharge authorisation was issued. Before 1967, liquid waste was released through the sewage pipeline to the Sogna, a tributary of the River Nitelva, with low circulation of river water. In 1967, a new pipeline (the NALFA pipeline) was constructed, releasing waste water near Nitelva Bridge in Lillestrøm (Figure 2.1).

During the decommissioning of the uranium purification plant, the discharge of plutonium and ^{241}Am increased considerably. However, the discharge was still within the limits that existed at that time. The discharge history of the IFE facilities in Kjeller is shown in Figures 2.2 and 2.3. These discharges led to the contamination of the Nitelva sediments. In 1999, the NRPA decided to collect additional samples in the Nitelva as part of the national monitoring programme. The results from the analysis of these samples have been published in an earlier report (Rudjord *et al.*, 2001). In February 2000, the NRPA decided that all sediments with a total concentration of plutonium and americium-241 in excess of 10 Bq g^{-1} had to be removed. In a clean-up operation in April 2000, a total of 181 m^3 of contaminated sediments were removed by the IFE. In connection with this, additional samples were collected of the remaining sediments and analysed with regard to plutonium and gamma-emitting radionuclides. The results of these analyses are presented in Chapter 4. Later, part of the NALFA pipeline was replaced by a new pipeline, and the effluent was released to the free water masses midstream.

Figure 2.1. *Map showing discharge pipelines from the IFE Kjeller facilities. The old pipeline was used until 1967. In 2000, the waste outlet was moved and part of the NALFA pipeline is no longer used and has been removed.*

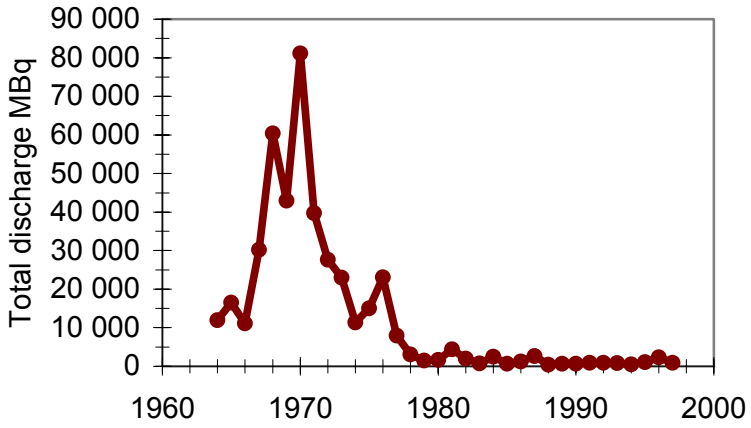


Figure 2.2. *Total discharge from IFE Kjeller, 1962-1997 estimated on the basis of gross alpha and gross beta measurements. Since 1983, the discharge has been calculated as the sum of the activities of individual radionuclides.*

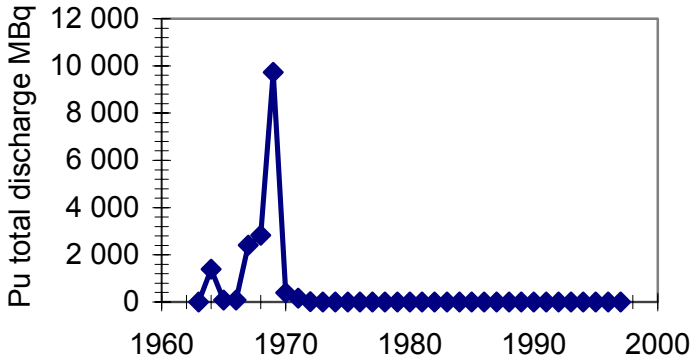


Figure 2.3. *Discharge of plutonium from IFE Kjeller, 1963-1997. The levels of plutonium discharged in the period 1963-78 were estimated on the basis of gross alpha measurements.*

2.1.3 IFE Halden

The Halden Boiling Water Reactor (HBWR) is located in the town of Halden, in the southeast of Norway, close to the Swedish border. The HBWR is heavy water cooled and moderated. The reactor was commissioned in 1959.

IFE Halden is allowed to discharge a certain amount of radioactivity to the River Tista (which discharges its water into the Iddefjord) from the research reactor. Discharge authorisation has been granted by the NRPA, and IFE Halden is responsible for monitoring the discharges and reporting the results to the authorities and for ensuring that discharge take place in accordance with the authorisation. The discharge limit for liquid waste to the marine environment is based on a dose limit of 1 μSv per year to a hypothetic critical group, and the actual annual discharge is typically 5-10 % of the authorised limit. Liquid discharges in the period 1996-2001, and the corresponding doses to the critical group are presented in Tables 2.3 and 2.4.

Table 2.3. *Annual liquid discharge (MBq) 1996-2001, IFE Halden.*

Radionuclide	1996	1997	1998	1999	2000	2001
^{137}Cs	530	250	410	530	289	58
^{60}Co	140	260	220	380	530	440
^{134}Cs	51	29	28	29	14.5	2
^{3}H	371,000	336,000	894,000	671,000	520,000	240,000
^{58}Co	18	37	22	19	13.9	49
^{95}Nb	9	53	20	60	38	40
^{51}Cr	240	540	330	240	610	290
^{54}Mn	1	5.4	6	5.6	5	7
^{95}Zr		24	7.6	14	21.4	16
^{124}Sb		4.9			1.2	
^{125}Sb		110	4.4	39	116	130
^{110m}Ag	1		1.4		3.4	0.5
^{106}Ru	7.5				34	0.002
^{131}I	1.8	31		6.5	0.4	0.04
^{144}Ce	4.8		18	8.3	15.5	14
^{56}Mn			2.7		13	

The calculation of the effective dose to the critical group is based on the following assumptions:

- An annual consumption of 30 kg of fish from the Iddefjord.
- 200 hours per year exposure on the shore of the fjord.
- 50 hours per year bathing in the fjord, and
- 1000 hours per year boating on the fjord.

Table 2.4. *Effective doses (μSv) to the critical group from marine exposure pathways as reported by IFE Halden.*

Effective dose (μSv)					
1996	**1997**	**1998**	**1999**	**2000**	**2001**
0.04	0.06	0.05	0.08	0.11	0.09

According to the authorisation, the liquid discharge, consisting mainly of cooling water and waste water from cleaning facilities, has to be led through a municipal drainpipe directly to the River Tista, where it is discharged into the running river water. In May 2000, the local authorities in Halden informed IFE that the municipal drainpipe had been modified and directed to the local municipal

waste-water treatment plant 9 years previously, in 1991. With this knowledge the IFE immediately reduced their liquid discharge to a minimum and informed the NRPA. A few days later a new pipe was installed in order to lead the waste water from the IFE directly into the River Tista as required by the authorisation. As a consequence of this lack of communication, part of the radioactivity (mainly ^{137}Cs and ^{60}Co) in the liquid discharge had been removed together with the sewage sludge at the water treatment plant, a fraction of which is recycled and used as soil amendment or filling material. Shortly after this mistake had been revealed, a programme was initiated to investigate the level of radioactivity in the sewage sludge, estimate occupational doses to workers at the water treatment plant, and doses arising from the use of sewage sludge as soil amendment. Results from this survey are presented in Table 2.5.

Table 2.5. *Activity concentration (Bq kg^{-1} d.w.) of gamma-emitting artificial radionuclides in sludge and fertilizers.*

Sample	**^{60}Co**	**^{51}Cr**	**^{95}Nb**	**^{95}Zr**	**^{131}I**	**^{144}Ce**	**^{134}Cs**	**^{137}Cs**
Sludge[1]	48-130	32-105	1.7-18.8	1.3-12.7	13.7-418	5.8-71	14.5-30	14.5-30
Fertilizer based on sludge (1996)	31	n.d.	n.d.	n.d.	n.d.	n.d.	4.3	168
Fertilizer based on sludge (1999)	49	n.d.	n.d.	n.d.	n.d.	n.d.	1.3	27
Fertilizer based on sludge (2000)	16.5	n.d.	n.d.	n.d.	n.d.	n.d.	0.9	31

[1]Collected from different stages of the treatment process at the waste-water treatment plant

n.d. = not detected

Doses arising from external radiation from contaminated sludge were calculated. Employees working close to piles of contaminated sewage sludge for 200 hours per year were estimated to have received effective doses of about 3 μSv per year (IFE, 2000b). Doses from the inhalation of dust and ingestion of sewage sludge were estimated using dose conversion factors from ICRP (1995). Committed effective doses to a worker spending 2,000 hours at the disposal site were estimated to be 0.1 μSv from inhalation (10 mg dust per m^3 and a breathing rate of 1.5 m^3 h^{-1}) and 0.26 μSv from ingestion (IFE, 2000b). Compared with the recommended dose limit of 1 mSv per year for non-radiological workers in Norway, these doses can be considered low. Using concentration factors published by IAEA (1982), the radioactivity transferred from soil to milk, meat and vegetables, where sewage sludge was used as soil amendment, was estimated. The results from this assessment showed that the activity concentrations of ^{60}Co, ^{134}Cs and ^{137}Cs were all below 1 Bq kg^{-1} in milk, meat and vegetables (IFE, 2000b). A conclusion of the results presented above is that the radiological impact of this incident was low. The incident itself can, however, not be considered negligible as it revealed a serious lack of communication and control over a long period of time during which the discharge from IFE in Halden was mixed with municipal sewage.

2.2 Unsealed radioactive substances in medicine, research and industry

Unsealed radioactive substances are used in hospitals, research laboratories and various industrial activities. According to regulations from 1981, laboratories etc. handling unsealed radioactive substances must be authorised by the NRPA. With this authorisation, laboratories and hospitals are allowed to discharge activity into the sewage system according to predefined limits. The present regulations are now under revision. Unsealed radioactive substances used in medicine dominate the anthropogenic radioactive discharges to the sewage system. Radioactive solutions are given to patients for diagnostic and therapeutic purposes, and enter the sewage systems mainly by the excretion of urine and faeces.

In some tracer experiments in the offshore oil industry, tritium (^{3}H) is injected into rock formations or drilled wells, a fraction of which is recovered. Water-based material is discharged to the sea while mud-containing oil must be stored. However, for the consequence assessments required by the NRPA, it is conservatively assumed that all the ^{3}H is discharged to the open sea. The release of radionuclides used in research laboratories is in general considered less important, partly because only small quantities of activity are used and partly because some of the waste is collected and sent to the IFE (Kjeller) for storage as radioactive waste. Furthermore, most of these radionuclides have short half-lives and the activity is rapidly reduced by storage. Exact data on the nuclides and amounts discharged from the above sources are not available. However, the manufacturers of unsealed radioactive sources are required to report their sales to NRPA monthly, listing customer, type of radionuclide and quantity (activity). In Table 2.6 the sales of unsealed radioactive sources in Norway in 2000 and 2001 are listed. Regarding sales of ^{99m}Tc, it is important to consider the short half-life of this radionuclide, as a large fraction will decay before it is even used.

Table 2.6. *Unsealed radioactive sources sold in Norway in 2000 and 2001. Only radionuclides where the total activity purchased exceeds 1 GBq have been included in the table.*

Radionuclide	Half-life	Activity sold in Norway, 2000 (GBq)	Activity sold in Norway, 2001 (GBq)
$^{99}Mo/^{99m}Tc$	66 h/6 h	24,414	25,104
^{131}I	8 d	1,663	1,837
^{111}In	2.8 d	< 1	25
^{51}Cr	27.7 d	3.3	4.2
^{67}Ga	3.3 d	4.4	2.7
^{14}C	$5.73 \cdot 10^{3}$ y	31.7	1.3
^{133}Xe	5.3 d	521	281
^{125}I	60 d	7.9	8.5
^{32}P	14.3 d	52.7	46.6
^{3}H	12.3 y	2,050	2,072
^{35}S	87 d	30	36
^{18}F	110 min	62	52
^{123}I	13.1 h	10.5	17
^{153}Sm	46.7 h	21	21
^{89}Sr	50.6 d	8.4	7.3
^{201}Tl	73.1 h	63.5	60.7
^{90}Y	64.1 h	3.5	2.4

2.3 Technologically enhanced naturally occurring radioactive material

All minerals and rocks in the earth's crust contain small, but measurable amounts of naturally occurring radioactive material often referred to as NORM. NORM includes a long-lived isotope of potassium (^{40}K), as well as isotopes of the uranium decay chain and the thorium decay chain (^{238}U and ^{232}Th are the parent radionuclides of these two natural radioactive decay series). Naturally occurring radionuclides are released into the marine environment by natural processes such as erosion. The material is carried in river sediments, or dissolved in river water and finally reaches the sea.

In certain industrial or other technological processes naturally occurring radionuclides can be concentrated to levels orders of magnitude higher than those normally found in nature. In Norway, there are two main processes where technologically enhanced concentrations of naturally occurring radioactive material (TENORM) can be regarded as a discharge or leakage of radionuclides into the marine environment: oil and gas production in the North Sea and runoff from mine tailings. Some data exist regarding the discharge of produced water from North Sea oil and gas production, but data on runoff from mine tailings are lacking.

2.3.1 TENORM in oil and gas production in Norway

Two isotopes in the uranium and thorium series are important in relation to the discharge of produced water and radioactive deposits in oil and gas production, namely ^{226}Ra and ^{228}Ra. The occurrence of natural radionuclides in North Sea oil and gas production was first detected in 1981, and enhanced levels of radioactivity are now found in the production systems of several North Sea oil fields (Strand *et al.*, 1997). The activity concentrations range from background levels to several hundred Bq g^{-1} of ^{226}Ra (Smith, 1987). Doses to workers involved in handling contaminated equipment or waste are usually low, and the main problems related to radioactive deposits are waste disposal and the discharges of produced water.

2.3.2 Discharge of produced water

Large volumes of produced water, containing dissolved ^{226}Ra and ^{228}Ra, are discharged into the sea during oil exploitation. Althougth the levels of ^{226}Ra and ^{228}Ra are not technologically enhanced, the natural concentrations of these isotopes in the saline formation water are generally much higher than the background concentration in sea water. A minor fraction, about 10 % of the total volume produced by Norwegian platforms, is currently reinjected into the reservoirs. An earlier investigation of produced water from 11 Norwegian production units in the North Sea (Strand *et al.*, 1997) showed average activity concentrations of 4.1 Bq l^{-1} of ^{226}Ra and 2.1 Bq l^{-1} of ^{228}Ra, which are about three orders of magnitude higher than North Sea water (IAEA, 1990). The concentration of radium in the produced water is assumed to change over the lifetime of the well. Injection of large volumes of sea water, to maintain the pressure within the well, may lead to dilution of the radium in the produced water, but at the cost of greater water-to-oil ratio later in the production process.

Volumes of discharge of produced water, for countries involved in oil and gas exploitation in the North Sea, have been reported by the Norwegian Oil Industry Association (2002), the Department of Trade and Industry (UK) (2002) and the Danish Energy Authority (2002), and are presented in Figure 2.4. Increased production and ageing of oilfields have over recent years resulted in increased discharge volumes. For 2001 the Norwegian Oil Industry Association reported that 116 million m^3 of produced water was discharged into the North Sea from the Norwegian sector, while about 14 million m^3 was reinjected.

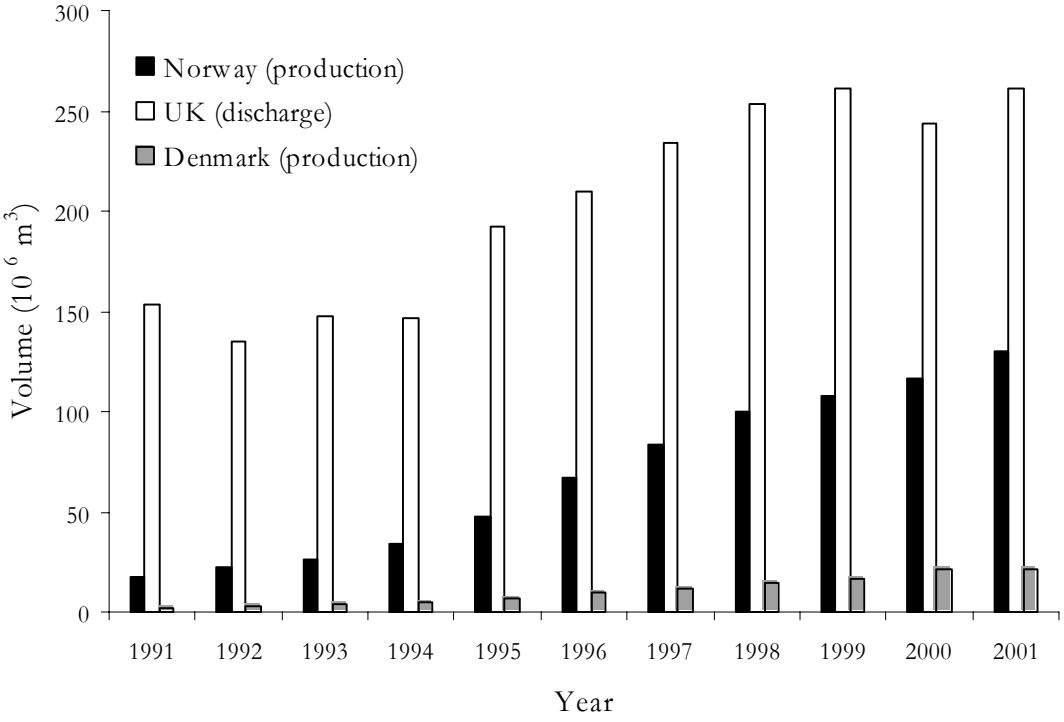


Figure 2.4. *Production or discharge of produced water by countries involved in oil exploitation in the North Sea. At Norwegian rigs, about 10 % of the produced water has been reinjected in recent years. (Sources: the Norwegian Oil Industry Association, 2002; the Department of Trade and Industry (UK), 2002; the Danish Energy Authority, 2002).*

Assuming the average activity concentration of ^{226}Ra and ^{228}Ra reported by Strand *et al.,* (1997), the total activities of ^{226}Ra and ^{228}Ra released in produced water in 2000 were about 0.44 TBq ^{226}Ra and 0.22 TBq ^{228}Ra, and in 2001 about 0.50 TBq and 0.25 TBq of ^{226}Ra and ^{228}Ra, respectively.

2.4 Long-range transport of radionuclides

There are several sources of radioactive contamination to the northeast Atlantic and the Arctic marine environment. The primary sources are fallout from atmospheric nuclear weapons testing during the 1950s and 1960s, transport of discharged radionuclides from reprocessing plants and fallout from the Chernobyl accident.

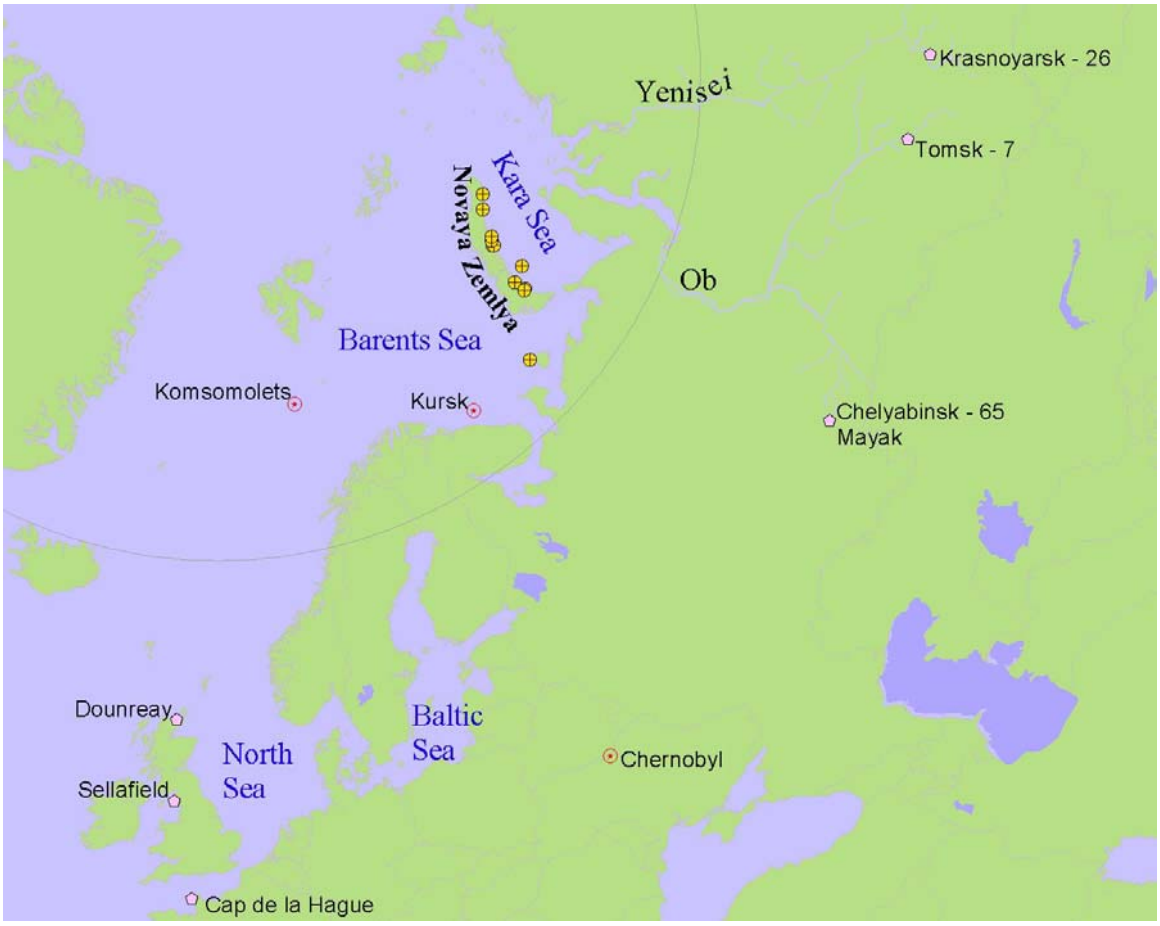


Figure 2.5. *Sources of radionuclides in the northern marine environment: Chernobyl in the Ukraine, the reprocessing plants at Sellafield, Cap de la Hague and Dounreay, the dumping sites for nuclear waste in the Kara Sea, the sites of the sunken submarines Komsomolets and Kursk (the Kursk was salvaged in 2001) and Russian nuclear installations (Mayak, Tomsk-7 and Krasnoyarsk-26) releasing radionuclides to the Russian rivers Ob and Yenisey.*

In addition, there are several potential sources of future radioactive contamination of the marine environment. In Figure 2.5 the locations of present and potential sources are shown.

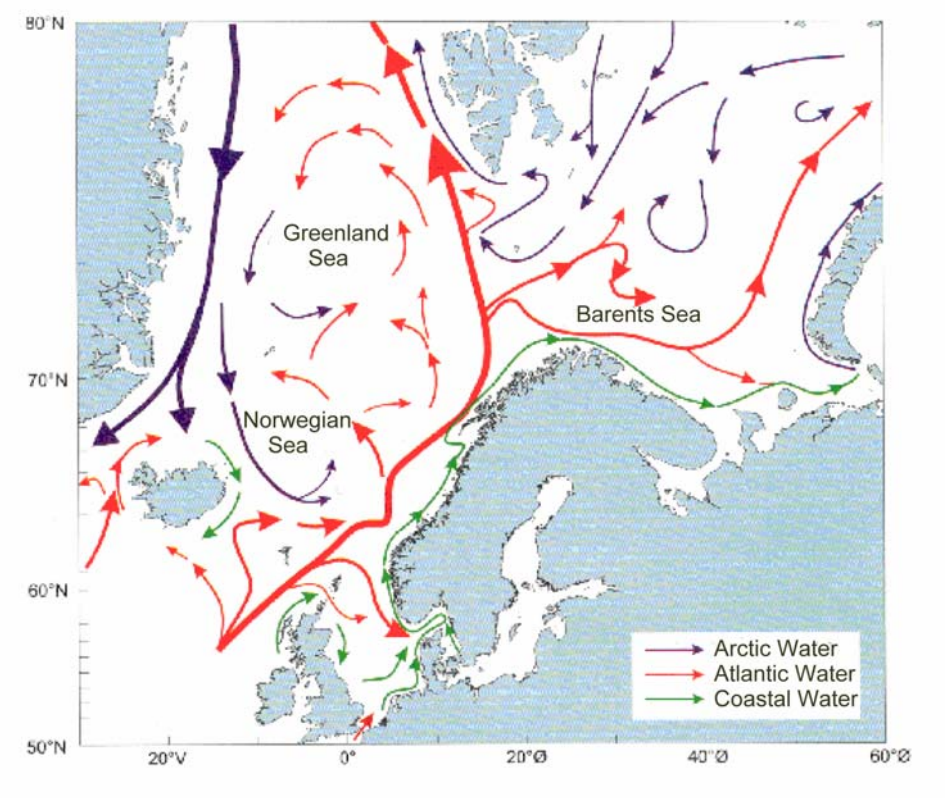


Figure 2.6. *The surface circulation pattern of the northern seas (adapted from Aure* et al.*, 1999).*

Figure 2.6 shows the main features of the water circulation of the North Atlantic. Radionuclides discharged from European reprocessing plants are transported from the Irish Sea and the English Channel via the North Sea and into the Norwegian coastal current, to the Barents Sea and beyond. Baltic water contaminated with fallout from the Chernobyl accident flows through the Kattegat and enters the Norwegian coastal current in the Skagerrak area.

2.4.1 Discharge of radionuclides from European nuclear installations

For decades, authorised discharges from nuclear reprocessing facilities in Europe have constituted a considerable source of anthropogenic radionuclides in Norwegian coastal areas. These facilities include Sellafield in England, Dounreay in Scotland, and Cap de la Hague in France. Radionuclides are also released to the marine environment from nuclear fuel fabrication plants and nuclear power stations.

A nuclear fuel reprocessing plant recovers spent nuclear fuel for reuse in fission reactors. The remaining radionuclides are either stored pending final management and disposal or released to the environment (UNSCEAR, 1993). Liquid radioactive waste from the operation of these plants is discharged via pipelines directly into the Irish Sea, Scottish coastal waters and into the English Channel. Soluble radionuclides from these sources are subsequently transported further northwards with regional oceanic currents.

Sellafield has been the main contributor to radioactive release among the three Western European reprocessing plants. The maximum discharges of ^{137}Cs and the actinides $^{239+240}$Pu and ^{241}Am from Sellafield occurred during the mid to late 1970s (Gray *et al.*, 1995). The introduction of the Site Ion-Exchange Effluent Plant (SIXEP) in 1985 subsequently led to a substantial reduction in the discharge

of ^{90}Sr, ^{134}Cs and ^{137}Cs (Gray *et al.*, 1995). However, increased throughput and processing of residues led to increased discharges of plutonium and americium during the early to mid 1970s. Throughout the 1980s and early 1990s (1981-1993), ^{99}Tc was discharged from Sellafield at a rate of 1.9-6.6 TBq per year. In 1994, the Enhanced Actinide Removal Plant (EARP) at British Nuclear Fuel's (BNFL) Sellafield plant in northwest England began operations to treat a backlog of stored waste (Gray *et al.*, 1995). This resulted in a step increase of ^{99}Tc from a level of approximately 5 TBq a^{-1} to a level of 72-190 TBq a^{-1} in the period 1994-1996. In the period 1997-2001 liquid discharge continued at a high level, with an annual discharge between 44 and 84 TBq. The initial impact, in terms of increased activity levels in biota and sea water, of the higher ^{99}Tc discharges from Sellafield was observable in Norwegian coastal environments by 1997 (Brown *et al.*,1999).

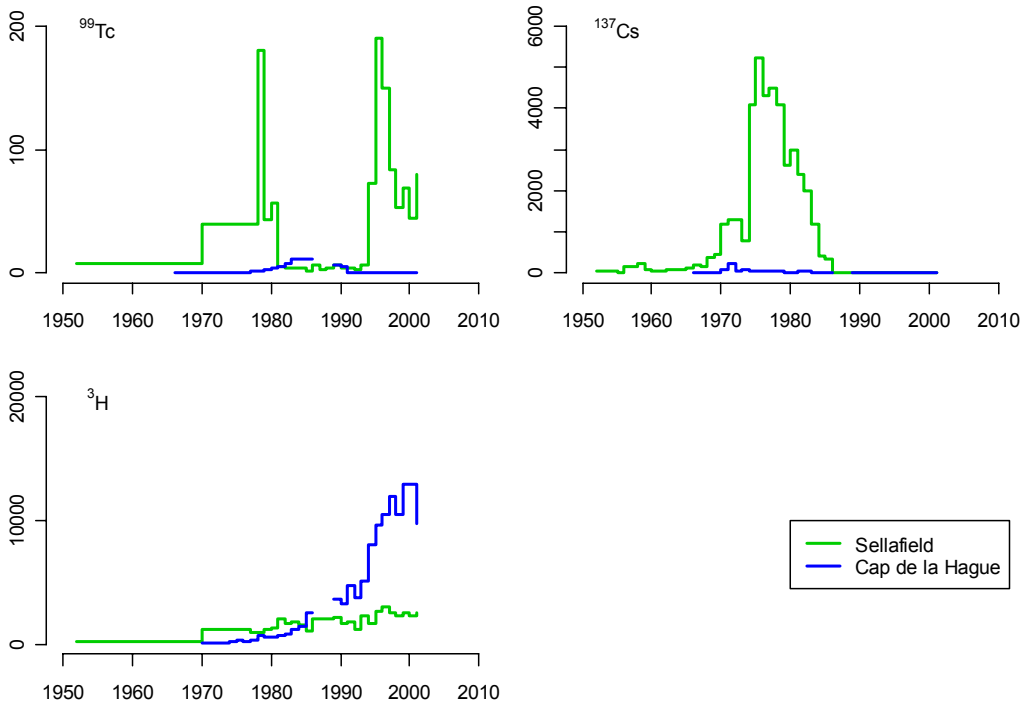


Figure 2.7. *Annual discharge of ^{99}Tc, ^{137}Cs and ^{3}H to the marine environment from Sellafield and Cap de la Hague from the 1950s and up to 2002, given in TBq.*

In Figure 2.7 the discharge to the marine environment of ^{99}Tc, ^{137}Cs and ^{3}H (tritium) from Cap de la Hague and Sellafield from the 1950s to the year 2001 is shown. The figure demonstrates that, except for tritium, discharges from Cap de la Hague have been considerably lower than those from Sellafield most of the time. The radiotoxicity of ^{3}H is very low and the radiological importance of this nuclide is much less than that of other radionuclides. To some extent, the ^{3}H discharge can be regarded as an indicator of the amount of spent nuclear fuel that has been reprocessed.

In Table 2.7 the discharges of some radionuclides in 2000 and 2001 from Sellafield, Cap de la Hague, Springfields and Dounreay are presented. The Dounreay facilities on the northern coast of Scotland were established in 1955, and have mainly been used in the development of technology for fast breeder reactors. Compared with the discharges from the other two reprocessing plants, the discharge from Dounreay is small. The amount of reprocessed nuclear fuel is also considerably lower.

Table 2.7. *Liquid discharge of radionuclides from Sellafield, Cap de la Hague, Springfields and Dounreay to the marine environment in 2001 (OSPAR, 2002; OSPAR, 2003).*

Liquid discharge of radionuclides 2000-2001 (TBq)								
	Cap de la Hague English Channel		Sellafield Irish Sea		Springfields Irish Sea		Dounreay Scottish coastal waters	
Radionuclides	**2000**	**2001**	**2000**	**2001**	**2000**	**2001**	**2000**	**2001**
Tritium	$1.1 \cdot 10^{4}$	$9.7 \cdot 10^{3}$	$2.3 \cdot 10^{3}$	$2.6 \cdot 10^{3}$	-	-	-	0.097
Total-α	0.037	0.051	0.12	0.20	0.17	0.16	$1.6 \cdot 10^{-3}$	$1.4 \cdot 10^{-3}$
Total-β	21	18	77	120	71	85	0.30	0.31
^{60}Co	0.30	0.36	1.2	1.2	-	-	$7.1 \cdot 10^{-4}$	$7.4 \cdot 10^{-4}$
^{90}Sr	0.52	-	20	26	-	-	0.16	0.16
(^{90}Sr+^{137}Cs)	1.4	1.9	27	-	-	-	-	-
^{99}Tc	0.39	0.25	44	79	0.035	0.60	-	-
^{129}I	1.4	1.2	0.47	0.63	-	-	-	-
^{134}Cs	0.047	0.040	0.23	0.48	-	-	-	-
^{137}Cs	0.087	1.5	6.9	9.6	-	-	0.014	0.015
Plutonium-α	0.014	0.012	0.12	0.16	-	-	-	-
^{241}Pu	0.28	0.21	3.2	4.6	-	-	$3.0 \cdot 10^{-3}$	$7.4 \cdot 10^{-4}$
^{241}Am	$7.3 \cdot 10^{-3}$	0.021	0.03	0.038	-	-	-	-
^{237}Np	-	$8.6 \cdot 10^{-4}$	-	-	$5.0 \cdot 10^{-4}$	0.040	-	-
^{230}Th	-	-	-	-	0.069	0.069	-	-
^{232}Th	-	-	-	-	$9.0 \cdot 10^{-4}$	$4.7 \cdot 10^{-3}$	-	-
Uranium-α	-	-	-	-	0.059	0.048	-	-
Uranium (kg)	-	-	610	390	-	-	-	-

Springfields is located on the west coast of the United Kingdom, and liquid is discharged to the Ribble estuary. This facility is mainly involved in the manufacture of fuel elements for nuclear reactors and the production of uranium hexafluoride. The discharge of liquid radioactive waste from Springfields consists mainly of thorium and uranium and their daughter products. In Tables 2.8 and 2.9 the total alpha and total beta discharges to the northeast Atlantic Sea in the period 1996-2000 from different types of nuclear installations are given (OSPAR, 2002). The discharge from research and development facilities has been reduced by roughly an order of magnitude in the six-year period. Nuclear power stations also discharge small amounts of radionuclides, but contributed at most a few percent to the total beta discharge.

In addition to the direct discharges from reprocessing, the remobilisation of ^{137}Cs and plutonium from contaminated sediments in the Irish Sea acts as a secondary source of radionuclides in the marine environment.

Table 2.8. *Assessment of total alpha liquid radioactive discharges to the NE Atlantic from nuclear installations in the period 1996-2000 (OSPAR, 2003).*

Total alpha	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
All nuclear installations (TBq)	0.57	0.38	0.43	0.42	0.33	0.41
Reprocessing plants (TBq)	0.32	0.23	0.22	0.17	0.16	0.25
% of all installations	56.1	60.5	51.2	41.6	47.7	59.9
Nuclear power plants (TBq)	-	-	-	-	-	-
% of all installations	-	-	-	-	-	-
Nuclear fuel fabrication (TBq)	0.12	0.12	0.20	0.24	0.17	0.16
% of all installations	21.1	31.6	46.5	57.7	51.7	39.7
Research and development facilities (TBq)	0.13	0.03	0.01	0.003	0.002	0.0016
% of all installations	13.3	22.8	7.9	2.3	0.6	0.4

Substantial discharges of ^{238}Pu, $^{239+240}$Pu, ^{241}Am and ^{137}Cs and other radionuclides in the 1970s and early 1980s resulted in widespread contamination of Irish Sea sediments. It has been shown that these radionuclides can be redissolved and transported out of the Irish Sea. An annual loss of 1.19 TBq $^{239+240}$Pu and 86 TBq ^{137} Cs from the Irish Sea has been estimated by Cook *et al.*, (1997), while Leonard *et al.*, (1999) estimated annual losses of plutonium based on remobilisation from surface sediments to be 0.59 TBq. The half-lives of plutonium and americium in Irish Sea sediments were estimated to be 58 years and ~1000 years, respectively. This implies that remobilisation of radionuclides from Irish Sea sediments is a significant source of anthropogenic radionuclides in the North Sea and Norwegian coastal areas, and will remain so for a long time.

Table 2.9. *Assessment of total beta liquid radioactive discharges to the NE Atlantic from nuclear installations in the period 1996-2000 (OSPAR, 2003).*

Total beta (*excluding tritium from nuclear power plants**)	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
All nuclear installations (TBq)	332	315	265	256	173	231
Reprocessing plants (TBq)	169	167	112	126	98	141
% of all installations	50.9	53.0	42.4	49.1	57.5	61.2
Nuclear power plants (TBq)	5.2	7.4	2.0	2.0	3.0	4.2
% of all installations	1.6	2.3	0.8	0.7	1.7	1.8
Nuclear fuel fabrication (TBq)	150	140	150	128	71	85
% of all installations	45.1	44.4	56.6	50.0	41.6	36.8
Research and development Facilities (TBq)	8.1	1.0	0.66	0.36	0.30	0.46
% of all installations	2.4	0.3	0.2	0.1	0.2	0.2

2.5 Fallout from atmospheric nuclear weapons testing and the Chernobyl accident

2.5.1 Global fallout from nuclear weapons testing

From a global perspective, the dominating radioactive contamination source is global fallout of debris from the atmospheric nuclear bomb tests conducted in different parts of the world between 1945 and 1980. In total, 520 atmospheric nuclear explosions were carried out. The United States, the Soviet Union, the United Kingdom, France and the People's Republic of China mainly conducted atmospheric nuclear weapons tests. The three major test sites for atmospheric testing were Novaya Zemlya in the Arctic Ocean (Russia), the Bikini and Eniwetok Atolls in the Pacific Ocean (USA) and the Nevada test site (USA) (AMAP, 1998). Since most of the weapons tests were carried out in the northern hemisphere, the highest radioactive contamination is found there. These weapons tests have contributed to an overall background contamination level of long-lived fission products and transuranics in the northern marine environment. In terms of specific radionuclide releases, some 600 PBq ^{90}Sr were released in the period 1952-1962 compared with a ^{137}Cs release of 910 PBq (Balonov, 1997).

2.5.2 Outflow of Chernobyl fallout radionuclides from the Baltic Sea to the Norwegian coastal current

The accident at the Chernobyl nuclear power plant on April 26, 1986, resulted in large-scale fallout in Europe. The accident was a consequence of uncontrolled fission in the reactor, followed by a powerful explosion and devastating fire. The radioactive materials released were transported by air currents in the form of gases and dust particles. The prevailing meteorological conditions at the time of the accident resulted in considerable radioactive fallout in Norway and Sweden.

Outflow of water from the Baltic Sea through the Skagerrak is one of the major sources of radionuclides in the Norwegian coastal current and further into Arctic waters. According to Josefsson (1998), over 90 % of the net outflow of ^{137}Cs from the Baltic Sea originates from the Chernobyl accident. The relatively high concentration of ^{137}Cs in the water masses of the Baltic Sea is partly due to runoff from the Baltic drainage area. The general circulation pattern in the Skagerrak/Kattegat area is anticlockwise (Figure 2.6). The Baltic current carries the brackish surface waters out of the Baltic Sea and into the Skagerrak where it enters the Norwegian coastal current.

Higher salinity water enters the Baltic through a subsurface current from the Skagerrak. Radionuclides released from Cap de la Hague and Sellafield are transported by this current into the Kattegat, where mixing with Baltic water occurs. The rate of water exchange between the Skagerrak and the Baltic depends on weather conditions, and is subject to strong seasonal variations. Events of major inflow of saline waters into the Baltic can take place under specific weather conditions.

The net outflow of ^{137}Cs from the Baltic Sea into the North Sea has been estimated by Dahlgaard (2002). The estimate is based on the water exchange between the North Sea and the Baltic Sea, and biannual measurements of the ^{137}Cs activity concentration and salinity in the water at several sampling stations in the Danish straits. The annual net outflow in 2000 was estimated to be 39 TBq, with an exponential decrease during 1991-2000 with a half-life of 13.4 years. This is about 3.5 times higher than reprocessing discharges, and comparable to the estimates for remobilised ^{137}Cs for the Irish Sea.

2.6 Other present and potential sources of radioactivity in the northern marine environment

In addition to discharges from the Western European reprocessing plants, northern marine waters have also received an input of various radionuclides from Russian reprocessing plants situated on the tributaries of the Russian rivers Ob and Yenisey (see Figure 2.5). These are the Mayak Production Association in the southern Urals and the Siberian Chemical Combine (Tomsk-7) north of the town of Tomsk, and the Krasnoyarsk Mining and Chemical Combine (KMCC). Uncertainty exists regarding the magnitude of radionuclide contributions from these sources, although estimates have been made. For example, between 1958 and 1993 routine discharges from the KMCC are estimated to have led to an input of 30-100 TBq of ^{137}Cs into the Kara Sea; a level which is of a similar order of magnitude to inputs from Sellafield-derived ^{137}Cs to the area (Vakulovsky *et al.*, 1995). However, the fact that the prevailing surface currents tend to transport contamination away from the Kara Sea in predominantly easterly and northerly directions, suggests that the resultant inputs to the Barents and Norwegian Seas have been relatively low. Nonetheless, there is a potential for significant radionuclide contamination following large accidental releases of radioactivity from these nuclear complexes.

Several other sources exist which also represent potential sources of radionuclides in the Barents and Norwegian Seas. Among these are radioactive waste containers dumped in the Barents and Kara Seas by the Former Soviet Union (FSU) and the sunken submarine the Komsomolets in the Norwegian Sea. In Chapter 5 the accident involving the Russian nuclear submarine the Kursk on August 12, 2000 is described in more detail. The dumping areas and the location of the sunken submarine the Komsomolets are given in Figure 2.5. Several investigations have been conducted to detect possible leakage from these sources. As part of the bilateral environmental cooperation with the Russian Federation, a joint Russian-Norwegian expert group has been investigating the condition of the contained dumped objects and has analysed sediment and water samples at these sites. According to Strand *et al.* (1998), elevated levels of radionuclides in sediments collected in the vicinity of the dumped objects demonstrated that leakage had occurred, but no inputs of radionuclides to the open sea from this source have been detected. Following an accident on April 7, 1989, the Russian nuclear submarine the Komsomolets, lies at a depth of 1700 metres, 180 km southwest of Bear Island in the Norwegian Sea. The submarine contains a nuclear reactor and two torpedoes with nuclear warheads. According to Kolstad (1995) a very small leakage of radiocaesium isotopes may have occurred.

3. Collection of samples

Anne Lene Brungot, Norwegian Radiation Protection Authority (NRPA) and Lars Føyn Institute of Marine Research (IMR)

Photo: S. Gerland, Kongsfjorden, Svalbard 2001.

In 2000 and 2001, samples for the monitoring of radioactivity in the marine environment were collected in the Barents Sea, the Norwegian Sea, the North Sea and the Skagerrak, in selected fjords and at coastal stations including the islands of Svalbard, Bjørnøya, Hopen and Jan Mayen. A geographic overview of the sampling areas covered by the marine monitoring programmes, with the permanent coastal stations marked, is shown in Figure 3.1.

Participating organisations in the monitoring programmes are the Norwegian Radiation Protection Authority (NRPA), the Institute of Marine Research (IMR), the Directorate of Fisheries (Fdir), the Institute for Energy Technology (IFE) and the Norwegian Food Control Authority (SNT).

Based on the available information on previous discharges of radionuclides from IFE Kjeller to the River Nitelva, the NRPA decided to take part in the sampling programme near the former discharge point in 2000. Also, samples from the discharge from IFE Halden to Iddefjord were collected in 2000. In 2001 samples were also collected from a lake in Bergen where an earlier discharge point from Haukland hospital was located. The results from the analysis of these samples are given in Chapter 4. In addition, three expeditions to the sunken Russian submarine, the Kursk, took place in August and October 2000, and in October 2001. A summary of the measurement and sampling programme and analytical results are presented in Chapter 5 in this report.

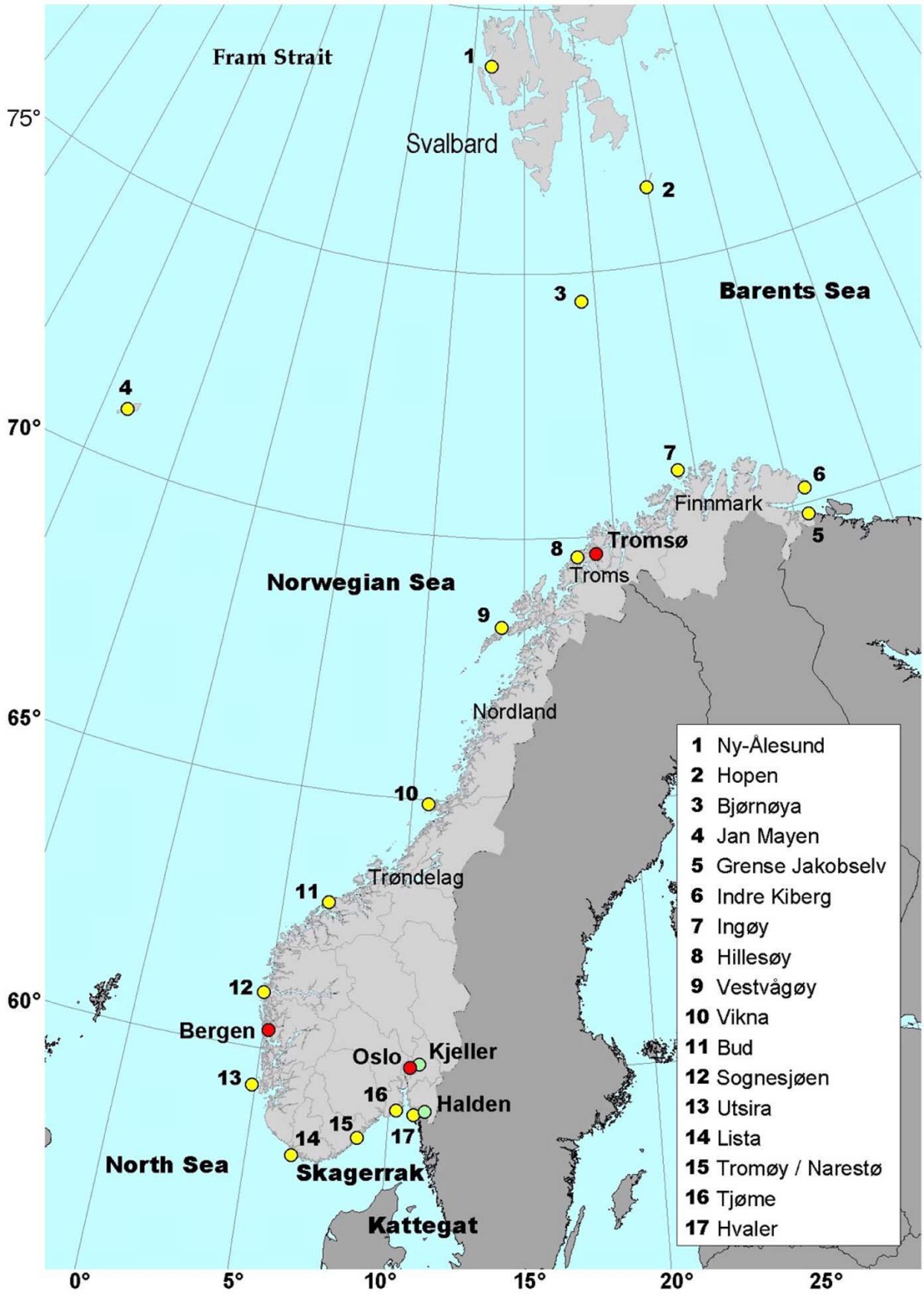


Figure 3.1. *Geographic overview of the sampling area covered by the marine monitoring programmes (permanent coastal sampling stations are indicated by yellow dots).*

Table 3.1. *Number of samples collected and analysed in 2000 and 2001.*

Sample	**Number of samples analysed**
Seawater	380
Sediments	210
Fish	770 (5,000 fish)
Crustacean and molluscs	130
Seaweed	172
Other	30

In 2000, the NRPA had the opportunity to collect samples during an expedition in the Fram Strait with the research vessel R/V Polarstern. The expedition was organised by the Alfred Wegner Institute for Polar and Marine Research. Additional samples were collected along the west coast of Svalbard by NRPA during the OHRRE/BIODAFF expedition with the R/V Lance (Norwegian Polar Institute) in 2001, and the results from these are included in this report. Table 3.1 gives an overview of the total number of samples analysed during 2000 and 2001.

3.1 Sea water

In 2000 sea water samples were collected during the expedition with R/V Johan Hjort to the Norwegian Sea, and the expedition with R/V G.O. Sars in the North Sea and the Skagerrak in 2001. In addition, water samples from the Barents Sea and the fjords, from Nordfjord in the south to Tanafjorden in the north, were collected by the IMR during 2000 and 2001.

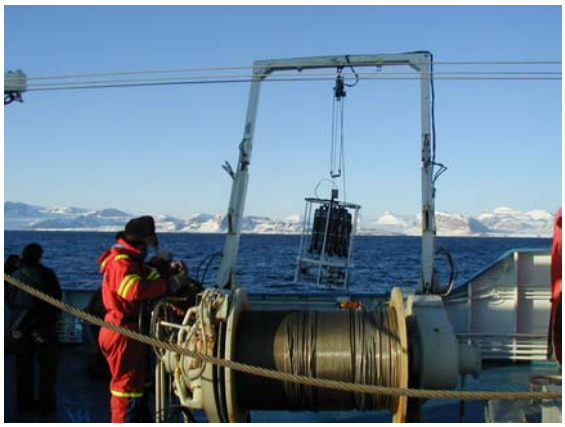


Photo: B. Lind, water sampling from Svalbard with R/V Lance in 2001.

Sea water samples were collected monthly from the sampling station at Hillesøy in Troms (see Figure 3.1), and yearly from locations along the southern coast of Norway. In the northern areas, NRPA collected water samples from the islands of Svalbard, Bjørnøya, Hopen and Jan Mayen (see Figure 3.1) in 2000 and 2001. In addition, some of the results from water sampling during the expedition to the Fram Strait with the research vessel R/V Polarstern in 2000, and the expedition to Svalbard with the research vessel R/V Lance in 2001 are included. Water samples from the area around the Russian

submarine the Kursk were collected from the bottom and the surface during 2000 and 2001. The results are presented in Chapter 5.

Sea water samples normally contain very low concentrations of ^{137}Cs, and therefore the radionuclide is concentrated by pumping up to several hundred litres through a filter system with caesium-binding sorbents (Roos *et al.*, 1994). The system consists of a prefilter (1 micron) and two $Cu_2[Fe(CN)_6]$-impregnated cotton filters connected in series. Assuming the same collection efficiency for the $Cu_2[Fe(CN)_6]$-impregnated filters, the amount of caesium passing through the prefilter can be calculated by considering the two filters as the first two terms in a geometrical series, which has the sum:

$$A(^{137}Cs) = A_1/(1-A_2/A_1)$$

where A_1 and A_2 are the ^{137}Cs activities on the first and second of the impregnated filters.

Sea water samples of 200 litres were collected for determination of the activity concentration of ^{238}Pu, $^{239+240}Pu$ and ^{241}Am in the water. ^{242}Pu and ^{243}Am were added for chemical yield determination. The precipitation of plutonium and americium from the water samples was performed *in situ* according to the analytical procedure described by Chen *et al.* (1991). The results from water sampling in the marine environment are described and presented in Chapter 6.

For determination of ^{99}Tc activity, samples of 50-100 litres of filtrated (< 1 micron) sea water are collected and transported to the laboratory for further analysis. For determination of ^{90}Sr activity, samples of 50 litres are collected and acidified *in situ* before transportation to the laboratory for further analysis.

3.2 Sediment

Based on the available information on previous discharges of radionuclides from IFE Kjeller (mainly plutonium) to the River Nitelva, the NRPA decided to take part in the sampling of sediments near earlier discharge points in 2000 and 2001. Samples were collected by the IFE as part of their regular monitoring programme. NRPA also collected parallel samples at a sewage treatment plant in connection with radioactive contamination by discharged water from IFE Halden.

Photo: A. L. Brungot. Sediment sampling from G.O. Sars, November 2001.

In 2001 sediment samples were collected from the local lake in Bergen (Store Lundegårdsvann). In the 1960s, the regional hospital released radioactive waste into this lake. The analytical results are given in Chapter 4.

Sediment samples were collected during the expedition with R/V Johan Hjort to the Norwegian Sea in 2000, and the expedition with G.O. Sars in the North Sea and the Skagerrak in 2001. Sediment was retrieved from the sea bed using a Smøgen box-corer. Sediments were originally collected using the box-corer and a surface grab. Two profiles were collected from each box by slowly inserting PVC tubes. Surface sediment samples were obtained from the upper 2 cm layer from the left-overs in the box-corer. The sediment samples were frozen shortly after sampling onboard the research vessel, and kept frozen until they were sliced in appropriate sizes and analysed. In addition, some of the results from sediment sampling from the expedition to the Fram Strait with R/V Polarstern in 2000, and the expedition with R/V Lance in 2001 are also included in this report.

IMR have also collected sediment samples from the North Sea, the fjords from Nordfjord in the south to Tanafjorden in the north. The analytical results for sediment samples are given in Chapter 6. The results from the analysis of sediment samples from the area around the sunken Russian submarine the Kursk are presented in Chapter 5.

3.3 Fish and shrimps

The Fdir collected fish and shrimp samples from commercial fishing locations. Individual fish were collected from five different locations around the Norwegian coast, but mainly from the Barents Sea. The Fdir collects cod and prepares pooled samples by combining muscle samples of 50 grams from 100 individual fish four times per year. Additionally, the SNT's local office in Salten collected different species of fish and shrimps from the fjords in the northern part of Norway and prepared pooled fish samples, each containing the meat from 25 fish. The Fdir also analyses 25 individual cod each month.

Different fish species were also collected during the expedition with R/V Johan Hjort to the Norwegian Sea in 2000, and the expedition with G.O. Sars in the North Sea and the Skagerrak in 2001. In addition, different fish species were collected from the Barents Sea by the IMR and NRPA during different expeditions in 2000 and 2001. After the accident with the Kursk in 2000, some commercial fishing vessels also collected samples of fish in the Barents Sea. These samples were analysed by the IMR and NRPA during 2000 and 2001. The results from sampling of fish in the marine environment surrounding Norway are described and presented in Chapter 7. A few fish samples were collected from the area around the Kursk in three expeditions in which the NRPA participated during 2000 and 2001, and the results are presented in Chapter 5.

3.4 Crustaceans and molluscs

In 2000 and 2001, lobsters and crabs were collected by local fishermen in different stretches of water along the western and southern parts of the Norwegian coastline. Additionally, king crab and starfish were collected during the Norwegian Sea expedition on the R/V Johan Hjort in 2000 and the G.O. Sars in 2001. Mussels are collected each year at coastal stations in the northern and southern parts of Norway. The NRPA has analysed samples of lobster, crab and mussel with regard to ^{99}Tc and gamma-emitting nuclides.

Foto: E. Svensen, crab pot.

Lobsters were mainly sampled from Kvitsøy on the coast of Rogaland and in Stefjord further north. Also, crabs and crawfish from the coastline along the south and west part of Norway, and king crab from the northern part of Norway were collected and included in the analysis for 2000 and 2001. The results of radionuclide analysis for crustacea are presented in Chapter 7.

3.5 Seaweed and other biota

The NRPA collected seaweed samples from eight stations along the Norwegian coast as well as the islands of Svalbard, Bjørnøya, Hopen and Jan Mayen. At Hillesøy in northern Norway, seaweed is collected every month. In southern Norway, seaweed is collected once per year. In addition, IFE performs monthly or annually seaweed sampling at ten locations along the Norwegian coastline, from the Russian border in the north to the Swedish border in the south. The sampling locations and the results of radionuclide analysis of samples of seaweed and other biota are presented in Chapter 7 of this report.

4. Environmental radioactivity from Norwegian sources

Torbjörn Gäfvert and Anne Kathrine Kolstad, Norwegian Radiation Protection Authority (NRPA)

4.1 Environmental contamination from IFE Kjeller

As the operator of nuclear facilities requiring authorisation for the discharge of radioactive materials, the IFE Kjeller is responsible for monitoring these discharges and the resulting levels of radionuclides in the environment. The results of this monitoring programme are reported each year to the NRPA. The NRPA, as the authority on radiation protection, may carry out independent investigations, or collect separate control samples.

Based on the available information on the earlier discharges of radionuclides (mainly plutonium) to the River Nitelva, the NRPA decided to take part in the sampling of sediments near the discharge point of the NALFA (Ny Avfallsledning for Lavaktivt Flytende Avfall) pipeline in 1999, and to perform an independent analysis of parallel samples. The results of this analysis have been reported earlier by Rudjord *et al.,* (2001).

The general public and the NRPA were concerned by the high levels of historical plutonium contamination of sediments in the River Nitelva near the discharge point. The water level of the river is regulated, and may vary greatly, especially during the spring season when the water level may be lowered in order to avoid flooding as a result of melt-water. In such situations, the contaminated sediments could be exposed possibly resulting in radiation doses to the public exceeding present dose limits. Taking the above into account, the NRPA ordered a clean-up operation. All sediments with concentrations of transuranics (plutonium + americium) higher than 10 Bq g^{-1} were removed in early spring 2000. During the removal of the most contaminated sediments some additional control samples were collected by the NRPA and analysed with regard to ^{241}Am, ^{238}Pu, $^{239+240}$Pu and ^{241}Pu (see Table 4.1). After the removal of the heavily contaminated sediments, a new sampling campaign was conducted in 2001 and the sediment samples were analysed by gamma spectrometry (see Table 4.2).

Table 4.1. *Activity concentration of ^{241}Am, ^{238}Pu, $^{239+240}$Pu and ^{241}Pu [Bq kg^{-1} d.w.] in sediment control samples collected during removal of the most contaminated sediments in 2000.*

Sample	^{241}Am	^{238}Pu	$^{239+240}$Pu	^{241}Pu
Sediment sample 1	55 ± 4	19 ± 4	2,330 ± 288	440 ± 90
Sediment sample 2	26 ± 2	0.8 ± 0.2	77 ± 4	< 70
Sediment sample 3	3.5 ± 0.8	1.4 ± 0.3	157 ± 7	< 60

Table 4.2. *Measured activity concentrations [Bq kg^{-1}d.w.] of ^{137}Cs, ^{60}Co and ^{241}Am in sediment samples after removal of the most contaminated sediments in 2001.*

Sample (depth)	^{137}Cs	^{60}Co	^{241}Am
Sediment core 1 (0-10 cm)	10.5 ± 0.5	n.d	n.d
Sediment core 1 (10-21 cm)	n.d	n.d	n.d
Sediment core 2 (0-10 cm)	55.1 ± 2.8	n.d	1.2 ± 0.6
Sediment core 2 (10-21 cm)	88.3 ± 4.4	n.d	4.9 ± 0.6
Sediment core 3 (0-10 cm)	113 ± 6	19.2 ± 1.0	33.1 ± 2.0
Sediment core 3 (10-19 cm)	1.5 ± 0.1	n.d	n.d

n.d = not detected

According to previous results (Rudjord *et al.,* 2001) and the results in Table 4.1, the $^{239+240}$Pu/^{241}Am ratio in the contaminated sediments is in the range 3-43. In the most contaminated sediments the ratio is normally around 30. Even with the most conservative estimate for $^{239+240}$Pu it can be seen in Table 4.2 that none of the sediment control samples in the contaminated area after the removal of the most contaminated sediments were above the limit of 10 Bq g^{-1} (for ^{241}Am + $^{239+240}$Pu) set by the NRPA.

5. The Kursk accident

Bjørn Lind, Norwegian radiation Protection Authority (NRPA)

5.1 The accident

On the morning of August 12, 2000, a Russian submarine sank in international waters east of the Rybatschi Peninsula in the Barents Sea. The nuclear submarine, the Kursk (Figure 5.1), a Russian Oscar II class attack submarine, sank to a depth of 116 metres at the position 69º 37'N, 37º 35'E, northeast of Murmansk about 250 km from Norway and 80 km from the coast of the Kola Peninsula (Figure 5.2).

Figure 5.1. *The Russian nuclear submarine, the Kursk.*

The Kursk (NATO code name OSCAR-II) was designed by the Rubin Central Design Bureau. It is a nuclear powered cruise missile attack submarine. Construction of the Kursk started in 1992 at the Sevmash shipyard in Severodvinsk and she was commissioned in 1995. The vessel was 154 m long, was equipped with two pressurized water reactors and the submerged displacement is 24,000 tons. Each reactor had a thermal effect of 190 MW, or less than 10 % of a typical nuclear power plant reactor. According to official Russian sources, the reactors were shut down during the accident and the submarine was not carrying nuclear weapons.

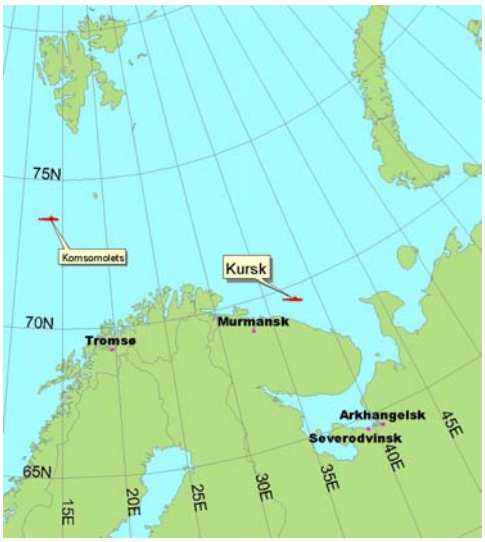


Figure 5.2. *Location of the Kursk and the Komsomolets (AMAP data centre).*

The Kursk left its home base of Vidiayevo in Uraguba Bay on August 10, 2000, with a total of 118 men aboard to participate in military exercises in the Barents Sea. On the morning of August 14, the NRPA received a message from the Rescue Centre of Northern Norway in Bodø. The centre had heard rumours of an accident on board the Russian nuclear submarine, the Kursk. The NRPA declared a state of "information emergency preparedness" and the Norwegian "crisis committee for nuclear accidents" was activated. Later, other Scandinavian countries and the International Atomic Energy Agency (IAEA) were informed about the rumours. The crisis committee met later the same day and decided to establish a programme for collecting water samples in the area of the accident.

In collaboration with the headquarters of Defence Command in Norway, the NRPA carried out measurements on sea water samples taken as close as possible to the site. A Norwegian defence research vessel initially collected the samples. The choice of sampling location was decided after consultation with the Norwegian Institute of Marine Research, the Norwegian Meteorological Institute and the Norwegian Polar Institute. The NRPA gathered information from stations monitoring radioactivity in the air at Viksjøfjell and Svanvik in eastern Finnmark, northern Norway. Furthermore, the NRPA also had access to data from monitoring networks in Russia, Finland, Sweden and Norway, which continuously monitor and register possible fallout or increases in radioactivity levels in the air. Further information regarding the accident can be found in Amundsen *et al.*, (2001).

5.2 Expeditions to the Kursk and sampling at the site of the accident

Two expeditions took place: a rescue operation during the period August 17-22, 2000 with the vessel DSV Seaway Eagle and an expedition in the period October 20-November 7, 2000 with MSV Regalia to recover the bodies of the casualties. During the lifting operation of the Kursk from the seabed, a monitoring expedition with the Russian vessel Semen Djeshnov took place in the period September 25-October 10, 2001. Laboratories for preparation and measurement of samples were established on board the vessels used for the expeditions. During the expeditions in 2000, the collection of surface and bottom water and sediment samples was conducted in the close vicinity of the wreck (Figure 5.3). In addition, air samples and water samples were collected from inside the submarine. The monitoring programme also included personal dose meter measurements on divers and dose rate measurements inside and outside the hull as well as on debris brought up on deck on the vessels.

During the 2001 expedition with the Semen Djeshnov, environmental samples were collected in the area of the accident before, during and after the raising of the Kursk. Background sampling was performed at a distance of about 30 km SSE of the Kursk, and at a distance of 3-4 km south of the submarine (Figure 5.3). Six days before lifting, the Semen Deshnov was positioned about 1.2 km southeast of the Kursk at a position which was favourable with regard to the direction of the underwater current. During the lifting operation, which took place on October 8, bottom water was collected. Air sampling and dose rate measurements were also performed during the lifting operation. After the Kursk was towed towards Roslyakovo, sampling of water, sediment and fish took place at eight locations around the site, at distances varying from 0.6 to 1.1 km. Finally, environmental samples were taken at the site where the Kursk had been located.

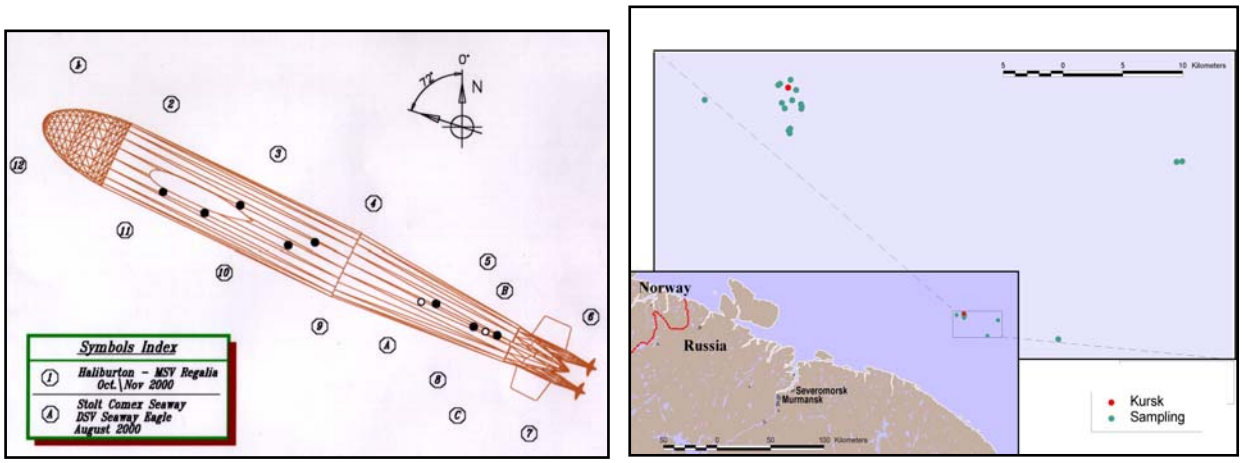
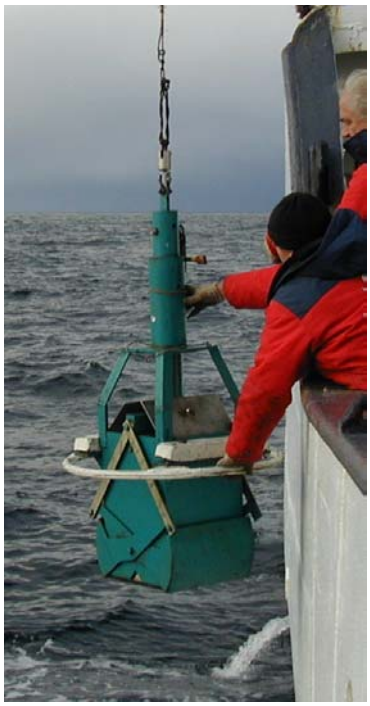


Figure 5.3. *Sediment sampling locations in August and October 2000 (left) (Source: Halliburton) and environmental sampling sites during the expedition in September-October 2001 (right).*



Sampling of sediments.

(Photo: B. Lind)

Collection of sediment profiles from the box-corer.

(Photo: B. Lind)

Large volumes of surface and near bottom water were collected using flexible plastic tubes and an electric pump submerged in the water just below the surface, or using the fire pump on board the vessel. On deck, the water was pumped through a Cs-sorbent rig for caesium measurements. Most of the sediment samples were obtained using a Smøgen box-corer with an inner area of 30 x 30 cm. Subsamples of the sediment core profiles were obtained by inserting PVC tubes into the sediment layer inside the box. The cores were sliced into 1 cm sections on board and stored in plastic bags. In addition and when the quality of the sample did not allow for profile collection, sediment surface samples were collected.

Sampling of sea water for Cs measurements.

(Photo: B. Lind)

Collection of fish samples.

(Photo B. Lind)

Commercial fish species for human consumption (cod and haddock) and some other marine organisms were mainly collected using traditional fishing equipment (fish line and jig).

The radioactivity levels of some samples were measured on board with gamma detectors, and later all samples underwent more accurate investigation in laboratories onshore. Air sampling devices, drawing 140 m^3 h^{-1} through a Whatman GF/A glass fibre filter was mounted on the deck of each vessel. Filters were replaced at intervals of 1-2 days, packed in a plastic container and the gamma emitters measured on board. Finally, each sample was compressed to a small brick, packed in a container and measured on a HPGe detector in a laboratory onshore.

5.3 Measurements

Dose rate measurements were performed frequently on air out on deck using an Automess 6150AD1 SF dose rate meter connected to a gamma probe. The readings from the meter are given in μSv h^{-1}. For gamma measurements on board, two types of instruments were used: a high-resolution HPGe detektor (2.0 keV FWHM at 662 keV) and sodium iodide detectors (NaI) with lower resolution (58 keV FWHM at 662 keV). Different NaI set-ups were used: e.g. a 2" x 2" detector with an Easy Spec multichannel analyser and a 3" x 3" detector with a Canberra series 10 multichannel analyser and model 296 detector from EG&G ORTEC. After the expeditions the activity of the samples was finally measured with HPGe detectors in laboratories onshore. During both expeditions in 2000 all divers involved in the operation used personal dosimeters (badges) supplied by the National Radiation Protection Board (NRPB).

5.4 Results and conclusion

Dose rate measurements made by the remotely operated vehicels (ROVs) and divers close to the hull of the submarine and inside some of the compartments, as well as measurements performed on debris from the wreck did not show radiation levels above normal. Dose rate readings obtained on the expedition vessels were similar to background (0.04-0.05 μSv h^{-1}). During the expeditions in 2000, two of the divers received a radiation dose of 200 μSv while all the other results were below the detection limit of 100 μSv. Analysis of airborne activity on the filters failed to reveal levels above the detection limit $1.0 \cdot 10^{-5}$ Bq m^{-3}, showing that no airborne radionuclides from the Kursk were detected. The results obtained from the expeditions are summarised in Tables 5.1 and 5.2.

Table 5.1. *Activity concentrations in environmental samples taken on the Seaway Eagle (SE) and Regalia expeditions (REG), in 2000.*

Expedition / Sampling period	**Surface sediment**				
	^{131}I (Bq kg^{-1} d.w.)	**^{137}Cs (Bq kg^{-1} d.w.)**	**^{134}Cs (Bq kg^{-1} d.w.)**	**^{238}Pu (mBq kg^{-1} d.w.)**	**$^{239+240}$Pu (mBq kg^{-1} d.w.)**
SE / Aug. 20-22	< 0.7	0.7 (1)	< 0.6	n.a.	n.a.
REG / Oct. 20-Nov. 7	< 0.7	0.7-1.5 (1)	< 0.6	6-15 (2)	30-70 (2)
	Sea water				
	^{131}I (Bq l^{-1})	**^{137}Cs (Bq l^{-1})**	**^{134}Cs (Bq l^{-1})**	**^{238}Pu (mBq m^{-3})**	**$^{239+240}$Pu (mBq m^{-3})**
SE / Aug. 20-22	< 0.5	< 0.5	< 0.5	0.4 ± 0.1	3.4 ± 0.1
REG / Oct. 20-Nov. 7	-	$3.4 \cdot 10^{-3}$ ± 4%	-	< 0.5	5.0 ± 0.1

The uncertainty in single measurements were in the range 7-38% for (1), and 36-67% for (2).

Table 5.2. *Activity concentrations in environmental samples taken from the Semen Deshnov in the 2001 expedition.*

Sampling location / Period of sampling	Sea water **(Bq m^{-3})**	**Surface sediment (Bq kg^{-1} d.w.)**					**Fish (Bq kg^{-1} d.w.)**		
	^{137}Cs	**^{137}Cs**	**^{134}Cs**	**^{60}Co**	**^{238}Pu**	**$^{239+240}$Pu**	**^{137}Cs**	**^{134}Cs**	**^{60}Co**
Background area / Sept. 25-27	0.6	1.3	< 0.9	< 1.2	-	0.37 ± 0.08	< 5 *	-	-
Area of accident before lifting / Sept. 28-Oct. 07	1.8-4.4	0.4-1.5	< 1.4	< 1.3	-	-	< 7 *	-	-
Area of accidentduring lifting /Oct. 08	2.0-3.2	1.0	< 0.2	< 0.4	-	-	-	-	-
Area of accident after lifting /Oct. 09-10	1.1-2.8	0.8-1.5	< 0.7	< 0.7	0.011-0.021	0.38-0.76	< 6	< 4.2	< 4.0

Sea water samples include surface and near bottom water. The error in single measurements was in the range 0.2-1.1 Bq m^{-3} for sea water, and 0.1-0.3 Bq kg^{-1} d.w. for ^{137}Cs, ^{134}Cs and ^{60}Co in sediment. The uncertainty in single measurements was in the range 0.007-0.010 for ^{238}Pu and 0.03-0.15 for $^{239+240}$Pu in surface sediments.

* Results expressed as Bq kg^{-1} w.w.

The tables include selected data from monitoring performed on board the vessels as well as data obtained in laboratories onshore. When parallel data from monitoring on the vessels and in the laboratory onshore were available, data from laboratory measurements are given. Results from measurements performed during the expeditions in 2000 were in the same range as the results from the 2001 expedition.

Russian and Norwegian results from the last expedition have been compared and showed good agreement. All results from samples collected during different time periods during the 2001 expedition were in the same range. Concentrations of ^{137}Cs in bottom and surface water showed activity levels in the range 0.6-4.4 Bq m^{-3} and monitoring of ^{137}Cs in surface sediment showed activity concentrations in the range 0.4-1.5 Bq kg^{-1}. No ^{134}Cs or ^{60}Co activity was detected in any sea water samples and for sediment samples they were below 1.4 Bq kg^{-1} and 1.3 Bq kg^{-1}, respectively. Laboratory measurements on activity levels of ^{238}Pu and $^{239+240}Pu$ in surface sediments were in the ranges of 0.011-0.021Bq kg^{-1} and 0.37-0.76 Bq kg^{-1}, respectively. Activity concentrations of ^{137}Cs in fish (analysed on board) were all below 7 Bq kg^{-1} (w.w.). Fish analysed later in the laboratory were found to have activity concentrations in the range 0.9-2.0 Bq kg^{-1} (d.w.).

It was not possible to detect any differences in activity levels in samples collected before or after the lifting operation. The activity levels detected in water and sediment samples were similar to those found around the Kursk in August and October 2000 (Amundsen *et al.*, 2001). These activity concentrations in water and sediment are similar to background levels (AMAP, 1998; Grøttheim, 2000). No leakage of radionuclides from the reactors on board the Kursk was observed the weeks after the accident or immediately before, during or after the submarine had been removed from the accident site.

6. Radioactivity in sea water and sediments

Anne Kathrine Kolstad, Björn Lind, Torbjörn Gäfvert and Anne Lene Brungot, Norwegian Radiation Protection Authority (NRPA), Lars Føyn, Institute of Marine Research (IMR)

In this chapter results from the monitoring of selected radionuclides in the Norwegian marine environment in 2000 and 2001 are given. The methods of sample collection are described in detail in Chapter 3. The observed activity concentrations of ^{137}Cs, ^{99}Tc, ^{90}Sr, ^{238}Pu, $^{239+240}$Pu and ^{241}Am in sea water and sediment are reported below. The analytical methods used are described in more detail in the Appendix.

6.1 Caesium-137 in sea water and sediment

The activity concentrations of ^{137}Cs in sea water along the northern Norwegian coast, the North Sea and the Kattegat are presented in Figure 6.1.

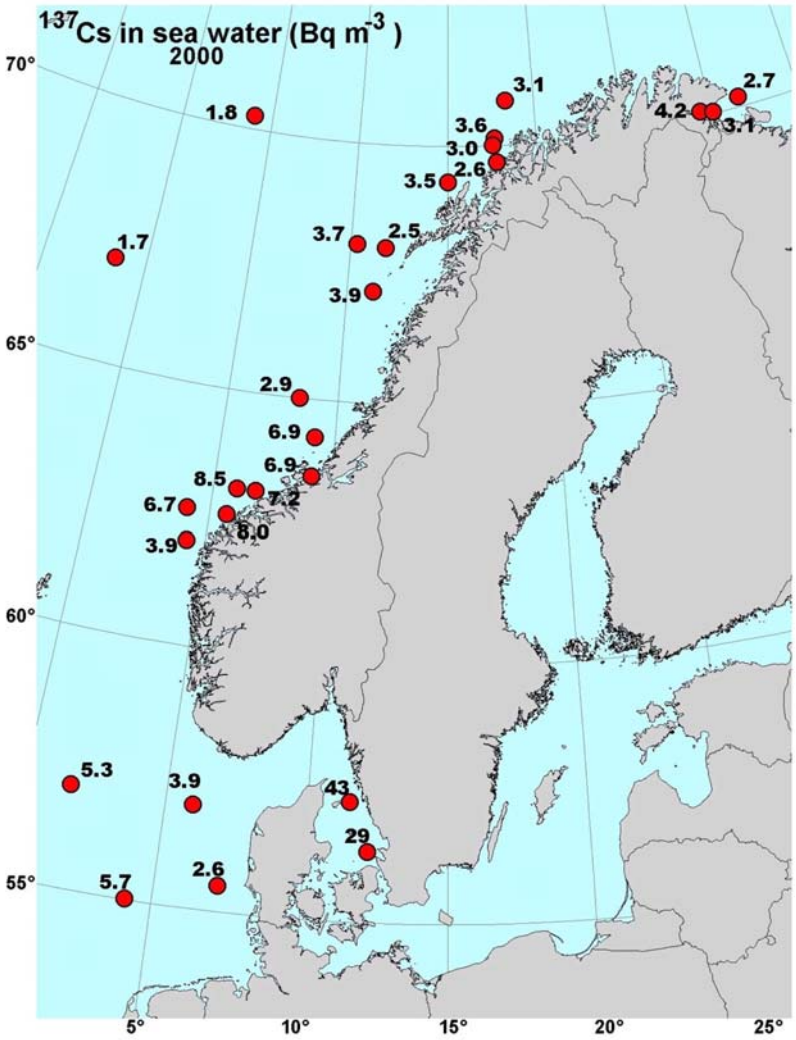


Figure 6.1. *Activity concentration of ^{137}Cs (Bq m^{-3}) in surface water samples collected along the coast of Norway in 2000.*

The concentrations of ^{137}Cs in surface water along the Norwegian coast are in the range of 2.5 to 8.5 Bq m^{-3}. The highest ^{137}Cs concentrations, 29.2 Bq m^{-3} and 42.5 Bq m^{-3}, were found in the Kattegat. This is due to the outflow of water contaminated by the Chernobyl accident from the Baltic Sea.

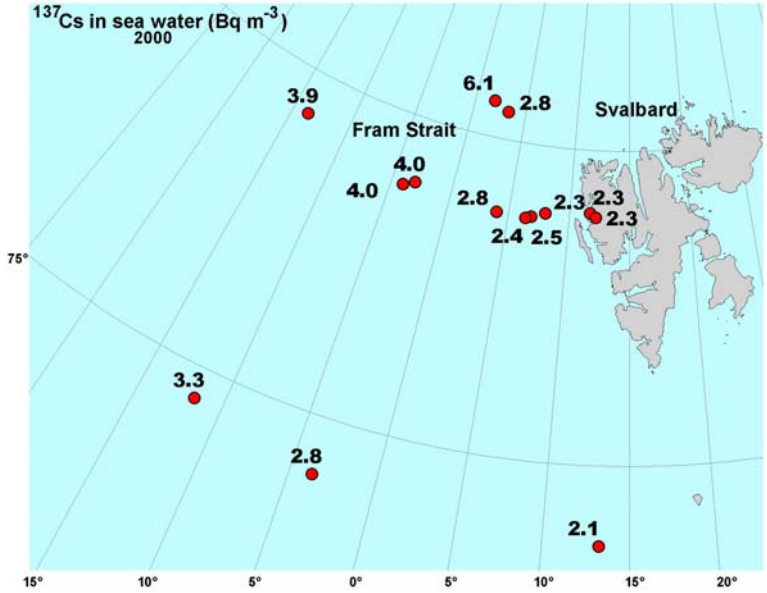


Figure 6.2. *Activity concentration of ^{137}Cs (Bq m^{-3}) in surface water samples collected in northern waters in 2000.*

The concentrations of ^{137}Cs in the northern waters and sediments in samples collected in 2000 are shown in Figures 6.2 and 6.3. Lower levels of ^{137}Cs were found in waters collected in the eastern Fram Strait and in Kongsfjorden (Svalbard). The highest ^{137}Cs concentration, 6.1 Bq m^{-3}, was observed in water under ice at 80°33'N. The levels are significantly lower than those observed in the Fram Strait in the 1980s (Nies *et al.*,1998).

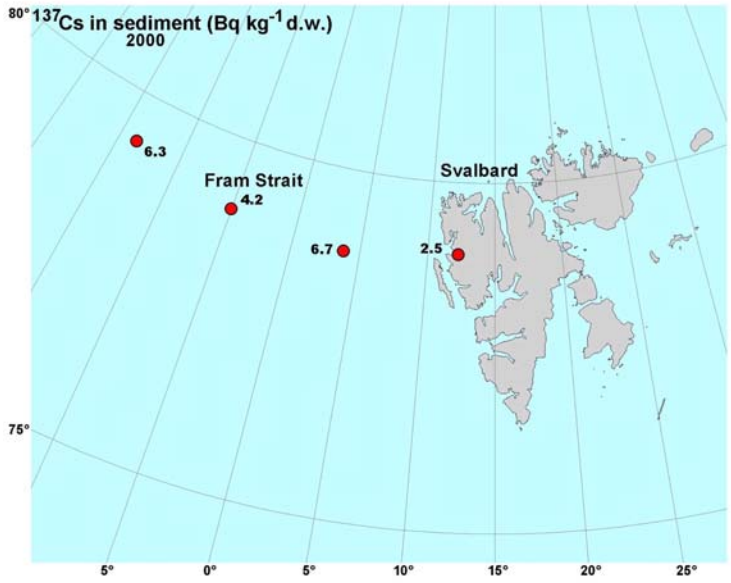


Figure 6.3. *Activity concentration of ^{137}Cs (Bq kg^{-1} d.w.) in surface sediment samples collected in northern waters in 2000.*

The observed activity concentrations of ^{137}Cs in surface sediment in 2000 are in the range of 2.50 to 6.74 Bq kg^{-1} (d.w.). The vertical distribution of ^{137}Cs at each location can be seen in Table 6.1. The sediments were divided into layers of 1 or 2 cm. Surface layers at all locations had low activity concentrations of ^{137}Cs, below 7 Bq kg^{-1} (d.w.).

Table 6.1. *Activity concentration of ^{137}Cs (Bq kg^{-1} d.w.) in sediment profiles collected in 2000.*

Location	**Depth (m)**	**Lat.**	**Long.**	**Depth (cm)**	**^{137}Cs (Bq kg^{-1} d.w.)**
Fram Strait, August 2000	2239 m	78°50' N	03°51' E	0-1 cm (surf.)	6.7 ± 0.3
				1-2 cm	7.7 ± 0.5
				2-3 cm	7.7 ± 0.5
Fram Strait, August 2000	1284 m	78°59' N	04°59' W	0-1 cm (surf.)	4.2 ± 0.3
				1-2 cm	1.7 ± 0.4
				2-3 cm	2.8 ± 0.2
Fram Strait, August 2000	173 m	79°20' N	13°35' W	0-1 cm (surf.)	6.3 ± 0.4
				1-2 cm	6.9 ± 0.4
				2-3 cm	5.8 ± 0.3
Svalbard, Gerdisland May 2000	-	78°58' N	12°17' E	Surface	2.5 ± 0.1
				0-2 cm	2.1 ± 0.2
				2-4 cm	2.3 ± 0.2
				4-6 cm	3.2 ± 0.3
				6-8 cm	2.8 ± 0.2

Concentrations of ^{137}Cs in the southern waters and sediment in 2001 are shown in Figures 6.4, 6.5 and 6.6. The concentrations of ^{137}Cs in surface water range from 2.3 to 10.0 Bq m^{-3}. The highest concentrations are seen in the western and southern parts of the North Sea and in the Skagerrak. The concentrations of ^{137}Cs in sea water along the Norwegian coast are in the same range as in 2000.

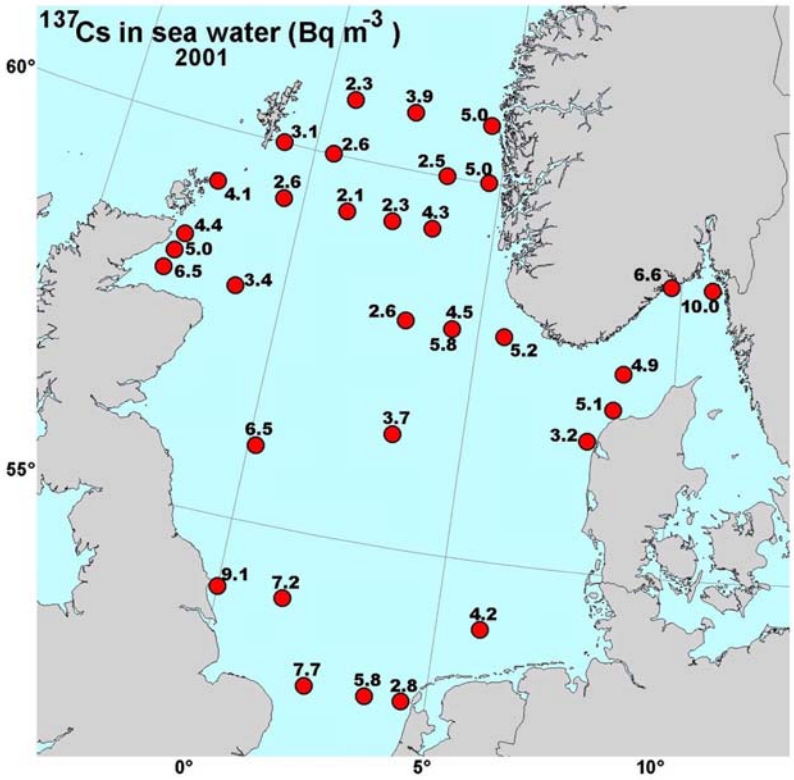


Figure 6.4. *Activity concentration of ^{137}Cs (Bq m³) in surface water samples collected in the Skagerrak and the North Sea in 2001.*

Concentrations of ^{137}Cs in surface sediment collected in the North Sea, the Skagerrak, the Kattegat and in a few southern Norwegian fjords can be seen in Figures 6.5 and 6.6. The observed activity concentrations of ^{137}Cs in surface sediment collected in the fjords and in the open sea ranged from 0.5 to 291 Bq kg^{-1} (d.w.) and from 0.7 to 13.2 Bq kg^{-1} (d.w.), respectively.

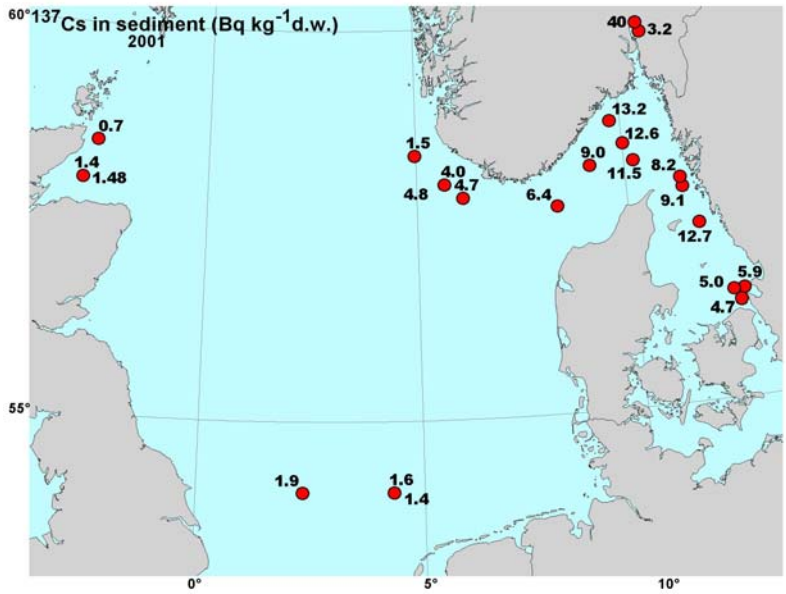


Figure. 6.5. *Activity concentration of ^{137}Cs (Bq kg^{-1} d.w.) in surface sediment samples collected in the Oslo fjord, the Skagerrak, the Kattegat and the North Sea in 2001.*

It should be noted that the highest concentration was found in Drammensfjorden (see Figure 6.6) but three more samples in the same fjord showed considerably lower concentrations, 10 Bq kg^{-1} (d.w.) or below.

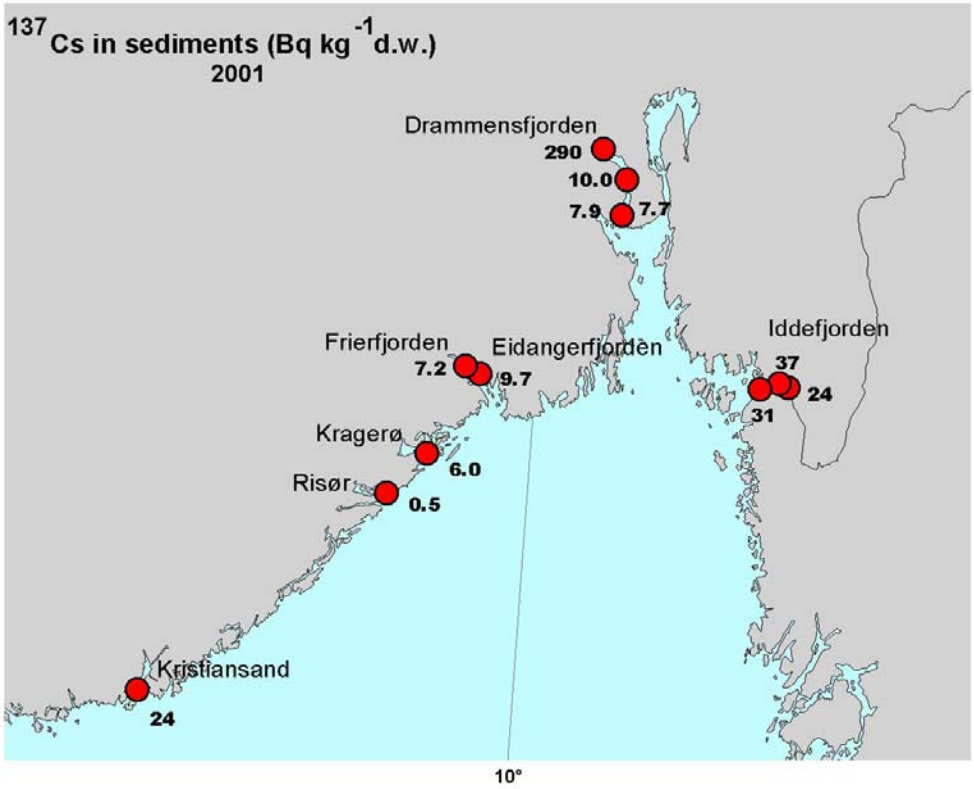


Figure 6.6. *Activity concentration of ^{137}Cs (Bq kg^{-1} d.w.) in surface sediment samples collected at the Skagerrak coast and in the Oslofjord in 2001.*

The Institute of Marine Research performed a survey of ^{137}Cs levels in water and sediment in northern and southern Norwegian fjords in November 2001. The results are shown in Figures 6.7 and 6.8. The concentration of ^{137}Cs in the sea water samples ranged between 4.9 and 18.9 Bq m^{-3} and the highest concentration was found at Narestø (see Figure 6.7). The levels are of the same order of magnitude as those found by NRPA at the south coast in 1997; between 20.2 and 26.7 Bq m^{-3} (Brungot *et al.*, 1999).

The levels of ^{137}Cs in the sediment samples collected in the fjords differ more than the concentration in the water samples, ranging from 3.9 to 126 Bq kg^{-1} (d.w.). The highest concentration was found in Ranafjorden.

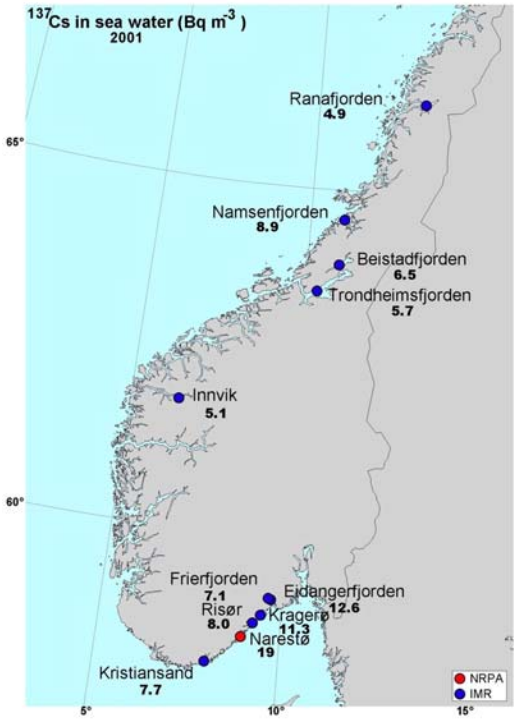


Figure 6.7. *Activity concentration of ^{137}Cs (Bq m^{-3}) in surface water samples collected in northern and southern Norwegian fjords in 2001.*

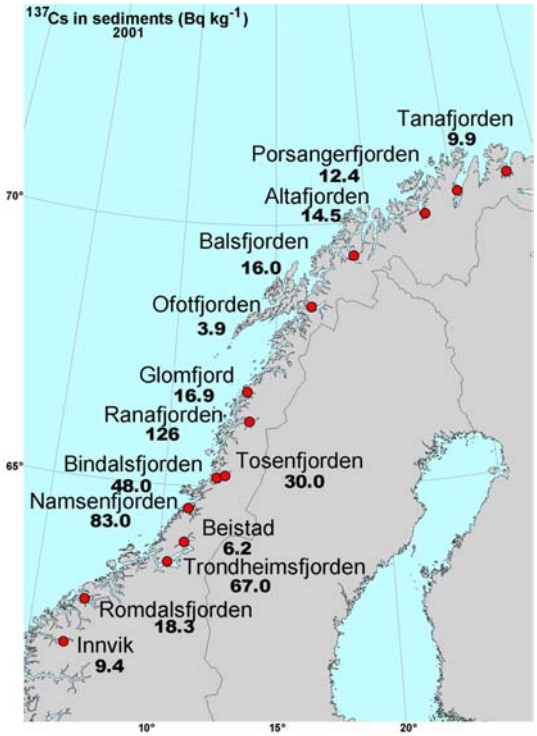


Figure 6.8. *Activity concentration of ^{137}Cs (Bq kg^{-1} d.w.) in surface sediment samples collected in northern and southern Norwegian fjords in 2001.*

6.2 Technetium-99 in sea water

^{99}Tc data from the northern Norwegian coast (red dots) and from coastal stations (blue and green dots) in 2000 are presented in Figure 6.9. All sea water concentrations were determined on filtered water (< 1 micron). The concentration of ^{99}Tc in surface water along the northern and western Norwegian coast is in the range 0.69 to 1.78 Bq m^{-3} (average 1.3 Bq m^{-3}, 1 SD = 0.26). At three locations, the concentrations were below 1.0 Bq m^{-3}. This is probably due to dilution by Atlantic waters since the water had a salinity of about 35 ‰.

^{99}Tc concentrations in northern waters in 2000 and 2001 were in the range 0.15 to 0.40 Bq m^{-3} and 0.10 to 0.20 Bq m^{-3}, respectively (see Figures 6.10 and 6.11). The highest ^{99}Tc concentration, 0.40 Bq m^{-3}, was observed in 2000 in the centre of the West Spitsbergen current along the western coast of Spitsbergen. The elevated ^{99}Tc levels in 2000 can be explained by increased discharges from Sellafield (Gerland *et al.*, 2002). From Figure 6.10 it can also be seen that the activity concentration of ^{99}Tc decreases with depth. Compared with earlier published data from 1994 (< 0.1 Bq m^{-3}) on ^{99}Tc activity the concentration in surface water in this area has increased (Kershaw *et al.*, 1999).

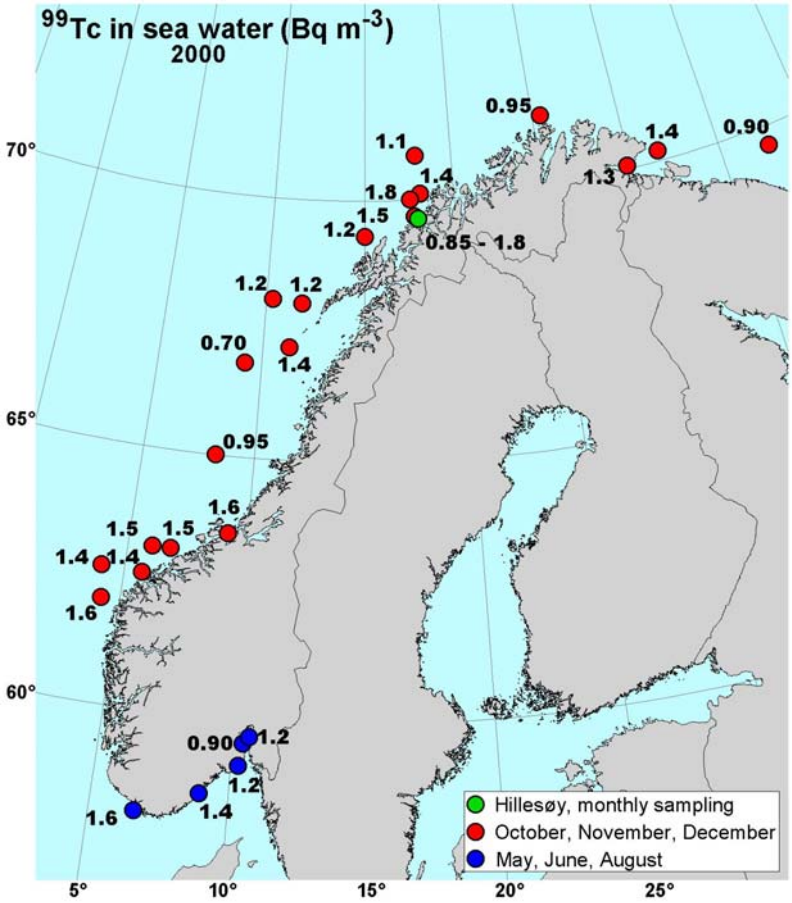


Figure 6.9. *Activity concentration of ^{99}Tc (Bq m^{-3}) in surface water samples collected along the northern Norwegian coast (red dots) and from coastal stations (blue dots) in 2000.*

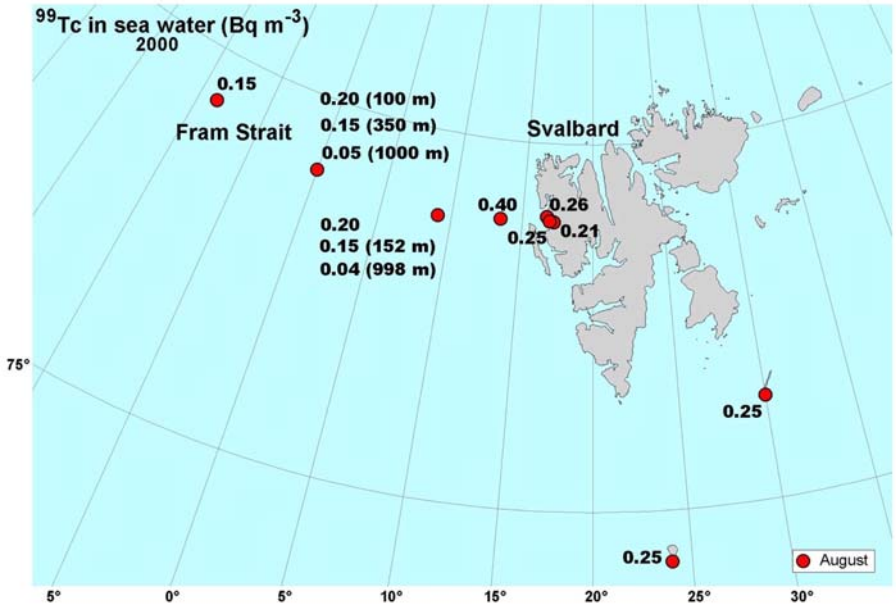


Figure 6.10. *Activity concentration of ^{99}Tc (Bq m^{-3}) in surface water samples collected in northern waters in 2000.*

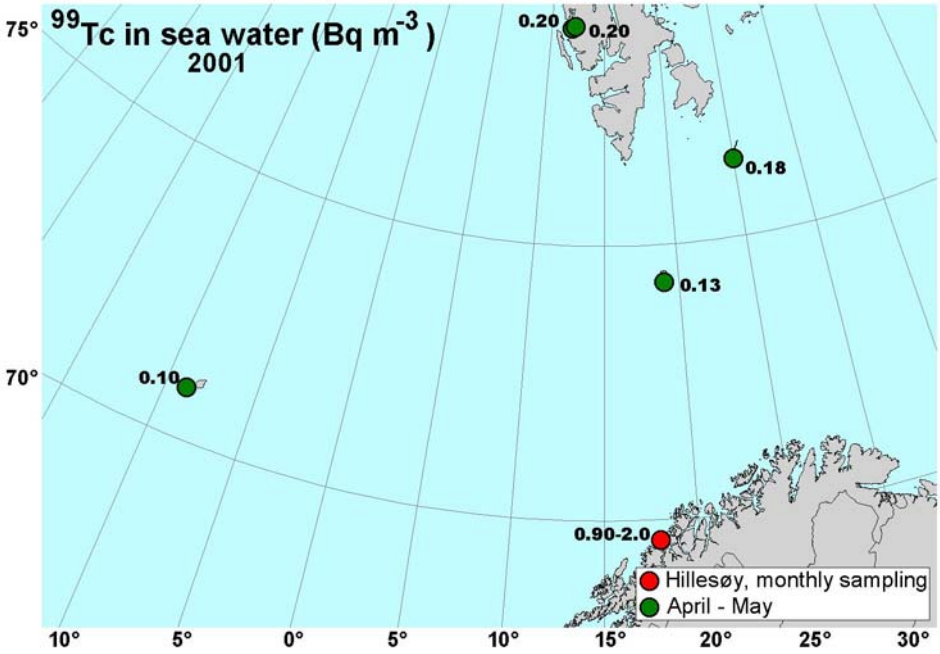


Figure 6.11. *Activity concentration of ^{99}Tc (Bq m^{-3}) in surface water samples collected in 2001, in northern waters.*

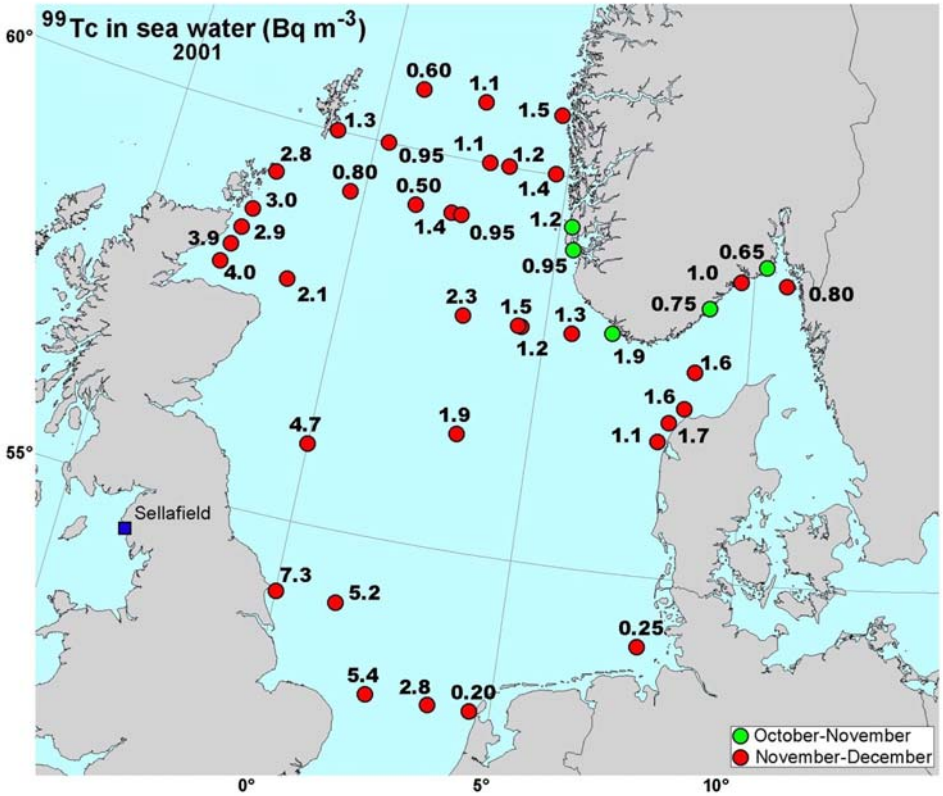


Figure 6.12. *Activity concentration of 99Tc (Bq m^{-3}) in surface water samples collected in 2001, in the Skagerrak and the North Sea.*

In November 2001, a total of 40 water samples was collected in the North Sea, covering the main part of the North Sea and the Skagerrak between 53°0'N and 61°0'N. The ^{99}Tc data are shown in Figure 6.12, together with the results from permanent coastal sampling stations on the south coast of Norway. The concentrations of ^{99}Tc in surface water are in the range 0.20 to 7.30 Bq m^{-3}. The highest concentrations are seen in western and southern parts of the North Sea, near the coast of Scotland and England. The very low concentrations observed at a few locations in the southeastern parts of the North Sea represent channel water or coastal water unaffected by discharge from Sellafield.

In northern Norway, at the Hillesøy station in Troms county, monthly sampling of sea water has been conducted since 1997. From July 1997 to January 2001 the ^{99}Tc concentration in sea water increased from a level of 0.45 Bq m^{-3} to a maximum of 2.0 Bq m^{-3} (see Figure 6.13). The concentration of ^{99}Tc ranged from 0.85 Bq m^{-3} to 1.75 Bq m^{-3} in 2000 and from 0.9 Bq m^{-3} to 2.0 Bq m^{-3} in 2001. The levels are in the same range as in 1999 (range 1.0 Bq m^{-3} to 1.9 Bq m^{-3}) (Rudjord *et al.*, 2001). The salinity is relatively high in all samples except for one sample collected in June 1998. The exceptionally low salinity measured at that time may be due to runoff of fresh water in connection with snow melting. A small dip in the salinity is also seen in the spring of 2000. There are indications of seasonal variations in concentrations of ^{99}Tc in the sea water, with generally higher concentrations in the winter season. The reasons for this are not clear. It could be due to variations in local currents, resulting in periodic mixing with uncontaminated Atlantic water, or some other coastal effect. Another possibility is that it reflects the variations in actual discharges from Sellafield (see Brown *et al.*, 2002).

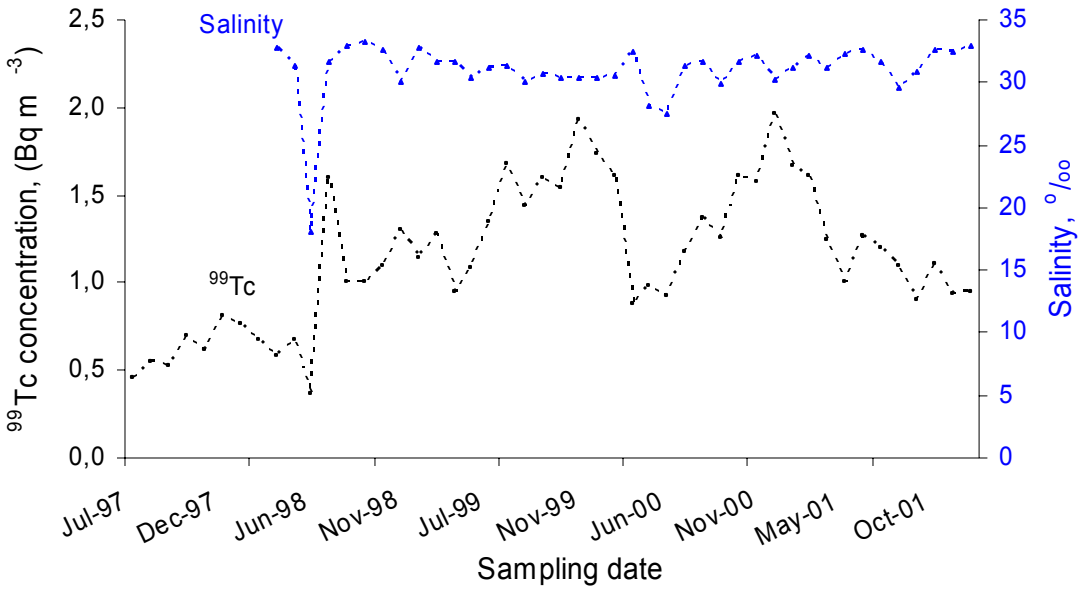


Figure 6.13. *Concentration of ^{99}Tc (Bq m^{-3}) in surface sea water samples collected at Hillesøy coastal station in Troms county from 1997 to 2001.*

6.3 Strontium-90 in sea water

In 2001, the analysis of ^{90}Sr in sea water samples was also included in the marine monitoring programme. Surface water samples were collected in the Skagerrak and in the North Sea, and the results of the analysis of these samples are shown in Figure 6.14. The main sources of ^{90}Sr in these waters are liquid waste discharged from reprocessing plants (mainly Sellafield), fallout from atmospheric nuclear weapons tests in the 1950s and 60s, and the outflow of water from the Baltic Sea. As strontium behaves conservatively in sea water (i.e. it will follow the water motion and is not noticeably affected by sedimentation processes), discharge from Sellafield will follow the sea currents and pass along the Norwegian coast, similar to ^{99}Tc.

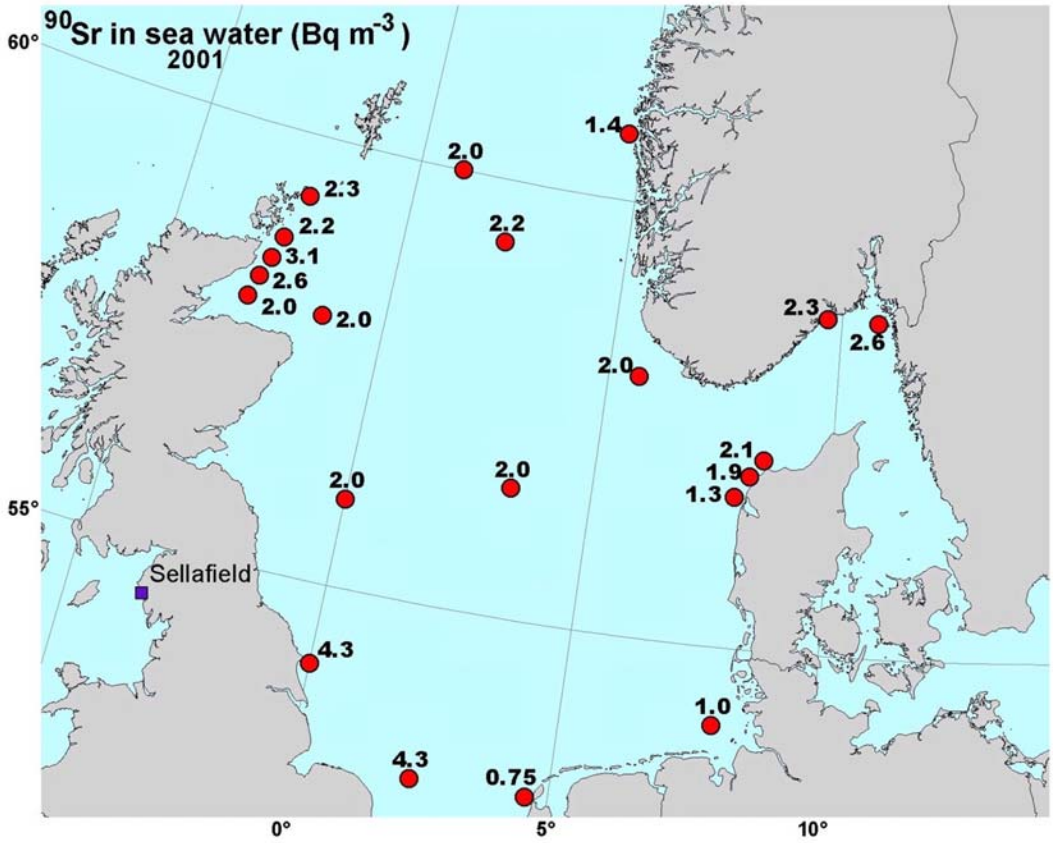


Figure 6.14. *Activity concentration (Bq m^{-3}) of ^{90}Sr in surface water samples collected in 2001, in the Skagerrak and the North Sea.*

The contribution to ^{90}Sr from fallout in the North Atlantic has been reported by Bourlat *et al.* (1996) and Dahlgaard *et al.* (1995a), who found activity concentrations of ^{90}Sr around 1.5 Bq m^{-3} in sea water during the first half of of the 1990s. The results from the 2001 monitoring range from 0.75 to 4.3 Bq m^{-3}, with an average of 2.2 Bq m^{-3}. The highest concentration, 4.3 Bq m^{-3}, was found off the east coast of the United Kingdom, indicating that liquid discharge from the reprocessing plant in Sellafield constitute a significant source of ^{90}Sr in the North Sea. Due to the relatively high levels of ^{90}Sr in Baltic Sea water, 10-30 Bq m^{-3} (Styro *et al.,* 2001; Nies and Nielsen, 1996), the contribution from outflowing Baltic Sea water, contaminated mainly by global fallout, is also a significant source.

6.4 Plutonium-238 and 239+240 and americium-241 in sea water

Activity concentrations of ^{238}Pu, $^{239+240}$Pu and ^{241}Am were analysed in sea water samples collected in Norwegian coastal waters and adjacent seas. Activity levels of $^{239+240}$Pu at sampling sites in 2000 are presented in Figure 6.15.

The concentrations of $^{239+240}$Pu in surface water along the Norwegian coast, in the Barents Sea and in the Fram Strait are in the range 1.8 to 11 mBq m^{-3}. Levels in sea water samples collected in the eastern part of the Barents Sea at the site of the Kursk accident are also within the same range. The mean concentration of all measurements is 4.7 mBq m^{-3}. In general, the levels are slightly lower along the southern coast of Norway and in the Skagerrak, compared with concentrations along the western and northern coast. Elevated levels in sub-surface water were found in samples collected west of Nordland, west of Bjørnøya and in the Fram Strait.

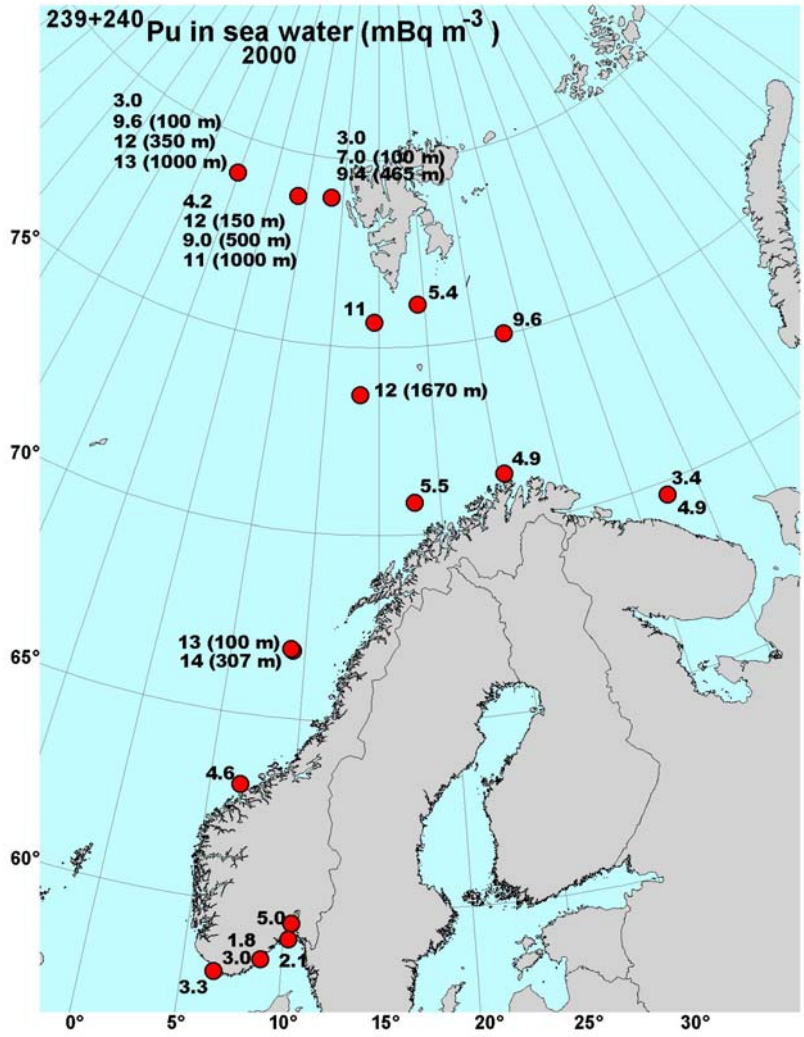


Figure 6.15. *Concentrations of $^{239+240}$Pu (mBq m^{-3}) in sea water samples collected in 2000 (sampling depth in partenthesis if not surface water).*

The concentrations in these samples are in the range 7 to 14 mBq m^{-3} with a mean value of 11 mBq m^{-3}. At a depth of 100 m, the concentrations are on average a factor three higher than in the surface water at the same location. This is due to the influence of the Atlantic deep water current as the main source of transport of some transuranic elements into the northern marine areas. The concentration of ^{241}Am was

measured in some of the water samples and the results were in the range 0.6 to 2.3 mBq m^{-3}. As for plutonium, a slight increase in activity concentration with sampling depth was observed. In 2001, water samples from the North Sea, the Skagerrak and west of Svalbard were collected for Pu and Am analysis (Figures 6.16 and 6.17).

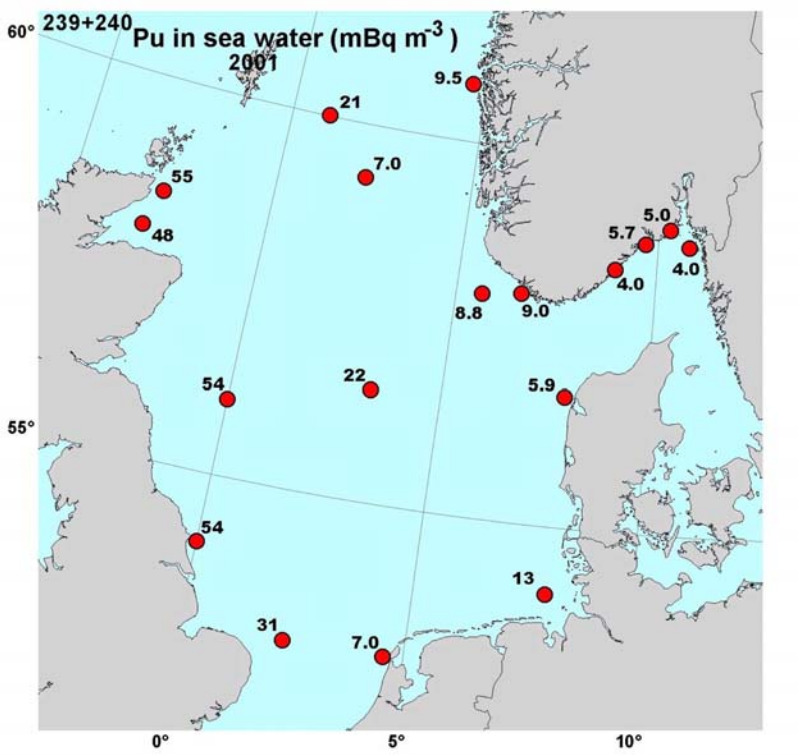


Figure 6.16. *Concentration of $^{239+240}$Pu (mBq m^{-3}) in surface sea water samples collected in the North Sea and the Skagerrak in 2001.*

The concentration of $^{239+240}$Pu in surface water along the east coast of Great Britain was in the range of 30.9 to 55.0 mBq m^{-3}, decreasing south towards the English Channel. The mean concentration in the central part of the North Sea is 16 mBq m^{-3} and 4.6 mBq m^{-3} in the outer Oslofjord and Skagerrak. Concentrations in samples collected in Kongsfjorden and west of Spitsbergen are in the range 5.6 to 8.9 mBq m^{-3}. A slight increase in the levels with sampling depth can be seen in most of the measurements.

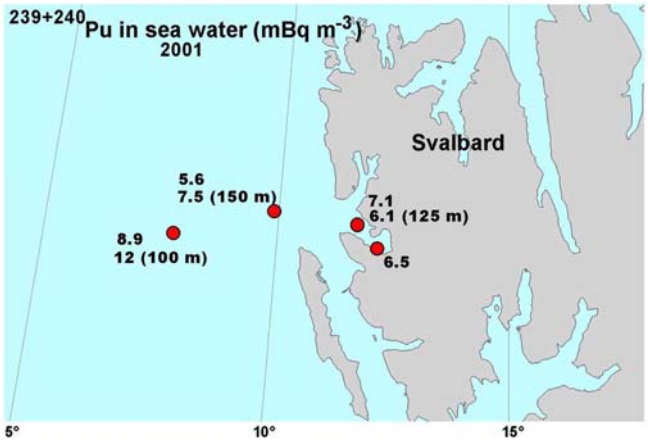


Figure 6.17. *Concentration of $^{239+240}$Pu (mBq m^{-3}) in sea water samples collected off the west coast of Svalbard in 2001.*

The concentration of ^{241}Am in the samples from the North Sea and west of Svalbard were in the range 1.3 to 13.2 mBq m^{-3} and 0.6 to 2.4 mBq m^{-3}, respectively. The concentration of ^{238}Pu in surface water for several samples in 2000 and 2001 was below the detection limit (< 1.8 mBq m^{-3} for the highest single measurement). Observed levels were in the range 0.4 to 1.0 mBq m^{-3} with a mean value of 0.5 mBq m^{-3} for all measurements except for samples collected in the North Sea in 2001. Results from these samples were about 10 times higher, in the range 1.3 to 10.0 mBq m^{-3}, with a mean value of 4.8 mBq m^{-3}.

Activity ratios can provide an important tool in identifying the sources of radioactive contamination. In Table 6.2, the ratios of ^{238}Pu to $^{239+240}Pu$ commonly associated with different sources are listed.

Table 6.2. *$^{238}Pu/^{239+240}Pu$ activity ratios associated with various radionuclide sources.*

Source	**$^{238}Pu/^{239+240}Pu$**
Global fallout	~ 0.03
Sellafield, historical	~ 0.20
Sellafield, recent	~ 0.30
Chernobyl fallout	~ 0.50

In all collected surface water samples, the reported $^{238}Pu/^{239+240}Pu$ activity ratios were in the range of 0.08 to 0.22. The highest ratios were found in samples from the North Sea. This indicates that, in addition to global fallout, other sources, such as remobilised plutonium from Irish Sea sediments contaminated by previous Sellafield discharges, may also be present in some samples.

7. Radioactivity in fish, crustaceans, molluscs and seaweed

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The Norwegian Radiation Protection Authority (NRPA) in cooperation with the Institute of Marine Research (IMR) and Directorate of Fisheries (Fdir) collected and analysed samples of fish, lobsters, crabs, starfish, periwinkles and shrimps in 2000 and 2001. In addition, results from the Food Control Authority's monitoring programme for fish are presented in this chapter. The NRPA and the IFE have also collected and analysed samples of seaweed along the Norwegian coast and off the coast of Svalbard during this period. The observed activity concentrations of ^{137}Cs and ^{99}Tc in fish, crustaceans, molluscs, seaweed and other biota are presented below. The analytical methods used are described in more detail in the Appendix.

7.1 Caesium-137 in different fish species

In 2000 and 2001, fish were collected from the Norwegian marine environment and analysed with respect to ^{137}Cs. Samples of fish were collected in the Skagerrak, the North Sea, the Norwegian Sea, the Barents Sea and in different fjords along the Norwegian coastline from the north to the south. The results of the analyses are given in Tables 7.1 to 7.4. Compared to sampling campaigns carried out in previous years, a larger variety of fish species were sampled in 2000 and 2001.

Caesium-137 in Norwegian marine waters originates from several sources. Among these are runoff from land areas affected by the Chernobyl accident in 1986, outflow of water from the Baltic Sea, fallout from atmospheric nuclear weapons tests in the 1950s and 1960s, and present and past liquid discharges from the nuclear industry, such as the reprocessing plants at Sellafield and Cap de la Hague.

In Figure 7.1 typical ^{137}Cs concentrations found in cod caught in different areas can be compared. The levels in the seas around Norway are very low. In the Baltic Sea, the uptake of caesium in fish is higher due to a higher activity concentration in the sea water (due to Chernobyl fallout) in combination with brackish water with lower salinity. In the Irish Sea, levels are influenced by past and present discharges from Sellafield. In the waters surrounding Iceland and in the English Channel, concentrations of ^{137}Cs in cod are about 0.2 Bq kg^{-1} (w.w.). This water is only slightly affected by releases from reprocessing plants and runoff from land contaminated by the Chernobyl accident, and the measured contamination mainly originates from the atmospheric nuclear weapons tests of the 1950s and 1960s.

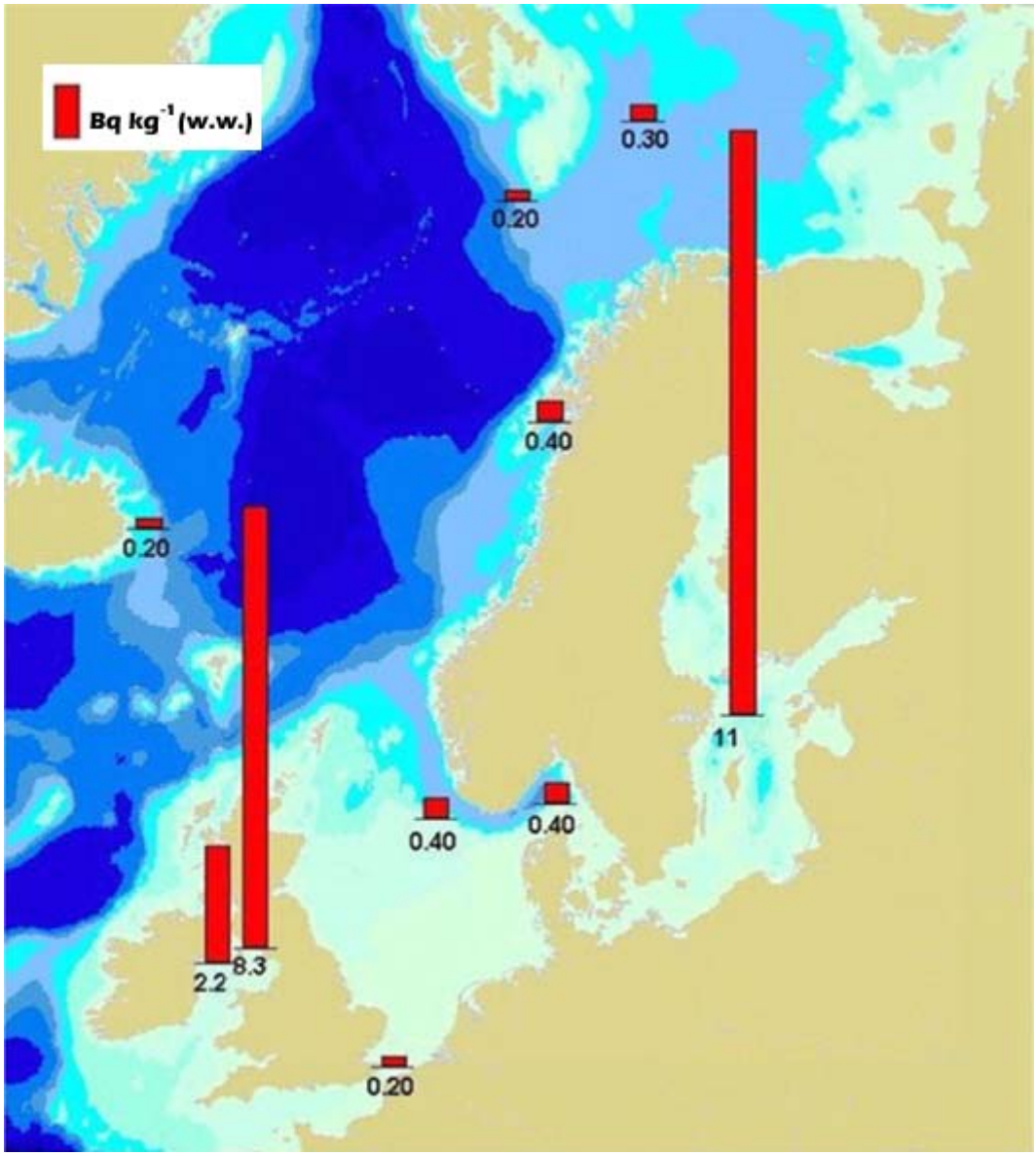

Figure 7.1. *Levels of ^{137}Cs (Bq kg^{-1} w.w.) in cod (*Gadus Morhua L*) from different marine areas; data from MAFF & SEPA 2001 and this report.*

The ^{137}Cs concentrations in fish caught in the Barents Sea, the fjords and the coastal waters of Finnmark, N Norway are given in Table 7.1. In cod from the Barents Sea, the results in 2000 and 2001 ranged from 0.15 to 0.40 Bq kg^{-1} (w.w.), which is similar to cod sampled in the Barents Sea in the period 1996-1999. The levels of ^{137}Cs in all species of fish from this area are in a range from 0.09 to 0.40 Bq kg^{-1} (w.w.). These results show no significant difference in ^{137}Cs levels between fish caught in the fjords and coastal waters and those caught in the Barents Sea.

Table 7.1. *Levels of ^{137}Cs in common fish species from the Barents Sea and the fjords and coastal waters of the northern part of Norway in 2000 and 2001.*

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
Cod *(Gadus morhua L.)*	Barents Sea	0.15-0.40 / < 5.5	30 pooled / 600	1902 / 600
Haddock *(Mellangorammus aeglefinus*		0.12-0.20	6 pooled	126
Long rough dab *(Hippoglossoides platessoides)*		0.21-0.28	5 pooled	119
European plaice *(Pleuronectes platessa)*		0.18	1 pooled	3
Golden redfish *(Sebastes viviparus)*		0.09	1 pooled	25
Cod *(Gadus morhua L.)*	Finnmark, coastline and fjords	0.22-0.40	17 pooled	410
Haddock *(Mellangorammus aeglefinus*		0.17-0.21	4 pooled	40
Saithe *(Pollachius virens)*		< 0.1-0.40	7 pooled	115
Atlantic Salmon *(Salmo salar)*		0.26-0.33	2 pooled	50

The ^{137}Cs concentrations in fish caught in the Norwegian Sea, the fjords and coastal waters of northern and central Norway are given in Table 7.2. The levels of ^{137}Cs in all species of fish from this area range from < 0.1 to 0.64 Bq kg^{-1} (w.w.)

Table 7.2. *Levels of ^{137}Cs in common fish species from the Norwegian Sea and the coastal waters and fjords in the northern and central parts of Norway in 2000 and 2001.*

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
Mackerel *(Scomber scombrus)*	Norwegian Sea, southern part	0.13	1 pooled	25
Cod *(Gadus morhua L.)*	Troms, coastline and fjords	0.21-0.53	5 pooled	125
Atlantic salmon *(Salmo salar)*		0.22	1 pooled	25

Table 7.2 continued

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
European plaice *(Pleuronectes platessa)*	Troms, coastline and fjords	< 0.27	1 pooled	4
Blue whiting *(Micromesistius poutassou)*		< 0.10	1 pooled	0.5 kg
Norway pout *(Trisopterus esmarkii)*		< 0.36	1 pooled	0.5 kg
Cod *(Gadus morhua L.)*	Nordland, coastline and fjords	0.42-0.56	6 pooled	150
Saithe *(Pollachius virens)*		0.27-0.64	3 pooled	55
Atlantic salmon *(Salmo salar)*		0.23	1 pooled	25
Witch *(Glyptocephalus cynoglossus)*		< 0.26	1 pooled	5
Blue whiting *(Micromesistius poutassou)*		< 0.31	1 pooled	0.5 kg
Norway pout *(Trisopterus esmarkii)*		< 0.36	1 pooled	0.5 kg
Saithe *(Pollachius virens)*	Trøndelag, coastline and fjords	0.33	1 pooled	5
Haddock *(Mellangorammus aeglefinus*		0.17	1 pooled	25
Whiting *(Meralangius melangus)*		0.55	1	1
Greater argentine *(Argentina silus)*		< 0.28	1 pooled	0.5 kg
Blue whiting *(Micromesistius poutassou)*		0.53	1 pooled	0.5 kg
Norway pout *(Trisopterus esmarkii)*		< 0.36	1 pooled	0.5 kg

The ^{137}Cs concentrations in fish caught in the North Sea, the Skagerrak and the fjords and coastal waters of the southern and eastern parts of Norway given in Table 7.3 range from 0.1 to 2.2 Bq kg^{-1} (w.w.). The highest levels were found in horse mackerel, whiting and sprat caught in the Skagerrak and the Kattegat, which are most affected by the outflow of water from the Baltic Sea.

Table 7.3. *Levels of ^{137}Cs in common species of fish from the North Sea including the Skagerrak and fjords and coastal waters of the southern and eastern parts of Norway in 2000 and 2001.*

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
Cod *(Gadus morhua L.)*	North Sea	0.30-0.32	2 pooled	30
Haddock *(Mellangorammus aeglefinus*		0.20-0.24	2 pooled	35
Saithe *(Pollachius virens)*		0.40	1 pooled	5
Atlantic herring *(Clupea harengus)*		0.30-0.64	2 pooled	0.5 kg
Whiting *(Meralangius melangus)*		0.4	1 pooled	10
Norway pout *(Trisopterus esmarkii)*		0.1	1 pooled	0.5 kg
Sprat *(Sprattus sprattus)*		0.3	2 pooled	0.4 kg
Dab *(limanda limanda)*		0.2	1 pooled	25
Cod *(Gadus morhua L.)*	Western coast of Norway	0.49	1 pooled	5
Saithe *(Pollachius virens)*		0.40	1 pooled	5
Whiting *(Meralangius melangus)*		0.73	1 pooled	5
Mackerel (*Scomber scombrus*)		< 0.43	1 pooled	2
Norway pout *(Trisopterus esmarkii)*		< 0.31	1 pooled	0.4 kg
Atlantic herring *(Clupea harengus)*	Southern coast of Norway	0.5-0.6	3 pooled	75
Sprat *(Sprattus sprattus)*		0.7-0.8	2 pooled	50
Atlantic herring *(Clupea harengus)*	Eastern coast of Norway	0.64-0.85	2 pooled	50
Sprat *(Sprattus sprattus)*		0.4	1 pooled	0.3 kg

Table 7.3 continued

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
Haddock *(Mellangorammus aeglefinus)*	Skagerrak and Kategatt	0.1	1 pooled	25
Atlantic herring *(Clupea harengus)*		0.3-1.0	3 pooled	75
Whiting *(Meralangius melangus)*		2.0	1 pooled	25
Sprat *(Sprattus sprattus)*		2.1	1 pooled	25
Dab *(Limanda limanda)*		0.3	1 pooled	25
Horse Mackerel *(Trachurus trachurus)*		2.2	1 pooled	25

In 2000 and 2001 screening of the ^{137}Cs activity concentration in less common fish species in Norwegian marine waters was performed. The results of this are presented in Table 7.4. The results do not differ significantly from those for the more common species of fish given in Tables 7.1 to 7.3.

Table 7.4. *Levels of ^{137}Cs in less common fish species from Norwegian marine waters in 2000 and 2001.*

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
Lemon sole *(Microstomus kitt)*	Finnmark, coastline and fjords	< 0.27	1 pooled	5
Catfish *(Anarhichas lupus)*		< 0.24	1 pooled	3
Norway redfish *(Sebastes viviparus)*	Troms, coastline and fjords	< 0.40	1 pooled	5
Torsk *(Brosme brosme)*		0.33	1 pooled	2
Catfish *(Anarhichas lupus)*		< 0.26	1 pooled	3
Ling *(Molva molva)*	Nordland, coastline and fjords	0.65	1	1
Lemon sole *(Microstomus kitt)*		0.4	1	1
Torsk *(Brosme brosme)*	Nordland, coastline and fjords	0.38	1	1
Rabbitfish *(Chimaera monstrosa)*		< 0.04	1	1

Table 7.4 continued

Species	Location	^{137}Cs in muscle tissue (Bq kg^{-1} w.w.)	Number of samples	Number of fish
Cat-fish *(Anarhichas lupus)*	Trøndelag, coastline and fjords	< 0.29	1 pooled	2
Blackmouthed dogfish *(Galeus melastomus)*		0.69	1 pooled	3
Norway redfish *(Sebastes viviparus)*		< 0.43	1 pooled	5
Torsk *(Brosme brosme)*		0.18	1	1
Round ray *(Raja fyllae)*		< 0.30	1	1
Rabbitfish *(Chimaera monstrosa)*		< 0.39	1	1
Lemon sole *(Microstomus kitt)*	North Sea	0.1	1 pooled	10
Spotted catfish *(Anarhicas minor)*		0.2	1	1
Norway redfish *(Sebastes viviparus)*		0.1-0.2	2 pooled	10
Lumpsucker *(Cyclopterus lumpus)*		< 0.2	1	1

The levels of ^{137}Cs in fish caught in the fjords could be expected to be slightly higher than in the open sea due to runoff from ^{137}Cs-contaminated land areas and a lower salinity in the water, but a clear difference in the ^{137}Cs activity concentration was not observed in these fish samples.

The level of ^{137}Cs in different species of fish caught in the Skagerrak and the Kattegat is less than 2.2 Bq kg^{-1} (w.w.). A conclusion that can be drawn from the results presented above is that the activity concentration of ^{137}Cs in all analysed fish samples can generally be considered low.

7.2 Caesium-137 and technetium-99 in crustaceans and molluscs

Samples of crustaceans and molluscs were collected in the Skagerrak, the Kattegatt, the North Sea, the Norwegian Sea, the Barents Sea and in different fjords and along the Norwegian coastline from the north to the south, and analysed with respect to ^{137}Cs and ^{99}Tc. The results from the analysis are shown in Table. 7.5. In contrast to ^{137}Cs, the main source of ^{99}Tc in crustaceans and molluscs is liquid discharge from reprocessing plants (mainly Sellafield). Discharges of conservatively behaving radionuclides such as ^{99}Tc from Sellafield are transported to the North Sea and further northwards with the Norwegian coastal current. The discharges and transportation paths are described in more detail in Chapter 2.

Table 7.5. *Activity concentrations of ^{137}Cs and ^{99}Tc in crustaceans, molluscs and other marine species collected and analysed in 2000 and 2001.*

Species	Location	Number of samples	^{137}Cs activity concentration [Bq kg^{-1} w.w.]	^{99}Tc activity concentration [Bq kg^{-1} w.w.]
Shrimps *(Pandalus borealis)*	Barents Sea	4 pooled	0.10-0.13	n.a
Shrimps *(Pandalus borealis)*	Coast of Finnmark	1 pooled	0.5	n.a
Shrimps *(Pandalus borealis)*	Coast of Troms and Nordland	4 pooled	0.18-0.21	n.a
Echinoderms *(Hippasteria phrygiana)*	Barents Sea	1 pooled	0.28	n.a
Polychaetes *(Scalibregmidae)*	Barents Sea	1 pooled	0.19	n.a
Kamchatca crab *(Paralithodes camtschaticus)*	Barents Sea, coast of Finnmark	3	< 0.1	n.a
Edible crab *(Cancer pargurus)*	SW coast of Norway	5	< 0.1-0.7	0.05
Mussels *(Mytilus Edulis)*	Hamarøy	3 pooled	< 0.1-0.16	n.a
Mussels *(Mytilus Edulis)*	Hillesøy	1 pooled	< 0.1	n.a
Mussels *(Mytilus Edulis)*	Laukvika	1 pooled	0.12	n.a
Mussels *(Mytilus Edulis)*	Rødtangen, Oslofjorden	1 pooled	< 0.1	0.75
Mussels *(Mytilus Edulis)*	Tjøme, outer Oslofjorden	1 pooled	0.17	0.73

Table 7.5 continued

Species	Location	Number of samples	^{137}Cs activity concentration [Bq kg^{-1} w.w.]	^{99}Tc activity concentration [Bq kg^{-1} w.w.]
Sea cucumbers *(Holothuroidea)*	Troms	2	< 0.2-0.43	n.a
Lobster, female *(Homarus gammarus)*	Kvitsøy, coast of Rogaland	4	< 0.1-0.32	31.1-41.5
Lobsters, roe *(Homarus gammarus)*	Kvitsøy, coast of Rogaland	3	< 0.1	9.1-12.6
Lobster, male *(Homarus gammarus)*	Kvitsøy, coast of Rogaland	17	< 0.1-0.2	2.2-12.7
Lobsters male claw *(Homarus gammarus)*	Kvitsøy, coast of Rogaland	6	< 0.1	3.0-11.5
Lobster, female *(Homarus gammarus)*	Stefjord, Nordland	1	0.19	20.2
Lobster, male *(Homarus gammarus)*	Stefjord, Nordland	1	< 0.1	2.8
Starfish *(Asteroida)*	North Sea	3 pooled	< 0.25	< 0.06
Shrimps *(Pandalus borealis)*	North Sea	1 pooled	0.21	n.a
Stone crab *(Lithodes maja)*	North Sea	1	< 0.1	0.06
Edible sea urchin *(Echinus esculentus)*	North Sea	2	< 0.1	< 0.22
Starfish *(Asteroida)*	Arendal, south coast of Norway	1 pooled	< 0.1	0.16
Periwinkles *(Littorinidae)*	Tromøy, south coast of Norway	1 pooled	0.41	n.a
Periwinkles *(Littorinidae)*	Lista, SW coast of Norway	1 pooled	< 0.1	0.95
Periwinkles *(Littorinidae)*	Tjøme, outer Oslofjord	2 pooled	< 0.1-0.23	0.85-2.95
Green shore crab *(Carcinus maenas)*	Tromøy, south coast of Norway	1 pooled	0.41	n.a
Green shore crab *(Carcinus Maenas)*	Lista, SW coast of Norway	3	< 0.1-0.12	0.18

Table 7.5 continued

Species	Location	Number of samples	^{137}Cs activity concentration [Bq kg^{-1} w.w.]	^{99}Tc activity concentration [Bq kg^{-1} w.w.]
Sea horse *(Hippocampus ramulosus)*	Kattegat	1 pooled	< 0.1	11.6
Gonatus *(Gonatus)*	English Channel	1 pooled	< 0.25	< 0.08
Swimming crab *(Macropipus)*	English Channel	1 pooled	< 0.1	n.a

n.a.- not analysed

The levels of ^{137}Cs in all species of crustaceans and molluscs are generally low. The concentrations found are in a range from < 0.1 to 0.7 Bq kg^{-1} (w.w.).

The ^{99}Tc concentrations in crustaceans and molluscs are also presented in Table 7.5. The levels of ^{99}Tc in all species except lobsters and sea horses are in the range 0.05 to 0.76 Bq kg^{-1} (w.w.). The ^{99}Tc concentrations in lobsters and sea horses are higher than in other analysed species. The high concentration factor for ^{99}Tc in lobsters is a well-known fact that has also been observed in, for example, the Irish Sea (Smith *et al., 2001)*. The level of ^{99}Tc in lobsters range from 2.2 to 41.5 Bq kg^{-1} (w.w.). It has also been observed that female lobsters tend to have a higher concentration factor for ^{99}Tc than male lobsters (Kolstad and Lind, 2002).

7.3 Caesium-137 and technetium-99 in seaweed

Seaweed was collected from different coastal stations along the Norwegian coastline, the islands of Svalbard, Hopen and Bjørnøya and analysed with respect to ^{137}Cs and ^{99}Tc, in 2000 and 2001. Seaweed *(Fucus vesiculosus)* has been used for a long time as an indicator species for radionuclides in sea water due to its high uptake of certain elements, and the fact that it is easily accessible in northern European waters. Long-term monitoring of the Norwegian coast shows that ^{137}Cs and ^{99}Tc levels in seaweed species respond to changes associated with the main sources of radioactivity in the marine environment.

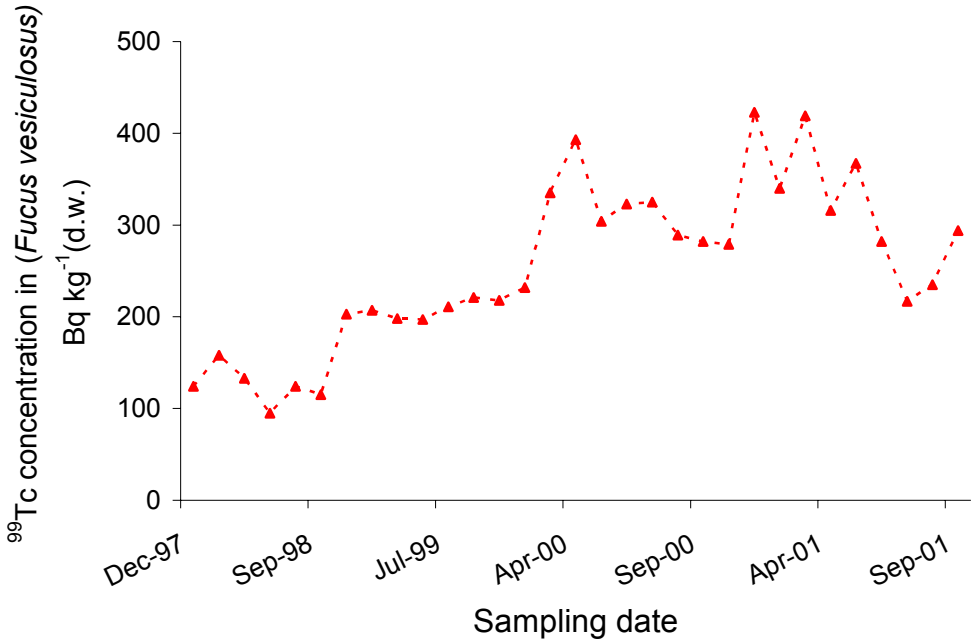

Figure 7.2. *Levels of ^{99}Tc in seaweed (*Fucus vesilculosus*) sampled at Hillesøy in the period from 1997 to 2001.*

Technetium-99 has been detected in the Norwegian marine environment since the beginning of the 1980s. Elevated liquid discharges of ^{99}Tc from Sellafield in 1978 resulted in increased activity concentrations in *Fucus vesiculosus* at Utsira of about 220 Bq kg^{-1} (d.w.) three years later (Yiou *et al.*, 2002). In the period 1981-1993 the liquid discharges of ^{99}Tc from Sellafield were low, 2-6 TBq a^{-1}, and a decrease in the activity concentration of ^{99}Tc was consequently observed in the seaweed. When the Enhanced Actinide Removal Plant (EARP) was brought into operation in 1995, a backlog of liquid waste was treated. Technetium-99 was not removed in this process and the discharge increased significantly (190 TBq in 1995) which, a few years later, was clearly observed in seaweed samples collected at Utsira (Yiou *et al.*, 2002) and Hillesøy (see Figure 7.2). During the period 1997-2001, the liquid discharges of ^{99}Tc were in the range 44 to 84 TBq a^{-1}.

The ^{137}Cs concentrations in *Fucus vesiculosus* collected in 2000 and 2001 at various stations along the Norwegian coastline are shown in Figures 7.3 and 7.5, respectively. The level of ^{137}Cs in *Fucus vesiculosus* collected in 2000 at the coastal stations ranges from 0.36 to 4.6 Bq kg^{-1} (d.w.). In 2001 the level of ^{137}Cs ranged from <0.2 to 5.7 Bq kg^{-1} (d.w.).

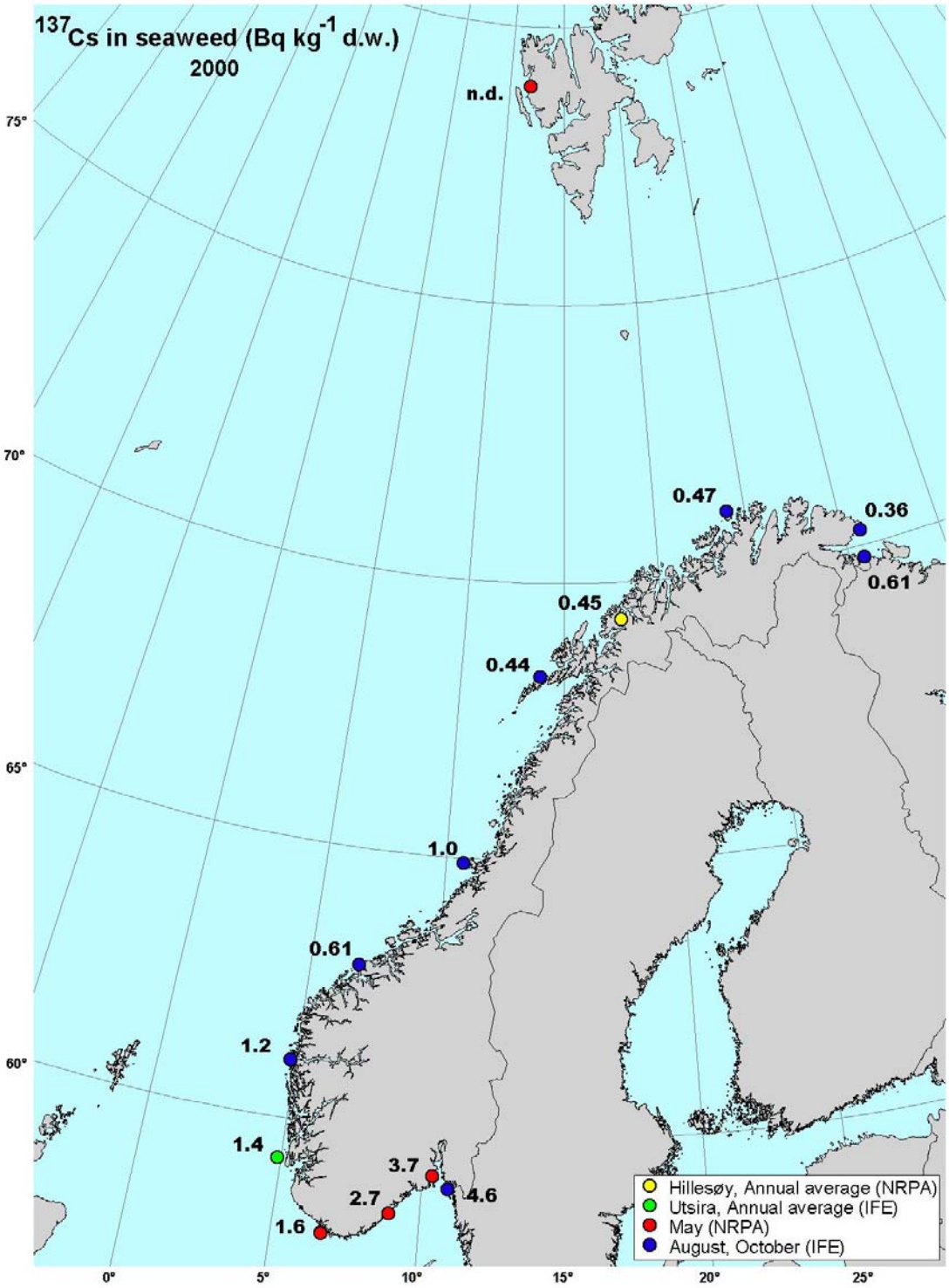

Figure 7.3. *Levels of ^{137}Cs (Bq kg^{-1} d.w.) in* Fucus vesiculosus *sampled along the Norwegian coastline in 2000.*

The ^{99}Tc concentrations in *F. vesiculosus* collected in 2000 and 2001 at the different stations along the Norwegian coastline are shown in Figures 7.4 and 7.6, respectively. The level of ^{99}Tc in seaweed collected in 2000 at the coastal stations (except Svalbard) is in the range 100 to 620 Bq kg^{-1} d.w. (422 Bq kg^{-1} is an annual average based on monthly sampling at Utsira. 620 Bq kg^{-1} d.w. was the highest ^{99}Tc activity concentration measured in these samples). In 2001, the level of ^{99}Tc in seaweed at the same stations ranged from 85 to 530 Bq kg^{-1} d.w. (As for 2000, the highest activity concentration of ^{99}Tc was found in one of the monthly samples from Utsira.)

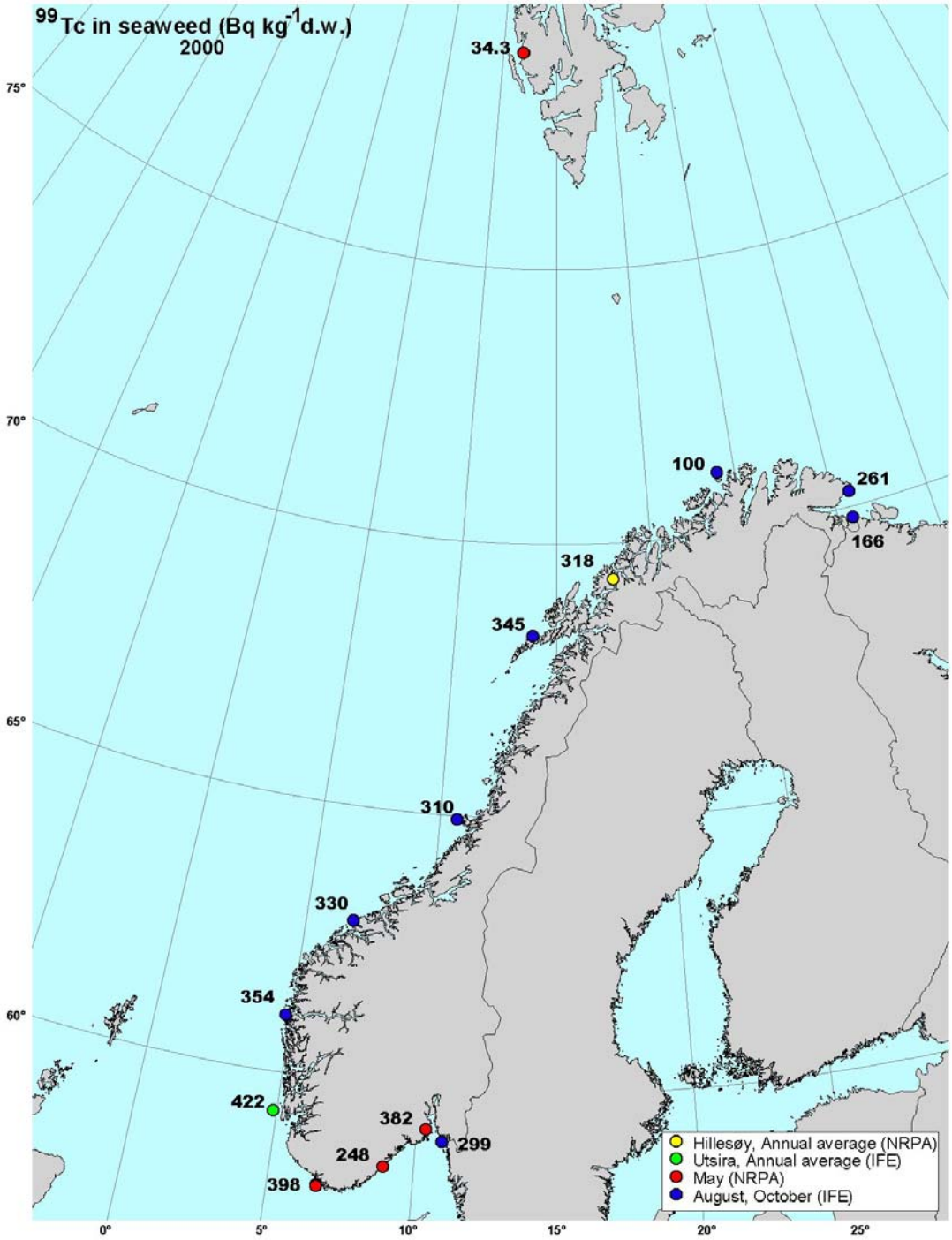

Figure 7.4. *Levels of ^{99}Tc (Bq kg^{-1} d.w.) in* Fucus vesiculosus *sampled along the Norwegian coastline in 2000.*

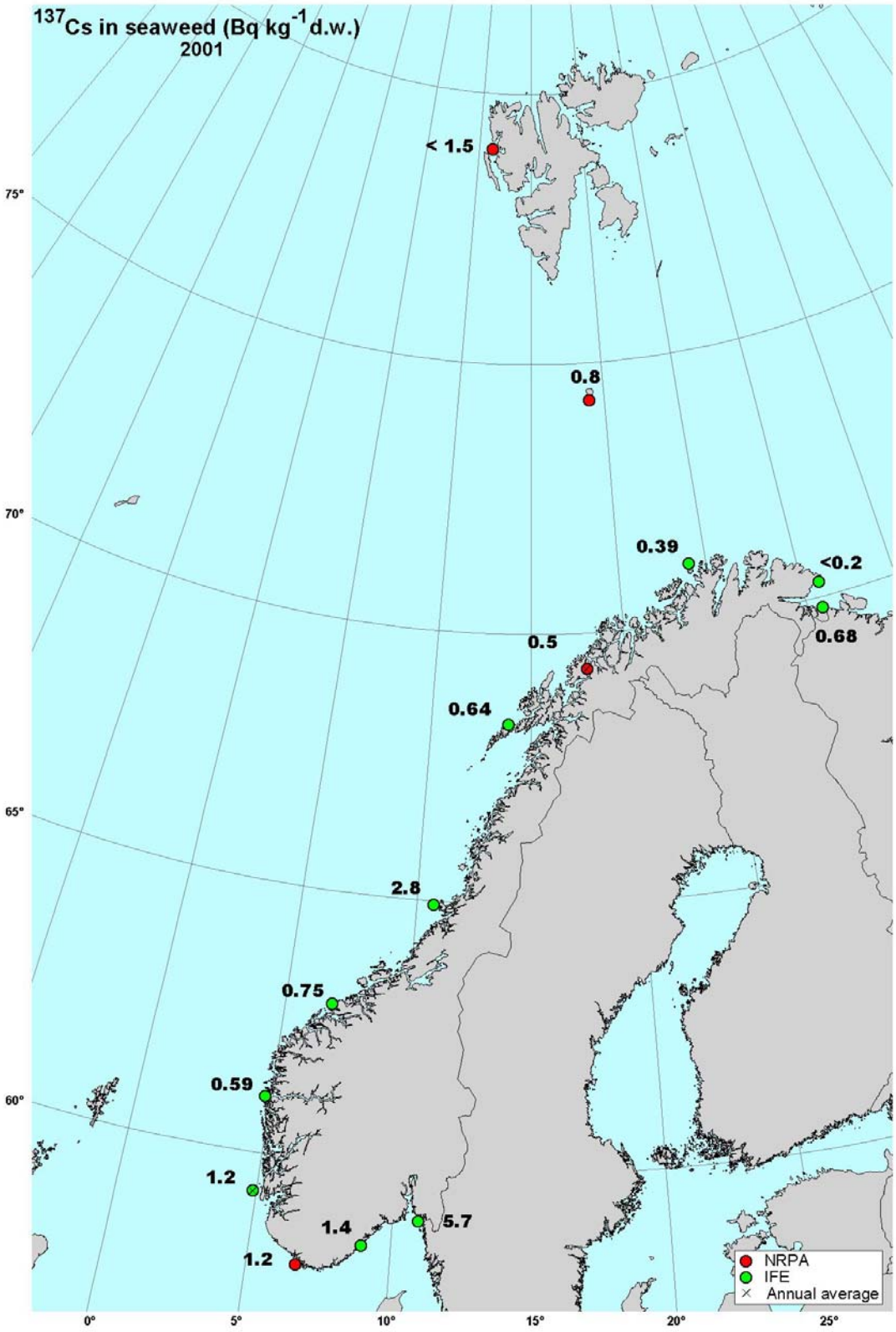

Figure 7.5. *Levels of ^{137}Cs (Bq kg^{-1} d.w.) in* Fucus vesiculosus *sampled along the Norwegian coastline in 2001.*

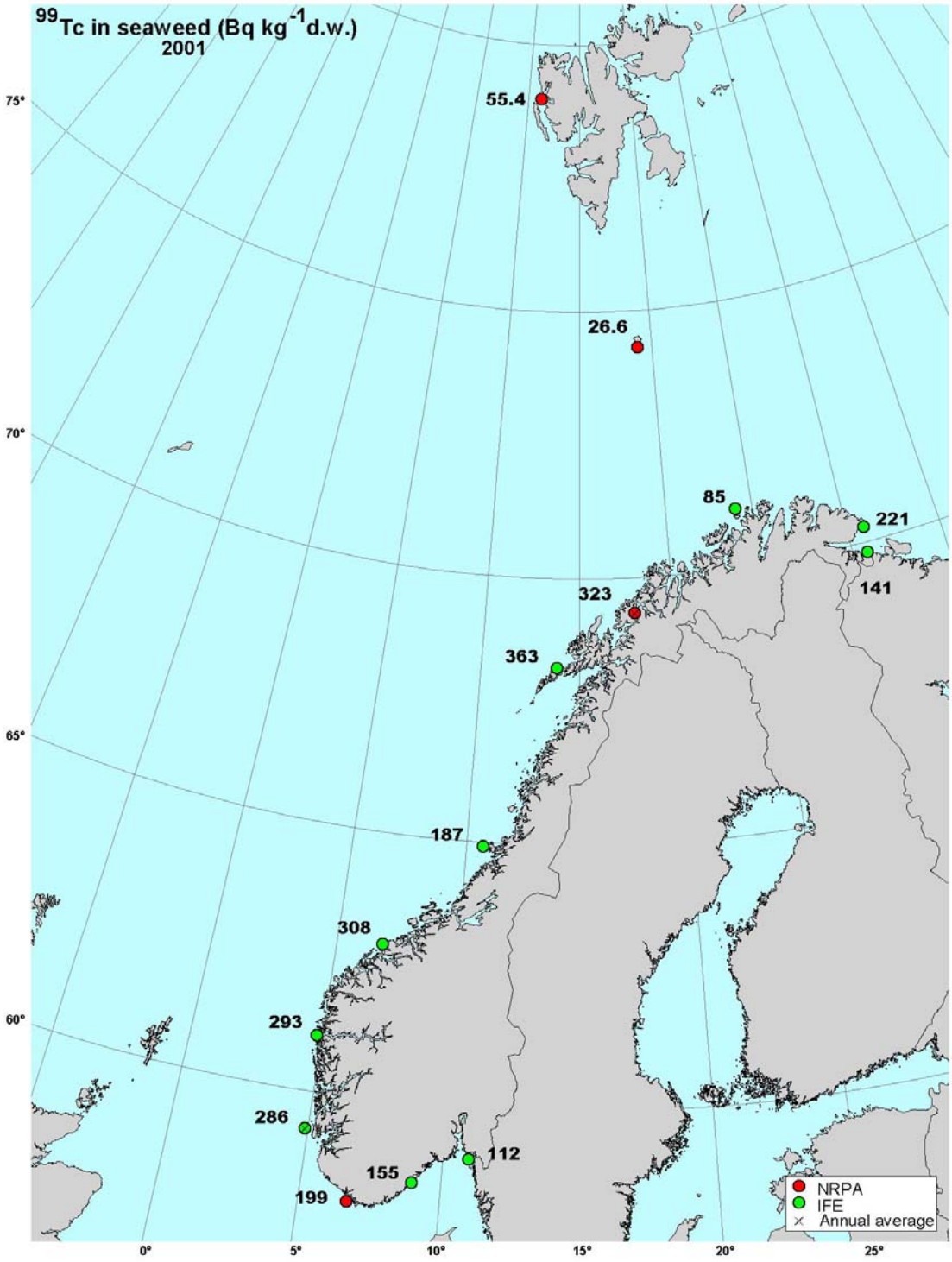

Figure 7.6. *Levels of ^{99}Tc (Bq kg^{-1} d.w.) in* Fucus vesiculosus *sampled along the Norwegian coastline in 2001.*

On the west coast, from Sognesjøen to Vikna, concentrations in 2000 were fairly constant; in the range 310 to 354 Bq kg^{-1} (d.w.). The largest variations in were seen in northern parts of Norway, where concentrations of ^{99}Tc ranged from 100 to 345 Bq kg^{-1} (d.w.) in 2000 and from 85 to 363 Bq kg^{-1} (d.w.) in 2001. It seems unlikely that salinity or temperature would produce such a large variation. A possible explanation may be fluctuations in the sea water concentration of ^{99}Tc due to pulsed discharges from Sellafield and/or mixing with Atlantic waters with a low concentration of ^{99}Tc. The sea water data from Hillesøy, show that concentrations varied throughout the year by approximately a factor of two in 2000 and 2001, although the salinity was reasonably constant (about 30 $^{0}/_{00}$).

Table 7.6. *Concentrations of ^{137}Cs and ^{99}Tc in different species of seaweed in 2000 and 2001.*

Species	Sampling location (number of samples)	^{137}Cs activity conc. [Bq kg^{-1} d.w.]	^{99}Tc activity conc. [Bq kg^{-1} d.w.]
Fucus distichus	Svalbard (2)	< 2.2	44-50
Fucus distichus	Hopen (1)	< 3.0	59
Laminaria hyperborea	Svalbard (2)	< 1.5-1.3	4.4-7.1
Laminaria hyperborea	Bjørnøya (3)	0.4-1.2	36-12.1
Laminaria hyperborea	Hopen (1)	0.9	15.1
Alaria esculenta	Svalbard (1)	< 1.0	13.2
Laminaria hyperborea	Coast of Finmark (1)	< 1.0	-
Ascophyllum nodosum	Haugesund, west coast of Norway (1)	1.0	340
Laminaria hyperborea	Lista, southern Norway (2)	1.8-5.3	27
Fucus serratus	Lista, southern Norway (2)	0.94	150
Ascophyllum nodosum	Arendal, south coast of Norway (1)	1.7-3.7	435-660
Ascophyllum nodosum	Tjøme, outer Oslofjord (1)	2.1	315
Seatree *Lopheia(read)*	Coast of Trøndelag (2)	n.d.	n.d.

In Table 7.6 activity concentrations of of ^{137}Cs and ^{99}Tc in different species of seaweed from different areas, including Svalbard, Hopen and Bjørnøya are reported. The ^{137}Cs concentrations range from below the detection limit up to 5.3 Bq kg^{-1} (d.w.). The ^{99}Tc concentrations in the seaweed (except seatree) range from 4.4 in the northern areas up to 660 Bq kg^{-1} (d.w.) in the southern areas. Due to different concentration factors (CF) for different seaweed species, the activity concentration can show a large variation between different seaweed samples collected at the same location and time. The highest activity concentration of ^{99}Tc in all analysed samples was found in *Ascophyllum nodosum,* which has been reported to have a higher CF than *Fucus vesiculosus* for technetium (Holm *el al.*, 1986).

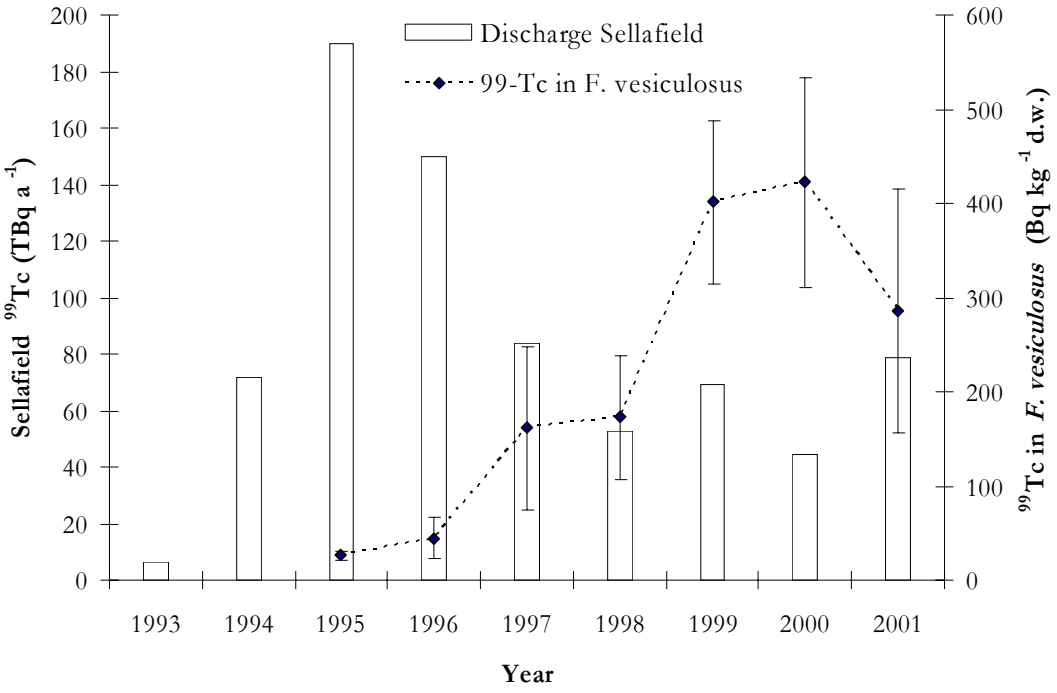

Figure 7.7. *Annual liquid discharge of ^{99}Tc from Sellafield (primary axis) and annual average (± 1 SD) ^{99}Tc activity concentration in seaweed (*Fucus vesiculosus*) sampled at Utsira (data provided by IFE) in the period 1995-2001 (secondary axis).*

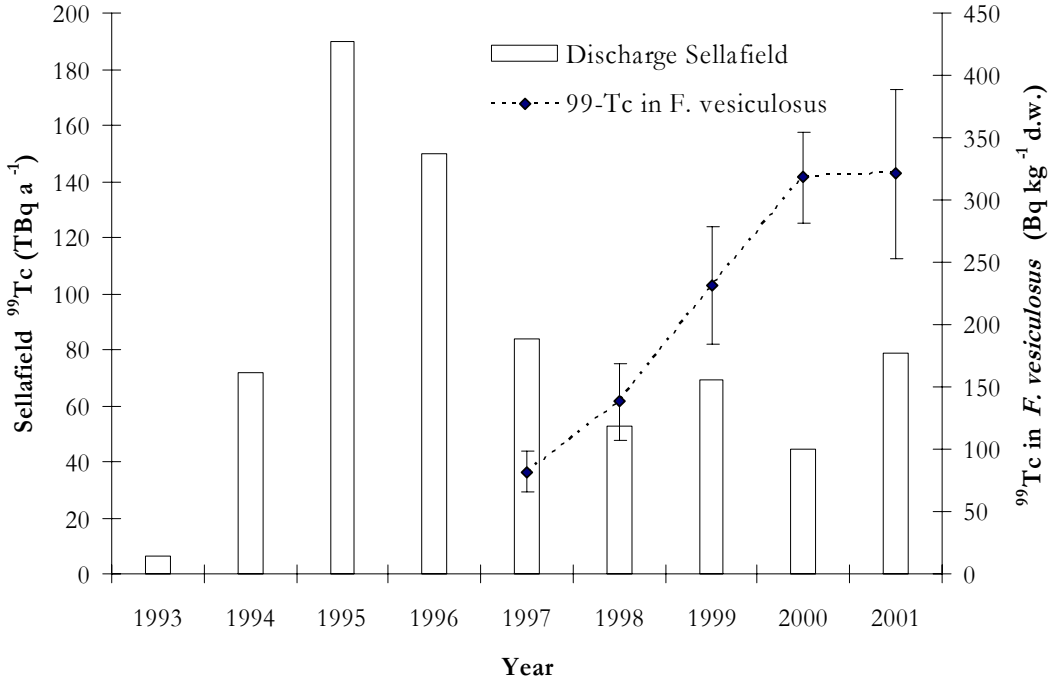

Figure 7.8. *Annual liquid discharge of ^{99}Tc from Sellafield (primary axis) and annual average (± 1 SD) ^{99}Tc activity concentration in seaweed (*Fucus vesiculosus*) sampled at Hillesøy by NRPA in the period 1997-2001 (secondary axis).*

In Figures 7.7 and 7.8 the response (mid 1990s to 2001) to the liquid discharge of ^{99}Tc from Sellafield in *Fucus Vesiculosus* sampled at Utsira and Hillesøy is shown. Although not significant, Figure 7.7 indicates that the ^{99}Tc activity concentration in *Fucus vesiculosus* is decreasing at Utsira, while no decreasing trend has been observed at Hillesøy. Assuming that the level of ^{99}Tc in Fucus at Utsira peaked in 2000, this would give an appriximate transit time of about 3-4 years for ^{99}Tc from the increased discharges at Sellafield in 1995 and later on. This is in accordance with transit times reported elsewhere (Dahlgaard, 1995b; Brown *et al.*, 2002).

8. Summary and conclusions

In Norway there are currently two monitoring programmes concerned with radioactivity in the marine environment, both coordinated by the Norwegian Radiation Protection Authority (NRPA), and funded by the Ministry of the Environment (which focuses of monitoring of radioactivity in the marine environment both in coastal areas and in the open seas), and the Ministry of Fisheries (which focus on monitoring of radioactivity in commerically important fish species), respectively. Results of both these programmes are presented in this report. In addition, results obtained by the Food Control Authority from a monitoring programme concerned with radioactivity in marine fish are included.

The collection and updating of discharge data from Norwegian sources and data concerned with the long-range transport of radionuclides from various sources are both included in the marine monitoring programme. Liquid discharge data for 2000 and 2001 from nuclear installations and recent trends in such discharges are summarised, together with the available information concerning nuclear weapons fallout and the outflow of ^{137}Cs of Chernobyl origin from the Baltic Sea. In addition, data regarding the discharges of ^{226}Ra and ^{228}Ra in produced water from the North Sea oil and gas industry are included.

In 2000 and 2001 samples of water, sediment, fish and/or other biota were collected in the Barents Sea, the Norwegian Sea, the North Sea, the Skagerrak, in selected fjords and at a number of coastal stations including those off the islands of Svalbard, Bjørnøya, Hopen and Jan Mayen. In addition, control samples were collected in the River Nitelva near the former outlet of the nuclear facilities of IFE Kjeller**.** Samples were also collected at a waste-water treatment plant that had unintentionally received liquid radioactive discharge from IFE Halden since 1991. During 2000 and 2001, three expeditions also took place in connection with the accident and salvage operation of the Kursk, where water, sediment and fish were sampled and analysed.

8.1 Sources

1. The liquid discharges from the nuclear facilities of IFE at Kjeller and in Halden are within authorised limits according to the estimate made by the operator. The effective dose to the critical group from liquid radioactive discharge at Kjeller was estimated to 0.04 μSv in 2000 and 0.21 μSv in 2001, which correspond to 4 and 21 % of the discharge limit, respectively. The effective dose to the critical group from IFE Halden liquid radioactive discharge was estimated to be 0.11 μSv in 2000 and 0.09 μSv in 2001, corresponding to 11 and 9 % of the discharge limit, respectively.

2. Unsealed radioactive substances are used in hospitals, research laboratories and various industrial activities. Among the most abundant radionuclides are ^{99m}Tc, ^{131}I and ^{3}H. Regarding the radiological impact on the public of the discharge of these substances, ^{131}I is one of the most important radionuclides. The amount of ^{131}I sold in Norway in 2000 and 2001 was 1.66 and 1.84 TBq, respectively.

3. Produced water from offshore oil production contains elevated levels of naturally occurring radionuclides. Estimates based on a survey of ^{226}Ra and ^{228}Ra in produced water in 1996 together with discharge data for produced water for 2000 and 2001 indicate an annual discharge in the North Sea in 2000 and 2001 of about 0.50 TBq ^{226}Ra and 0.25 TBq ^{228}Ra. Since the estimates are based on a limited data set, there is considerable uncertainty associated with these figures. Efforts will be made to improve this estimate in the near future.

4. The discharge of anthropogenic radionuclides from Norwegian sources is only detectable in the environment close to each discharge points and has no significant impact on the large-scale distribution of these radionuclides in the marine environment.

5. The long-range transport of radionuclides originating from nuclear weapons fallout, reprocessing of spent nuclear fuel and from the Chernobyl accident are still the main contributors to anthropogenic radionuclides found in Norwegian waters. In addition to direct discharges from reprocessing, water from the Baltic Sea and remobilisation of ^{137}Cs and plutonium from contaminated Irish Sea sediments acts as secondary sources of radionuclides to the Norwegian marine environment.

8.2 Environmental contamination in Nitelva sediment

Discharges of radionuclides from IFE Kjeller in the 1960s and early 1970s resulted in radioactive contamination of the sediment in the River Nitelva. In 2000, the IFE removed the most highly contaminated sediment close to a former discharge point. The activity concentration in the control samples of the remaining sediment collected by the NRPA were below the limit of 10 Bq g^{-1} for the sum of $^{239+240}Pu$ and ^{241}Am.

8.3 The Kursk accident

In connection with the rescue and lifting operations of the sunken submarine, the Kursk, in the Barents Sea, the NRPA assisted with environmental monitoring and radiation protection measurements for divers. Their monitoring did not reveal any release of radioactivity from the Kursk during the initial phase of the accident or during the salvage of the submarine.

8.4 Radioactivity in sea water and sediments

In 2000 and 2001 samples of sea water and sediment were collected in the North Sea, the Skagerrak, the Barents Sea and in selected fjords along the coast and at coastal sampling stations, and analysed with respect to ^{137}Cs, ^{99}Tc, ^{90}Sr, ^{238}Pu, $^{239+240}Pu$ and ^{241}Am.

1. *Caesium-137 in water and sediment*
   Sea water samples collected during 2000 and 2001 showed activity concentrations between 1.74 and 42.5 Bq m^{-3}. The highest levels were found in the Kattegat, where the water mass is affected by outflowing water from the Baltic Sea, contaminated by Chernobyl fallout. The lowest activity concentrations were found in open sea water from the Norwegian Sea. Samples collected along the coast showed a relatively large variation, but generally had an activity concentration of less than 10 Bq m^{-3}. Reasons for this could be temporal variations in sea currents transporting water from the Baltic Sea and remobilised ^{137}Cs from Irish Sea sediment. In some fjords the activity concentration exceeded 10 Bq m^{-3}, which can be explained by runoff from land contaminated by fallout from Chernobyl. The activity concentration in sediment showed the same characteristics with higher activity concentrations in the fjords, up to 291 Bq kg^{-1} (d.w.).

2. *Technetium-99 in sea water*
   Sea water samples collected at the permanent coastal stations and other sites along the Norwegian coast in 2000 showed an average activity concentration of ^{99}Tc of 1.3 Bq m^{-3} (1 SD = 0.26). In sea water collected in 2000 in the northern waters around the island of Svalbard the activity concentration was somewhat lower, below 1 Bq m^{-3}. In 2001 samples were collected in the North Sea and in the northern waters. In the North Sea the highest concentrations, up to 7.3 Bq m^{-3}, were found in the western and southern parts, near the coasts of Scotland and England. Off the southern and western coast of Norway the activity concentration of ^{99}Tc was around or slightly

above 1 Bq m^{-3}. In the northern waters around the islands of Svalbard, Hopen, Bjørnøya and Jan Mayen the activity concentrations in sea water were around 0.2 Bq m^{-3} or lower, which are similar to results reported in 1999 (Rudjord *et al.*, 2001). Results from monthly sampling at Hillesøy in northern Norway since 1997, show increasing activity concentration of ^{99}Tc in the water from July 1997 to January 2001. The highest activity concentration, 2.0 Bq m^{-3}, was recorded in January 2001.

3. *Strontium-90 in sea water*
   In 2001 sea water samples were collected in the North Sea and analysed with respect to ^{90}Sr. The average activity concentration in the water was 2.2 Bq m^{-3}, the highest levels being found off the east coast of the United Kingdom.

4. *Plutonium-238 and 239+240 and americium-241 in sea water*
   In 2000, samples of sea water were collected along the Norwegian coast, in the Barents Sea and in the Fram Strait. The levels of $^{239+240}$Pu in surface water ranged from 1.8 to 11 mBq m^{-3}, with an average of 4.7 mBq m^{-3}. For the northern waters, these results are similar or slightly lower than results reported earlier (Rudjord *et al.*, 2001 and Grøttheim, 2000). In sub-surface water, collected in the northern waters and off the west coast of Norway, the activity concentration of $^{239+240}$Pu was higher than that in surface water, and ranged from 7 to 14 mBq m^{-3}, with an average of 11 mBq m^{-3}. The activity concentration of ^{241}Am ranged from 0.6 to 2.3 mBq m^{-3}. In 2001 sea water samples were collected in the North Sea, the Skagerrak and west of Svalbard. The highest levels of $^{239+240}$Pu, 31 to 55 mBq m^{-3}, were found off the east coast of Scotland and England. Even if the liquid discharge of $^{239+240}$Pu from Sellafield has decreased since the mid 1990s, the levels of $^{239+240}$Pu off the east coast of the UK in 2001 are comparable of the levels found in 1995 by Grøttheim (2000). This indicates a contribution from remobilisation of plutonium from Irish Sea sediments contaminated by previous discharges from Sellafield. Compared with the levels found off the south coast of Norway in 2000, the activity concentrations in the water were slightly higher in 2001.

8.4 Radioactivity in fish, crustaceans, molluscs and seaweed

During 2000 and 2001 samples of fish, crustaceans, molluscs and seaweed were collected and analysed with respect to ^{99}Tc and gamma-emitting radionuclides, such as ^{137}Cs.

1. *Caesium-137 in different fish species*
   Samples of fish were collected in the Skagerrak, the Kattegat the North Sea, the Norwegian Sea, the Barents Sea and in selected fjords along the Norwegian coastline. The samples include both commercially important species, such as cod (*Gadus morhua L.*), and less common fish species that are found in the Norwegian marine environment. The results show that the levels of ^{137}Cs in fish from Norwegian marine waters are low. All analysed samples had activity concentrations of ^{137}Cs below 1 Bq kg^{-1} (w.w.), except for some samples of whiting, sprat and horse mackerell caught in the Skagerakk. These samples had activity concentrations of ^{137}Cs around 2 Bq kg^{-1} (w.w.).

2. *Caesium-137 and technetium-99 in crustaceans and molluscs*
   Samples of crustaceans and molluscs were collected from the Skagerrak, the Kattegat, the North Sea, the Norwegian Sea, the Barents Sea and in selected fjords along the Norwegian coastline. As for fish, the levels of ^{137}Cs in crustaceans and molluscs were low, below 1 Bq kg^{-1} (w.w.). In samples analysed for ^{99}Tc, elevated levels were found in lobsters and sea horses. The highest activity concentration in lobster (tail muscle), 41.5 Bq kg^{-1} (w.w.) was found in a sample collected at Kvitsøy (Rogaland) in 2001.

3. *Caesium-137 and technetium-99 in seaweed*
   Seaweed was collected from 14 sampling stations along the Norwegian coast including the islands of Svalbard and Bjørnøya. Results from long-term monitoring at two sites, Hillesøy and Utsira, are also presented. The activity concentration of ^{137}Cs in *Fucus vesiculosus* in 2000 and 2001 was generally low. The highest levels were found in *F. vesiculosus* collected off the southern coast of Norway, and can be explained by exposure to outflowing water from the Baltic Sea. The activity concentration of ^{99}Tc in *F. vesiculosus* collected in Norwegian waters in 2000 ranged from 100 to 620 Bq kg^{-1} (d.w.). The highest level, 620 Bq kg^{-1} (d.w.) was found in a sample collected at Utsira. In 2001 the range was 85 to 530 Bq kg^{-1} (d.w.) and, as in 2000, the highest level was found in a sample from Utsira. Long-term monitoring at Utsira and Hillesøy shows that the activity concentration in *F. vesiculosus* has increased continuously since 1996 as a result of increased discharges from Sellafield. However, at Utsira the activity concentration seems to have decreased since 2000.

References

AMAP, 1998

AMAP, 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Amundsen *et al., 2001*

Amundsen I., Lind B., Reistad O., Gussgaard K., Iosjpe M and Sickel M. (2001). The Kursk Accident. StrålevernRapport 2001:5.

Aure *et al.*, 1998

Aure J., ed 1998: Havets miljø 1998 (in Norwegian). Fisken og havet, særnr. 2-1998 Bergen: Havforskningsinstituttet, 1998.

Balonov, 1997

Balonov M.I. (1997). Internal exposure of populations to long-lived radionuclides released into the environment. In: Health Impacts of large releases of radionuclides. John Wiley and sons, New York, pp 120-138.

Bourlat *et al., 1996*

Bourlat Y., Milliès-Lacroix J.-C., Le Petit G., Bouruignon J. (1996). ^{90}Sr, ^{137}Cs and $^{239+240}$Pu in World Ocean Water Samples Collected from 1992 to 1994. In: Radionuclides in the oceans, edited by Guéguéniat P., Germain P. and Métivier, Institute de Protection et de Surete Nucleaire. ISBN 2-86883-285-7.

Brown *et al.* 1999

Brown J.E., Kolstad A.K., Brungot A.L., Lind B., Rudjord A.L. and Strand, P. (1999). Levels of ^{99}Tc in biota and seawater samples from Norwegian coastal waters and adjacent sea. *Marine Pollution Bulletin*, 38 (7), pp 560-571.

Brown *et al.*, 2002

Brown J, Iospje M., Kolstad A.K., Lind B., Rudjord A.L. and Strand P. Temporal trends for ^{99}Tc in Norwegian coastal environments and spatial distribution in the Barents Sea. *Journal of Environmental Radioactivity*, Vol. 60 (1-2) (2002) pp 49-60.

Brungot *et al.* 1999

Brungot Anne Lene, Føyn Lars, Caroll Joann, Kolstad Anne Kathrine, Brown Justin, Rudjord Anne Liv, Bøe Bjarne, Hellstrøm Turid. (1999). Radioactive contamination in the marine environment, Report no 3 from the national surveillance programme. Strålevern Rapport 1999:6. Østerås: Norwegian Radiation Protection Authority.

Chen *et al.*, 1991

Chen et al, (1991). Determination of Plutonium in environmental samples by controlled valence in anion exchange. Denmark: Risø National Laboratory, RISØ-M-2856.

Chen *et al., 2001*

Chen Q., Aakrog A., Nielsen S. P., Dahlgaard H., Lind B., Kolstad A. K. And Yu Y. (2001). Procedures for Determination of ^{239,240}Pu, ^{241}Am, ^{237}Np, ^{234,238}U, ^{228,230,232}Th, ^{99}Tc, ^{210}Pb and ^{210}Po in Environmental Materials. Risø National Laboratory, Roskilde, Denmark. December 2001. Risø-R-1263(EN).

Cook *et al.*, 1997

Cook GT, Mac Kenzie AB, Mc Donald P and Jones SR (1997). Remobilization of Sellafield-derived radionuclides and transport from the North-East Irish Sea. *Journal of Environmental Radioactivity*, Vol. 35(3), pp 227-241.

Dahlgaard *et al.,* 1995a

Dahlgaard H., Chen Q. J., Herrmann J, Nies H., Ibbett R. D. and Kershaw P. J. (1995). On the background level of ^{99}Tc, ^{90}Sr and ^{137}Cs in the North Atlantic. *Journal of Marine Systems,* Vol. 6, Issues 5-6, pp 571-578.

Dahlgaard, 1995b

Dahlgaard H. (1995). Transfer of European coastal pollution to the Arctic: radioactive tracers. *Marine Pollution Bulletin*, 31, pp 3-7.

Dahlgaard, 2002

Dahlgaard H. (2002). Baltic ^{137}Cs outflow through the Danish Straits indicates remobilisation. In proceedings from the International Conference on Radioactivity in the Environment, held in Monaco, 1-5 September 2002.

The Danish Energy Authority, 2002

The Danish Energy Authority (Energistyrelsen). 2002. Tal for produktion og injektion 1972-2001. (Available at: www.ens.dk)

The Department of Trade and Industry, 2002

The Department of Trade and Industry (DTI). Information on Permitted and Accidental Releases. Oil Discharged with Produced Water. (available at: www.og.dti.gov.uk/environment/index.htm)

Gerland *et al.*, 2002.

Gerland S., Lind B., Dowdall M., Kolstad A.K. (2002). Recent levels of Technetium-99 in sea water at the west coast of Svalbard. *The Scientific World,* Vol. 2, pp 1507-1513.

Gray *et al.*, 1995

Gray J, Jones SR, Smith AD. (1995). Discharges to the environment from the Sellafield site, 1951-1992. *Journal of Radiological Protection,* Vol. 15, pp 99-131.

Grøttheim 2000

Grøttheim, S., (2000). Artificial radionuclides in the Northern European Marine Environment. Distribution of radiocaesium, plutonium, and americium in seawater and sediments in 1995. Strålevern Rapport 2000:1. Østerås: Norwegian Radiation Protection Authority.

Holm *et al.* 1984

Holm, E., Rioseco, J., Garcia-Leon, M., (1984). Determination of ^{99}Tc in environmental samples. *Nucl. Instr. Meth. Phys. Res.*, Vol 223, pp 204-207.

Holm *et al.,* 1986

Holm E., Rioseco J., Aakrog A., Dahlgaard H., Hallstadius L., Bjurman B. and Hedvall R. (1986). Technetium-99 in Algae from Temperate and Arctic Waters of the North Atlantic. In: Technetium in the Environment (Ed: G Desmet and C Myttenaere), p 53, Elsevier Applied Science Publ.

IAEA, 1982

IAEA (International Atomic Energy Agency). *Generic models and parameters for assessing the environmental transfer of radionuclides from routine releases.* IAEA Safety Series No. 57, 1982.

IAEA 1990

IAEA, (1990). *The environmental behaviour of radium*, International Atomic Energy Agency, Technical Report Series No. 310, vol. 1 & 2, Vienna, 1990.

ICRP, 1995

ICRP (International Commission on Radiological Protection). *Age dependent doses to members of the public from intake of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients,* ICRP publication 72, Vol. 26, No. 1, 1995.

IFE, 2000a

IFE (2000a). Måling av radioaktive stoffer i utslipp til luft, i avløpsvann og i prøveobjekter fra IFEs omegn og Nitelva: Rapport for 2000. IFE rapport nr: IFE/I-2001/005.

IFE, 2000b

IFE (2000b). Analyse av slam fra det kommunale renseanlegget og de mulige radiologiske konsekvenser av håndtering, lagring og nyttelse av detta slammet. IFE, Halden. Sv-rapport 432.

IFE, 2001

IFE (2001). Måling av radioaktive stoffer i utslip til luft, iavløpsvann og i prøveobjekter fra IFEs omegn og Nitelva: Rapport for 2001. IFE Rapport nr: IFE/I-2002/09.

Josefsson, 1998

Josefsson D 1998. Antropogenic Radionuclides in the Arctic Ocean: Distribution and Pathways. Ph. D. thesis. Lund: Department of Radiation Physics, Lund University, 1998.

Kershaw *et al.*, 1999

Kershaw P.J., McCubbin, Leonard K.S. (1999). Continuing contamination of north Atlantic and Artic waters by Sellafield radionuclides. *The Science of the Total Environment* 237/238, pp 119-132.

Kolstad, 1995

Kolstad AK. (1995). Expeditions to «Komsomolets» in 1993 and 1994 (in Norwegian). Strålevern Rapport 1995:7. Østerås: Norwegian Radiation Protection Authority.

Kolstad and Lind, 2002

Kolstad AK. And Lind B. (2002) Radioactivity in the Marine Environment 2000 and 2001. Technetium-99 concentrations in Norwegian coastal waters and biota. Strålevern rapport 2002:6. Østerås: Norwegian Radiation Protection Authority.

Leonard *et al.*, 1999

Leaonard K.S., McCubbin D., Blowers P., Taylor B.R. (1999). Dissolved plutonium and americium in surface waters of the Irish Sea, 1973-1996. *Journal of Environmental Radioactivity,* Vol. 44 (2-3), pp 129-158.

MAFF&SEPA, 2001

MAFF&SEPA, (2001). Radioactivity in Food and the Environment, 2000. Food Standards Agency, Scottish environment protection agency, RIFE-5. MAFF&SEPA.

Nies and Nielsen, 1996

Nies H. and Nielsen S.P. (1996). Radioactivity in the Baltic Sea. In: Radionuclides in the oceans, edited by Guéguéniat P., Germain P. and Métivier, Institute de Protection et de Surete Nucleaire. ISBN 2-86883-285-7.

Nies *et al.*, 1998

Nies H., Harms I., Karcher M., Dethleff D., Bahe C., Kuhlmann G., Oberhuber J., Backhaus J., Kleine E., Loewe P., Matishov D., Stephanov and Vasiliev O., 1998. Anthropogenic radioactivity in the Nordic Seas and the Artic Ocean - results of a joint project. *Dtsch. Hydrogr. Zeitschr.* 50:313-343.

The Norwegian Oil Industry Association, 2002

The Norwegian Oil Industry Association (Oljeindustriens Landsforening). (2002). Utslipp fra olje- og gassvirksomheten 2001 (In Norwegian).

NRPA, 1999

NRPA. (1999). Radioaktive utslipp fra IFE Kjeller til Nitelva. Strålevernrapport 1999:11, (in Norwegian) Østerås, Norwegian Radiation Protection Authority.

OSPAR, 2002

OSPAR Commission. 2002. Liquid Discharges from Nuclear Installations in 2000. ISBN 0 946956 91 X.

OSPAR 2003

OSPAR Commission. 2003. Liquid Discharges from Nuclear Installations in 2001. ISBN 1 904426 11 5.

Roos *et al., 1994*

Roos P., Holm E., Persson R.B.R (1994). Comparison of AMP precipitate method and impregnated $Cu_2[Fe(CN)_6]$ filters for the detrmination of radiocesium concentrations in natural waters. *Nuclear Instruments and Methods in Physics Research A.* Vol. 339, pp 282-286.

Rudjord *et al.*, 2001

Rudjord Anne Liv, Føyn Lars, Brungot Anne Lene, Kolstad Anne Katrine, Helldal Hilde Elise, Brown Justin, Iosjpe Misja, Christensen Gordon. (2001). Radioactivity in the Marine Envioronment 1999. Strålevern rapport 2001:9. Østerås: Norwegian Radiation Protection Authority.

Smith, 1987

Smith A. L., (1987). Radioactive scale formation, Offshore Technology Conference, Journal of Petroleum Technology, June 1987.

Smith *et al.,* 2001

Smith V., Fegan M., Pollard D., Long S., Hayden E. and Ryan T. (2001). Technetium-99 in the Irish marine environment. *Journal of Environmental Radioactivity,* Vol. 56, pp 269-284.

Strand, 1998

Strand P., Balonov, M., Aarkrog, A., Bewers, M.J., Howard, B., Salo, A & Tsaturov, Y.S. (1998). Chapter 8: Radioactivity. In: AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and assessment Programme (AMAP), Oslo, Norway, pp 525-620, 1998.

Strand *et al.* 1997

Strand T., Lysebo I., Kristensen D., Birovljev A., (1997). Deposits of Naturally Occurring Radiation Radioactivity in Production of Oil and Natural Gas. Norwegian Radiation Protection Authority, Report 1997:1, Østerås, Norway, 1997, (Language: Norwegian).

Styro *et al.,* 2001

Styro D., Bumeliene Zh., Lukinskiene M., Morkuniene R. (2001). ^{137}Cs and ^{90}Sr behaviour in the southeastern part of the Baltic Seas. *Journal of Environmental Radioactivity,* Vol. 53, No. 1, pp 27-39.

Vakulovsky *et al*., 1995

Vakulovsky S.M., Kryshsev I.I., Nikitin A.I. (1995). Radioactive contamination of the Yenisei River. *Journal of Environmental Radioactivity*, Vol 29 (3), pp 225-236.

Varskog *et al., 1997*

Varskog P., Bjerk T. O., Ruud A. B. (1997). Ph-control EDTA titration as an alternative method for the determination of the chemical yield of yttrium in ^{90}Sr analysis. Presented in the conference on rapid radioactivity measurements in emergency and routine situations, 15-17 October, 1997 at NPL in Teddington, UK.

Yiou *et al.,* 2002

Yiou F., Raisbeck G. M., Christensen G. C., Holm E. (2002). $^{129}I/^{127}I$, $^{129}I/^{137}Cs$ and $^{129}I/^{99}Tc$ in the Norwegian coastal current from 1980 to 1998. *Journal of Environmental Radioactivity,* Vol. 60, pp 61-71.

Appendix

Analytical methods

During recent years, laboratories at the Norwegian Radiation Protection Authority, the local office of the Directorate of Fisheries in Tromsø, the Norwegian Food Control Authority in Salten and the Institute of Marine Research have all been accredited according to the requirements of NS-EN ISO/IEC 17025:1999. Laboratories and organisations that are not named here have not been accredited according to the requirements of NS-EN ISO/IEC 17025:1999. The scope and conditions governing the accreditation of the institutes mentioned above are quite different, but they have all been accredited for gammaspectrometric measurements. For example, the NRPA is accredited for gamma spectrometric measurements in the energy interval 100-1800 keV (except ^{226}Ra), while the other organisations are accredited for gamma spectrometric measurements of ^{137}Cs. The analytical techniques employed at each institution are described below. The results in this report are not claimed to be accredited results as not all results are accredited.

The Norwegian Radiation Protection Authority (NRPA)

NRPA analyses alpha, beta and gamma emitters, using the procedures described in this appendix.

Determination of ^{238}Pu, $^{239+240}$Pu and ^{241}Am activity

The concentrations of ^{238}Pu, $^{239+240}$Pu and ^{241}Am were measured in samples of 200 litres of sea water or 10-20 g of sediment. ^{242}Pu and ^{243}Am were added for chemical yield determination. Precipitation from the water samples was achieved according to the analytical procedure described by Chen *et al.*, (1991). Different radiochemical separation techniques were applied to separate plutonium and americium from other nuclides using solvent extraction with 10% TIOA/xylene solution and ion-exchange chromatography with a BIO-RAD AG1-X4 (100-200 mesh) column. Purified americium and plutonium fractions were electrodeposited on stainless steel discs and the activity measured in semiconductor silicon detectors. As alpha spectrometry is not able to distinguish between ^{239}Pu and ^{240}Pu, because the energies of their emitted alpha particles are too close to be resolved, these isotopes are measured and reported as the sum $^{239+240}$Pu. Relative efficiencies of the detectors were in the range 25 to 30%. The resolution of the detectors, the full width at half maximum (FWHM), was approximately 20 keV at 5486 keV (^{241}Am). Chemical yields obtained from the ^{242}Pu and ^{243}Am yield monitor were in the range 40% to 75%.

Determination of ^{99}Tc activity

To determine the activity concentration of ^{99}Tc in sea water, samples of 50 litres were filtered through a 1 micron polypropylene cartridge to remove suspended particulate matter. Seaweed and other biota samples were dried, milled and homogenised. A 10-20 g dried sample was transferred to a specially designed bottle and carbonised and then dissolved by adding concentrated H_2SO_4 followed by HNO_3. ^{99m}Tc was added to all samples for chemical recovery determination.

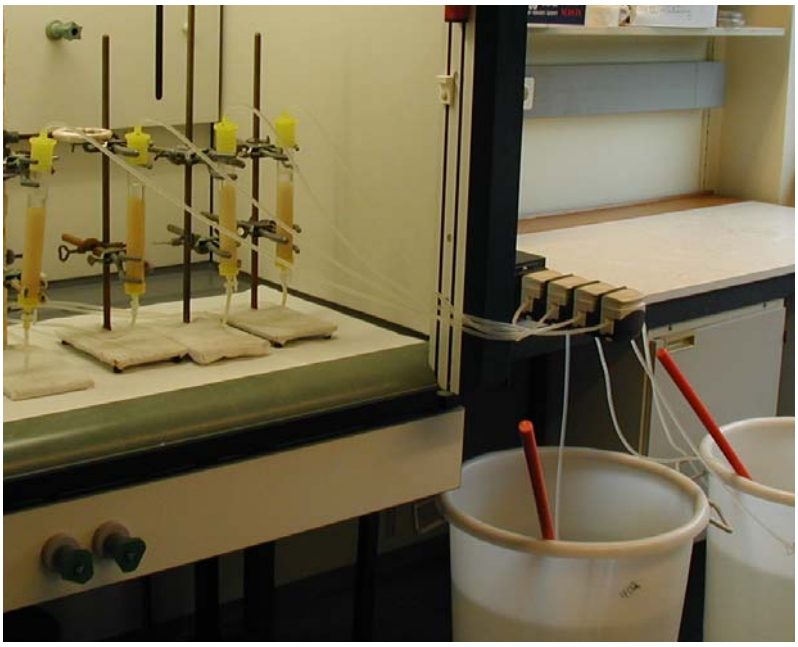

Figure A.1. *50 litres of sea water is passed through an ion-exchange column.*

The analytical procedure used is a modified version of that developed by Risø National Laboratory, Denmark (Chen *et al.*, 2001). The procedure is outlined briefly below. Technetium was initially separated from the matrix by ion-exchange chromatography using a BIO-RAD AG1-X4 (100-200 mesh) column (Figure A.1) and separation techniques such as precipitation and solvent extraction were then applied before the technetium was electrodeposited onto stainless steel discs (Figure A.2). The chemical yields were determined by gamma counting of the ^{99m}Tc tracer in a NaI well-type detector. Typically, the yields varied between 70% and 85%. After one week, the ^{99}Tc activity was measured using a low-background anti-coincidence beta counter (Model Risø GM-25-5).

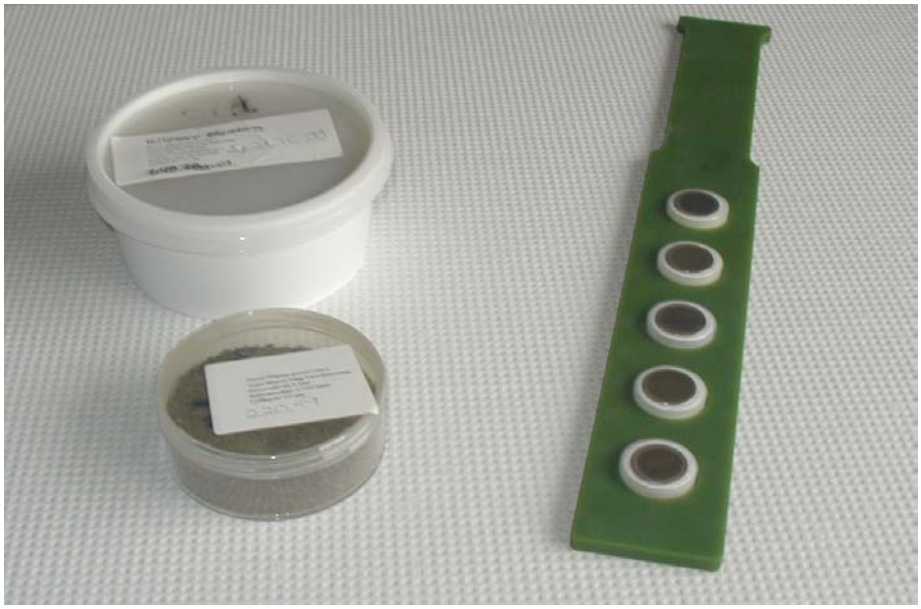

Figure A.2. *Dried sample material in different containers ready for gamma measurements. To the right, ^{99}Tc preparations ready for counting.*

The limits of detection for 10 g seaweed and 50 l sea water have been calculated to be approximately 0.5 Bq kg^{-1} (d.w.) and 0.10 Bq m^{-3} respectively. The limit of detection may vary slightly owing to variations in

chemical yield, counting efficiency and the mass of the sample. The total uncertainty in ^{99}Tc analysis is normally around 10%.

Detection of gamma emitters

At NRPA analyses of gamma emitting nuclides are performed with low-level, HPGe detectors. All the detectors are situated in a low-background laboratory to ensure low detection limits. The HPGe detectors have relative efficiencies in the range of 23% to 40%. The resolution of the detectors, the full width at half maximum (FWHM) at 1332 keV, was less than 1.9 keV. Three of the detectors cover the energy interval 50-2000 keV, and two cover the interval 20-2000 keV.

Caesium-absorbing filters (sometimes also the prefilter) from the filtering system for sea water samples were dried separately at 105°C and ashed at 450°C before the activity was determined with a HPGe detector. The counting time varied from 1 to 4 days.

Samples of fish and seaweed were dried at 105°C and homogenised, and placed in containers prior to gamma counting. The activity from each fish sample was counted for a minimum of 2 days. In fish and shrimp samples the detection limit of ^{137}Cs at the NRPA ranges from 0.2 to 0.4 Bq kg^{-1} (w.w.).

Sediment samples were freeze-dried and placed in containers prior to gamma counting. Samples were counted for a minimum of 2 days. At NRPA, the detection limits for ^{137}Cs and ^{134}Cs in the sediment samples ranged from approximately 0.3-2 Bq kg^{-1} (d.w.) Uncertainties in the analysis include uncertainties from counting statistics, calibration and sample preparation and are normally in the range 5% to 20%.

The Institute of Marine Research (IMR)

Detection of gamma emitters

Biota and sediment samples were transported deep-frozen to IMR, where they were subsequently ground, freeze-dried, homogenised and transferred to polyethylene containers of appropriate size prior to analysis. The gamma counting for ^{137}Cs detection was performed in IMR's low-background laboratory using a HPGe detector with 30% relative efficiency and an extra-low-background HPGe detector with 60% relative efficiency. Both detectors have electric cryostat cooling systems, and 10 cm lead shielding.

Institute for Energy Technology (IFE)

Detection of beta emitters

Samples of dried and homogenised *Fucus vesiculosus* were analysed with regard to ^{99}Tc content. The pretreatment was performed at Kjeller and the analysis at the Department of Radiation Physics, at Lund University. The following analytical procedure was used at the Department of Radiation Physics at Lund University. Technetium was extracted into tri-butyl-phosphate (TBP) from sulphuric acid-hydrogen fluoride solution. Technetium was then back-extracted from the organic phase with a sodium hydroxide solution from which the technetium was electrodeposited onto stainless steel discs, and ^{99m}Tc was used as a radiochemical yield determinant. After decay of the yield determinant, ^{99}Tc was measured with an anti-coincidence shielded GM counter (Holm *et al.*, 1984).

For ^{90}Sr, the standard method using fuming nitric acid was used. The recovery of ^{90}Sr in the analytical process was monitored by adding ^{85}Sr as a yield determinant, and the recovery of the daughter nuclide ^{90}Y was determined by titration with EDTA (Varskog *et al.*, 1997). Finally, ^{90}Y was measured with an anti-coincidence shielded GM counter.

Detection of gamma emitters

At IFE analyses of gamma-emitting nuclides are performed with low-level HPGe detectors. Samples of seaweed were dried at 105°C and then homogenised, and placed in suitable containers prior to gamma counting.

Department of Radiation Physics, Lund University

Detection of gamma emitters

The analysis of ashed Cs sorbents ($Cu_2[(CN)_6]$-impregnated cotton filters) was performed with a HPGe detector (35% relative efficeincy and FWHM = 1.9 keV at 1332 keV) placed in a low-background laboratory.

Risø National Laboratory, Denmark

Detection of gamma emitters

Samples of ashed Cs sorbents were analysed by gamma spectrometry using high-resolution HPGe detectors.

Detection of alpha emitters

Sediment samples collected close to the sunken submarine Kursk were analysed with respect to plutonium by alpha spectrometry after radiochemical separation, using the procedure described by Chen *et al.,* (1991).

The Norwegian Food Control Authority (SNT) in Salten

Detection of gamma emitters

The Food Control Authority in Salten uses both a NaI and a HPGe detector for gamma measurements. The NaI detector is a Canberra series 10 portable detector. The detection limit for radiocaesium is 20 Bq kg^{-1}.

The Laboratory uses a HPGe detector when investigating samples of fish and shrimp with low activity. The detector is an EG&G Ortec GEM (p-type) detector with 45% relative efficiency. 500 g dried muscle (pooled sample of 25 fish) was put in a Marinelli beaker and the activity counted for 2 to 3 days. The detection limit is estimated to be 0.1 Bq kg^{-1} (w.w.).

The Laboratory of the Local Office of the Directorate of Fisheries in Tromsø

Detection of gamma emitters

The laboratory of the local office of the Directorate of Fisheries in Tromsø is equipped with a Canberra series 10 portable NaI detector. The detection limit for fish reported by the Directorate of Fisheries in Tromsø is approximately 11 Bq kg^{-1}. Samples of 200 g fresh fish containing both meat and bone were analysed.

Harwell Scientifics Ltd

Detection of alpha emitters

Radiochemical analysis of ^{241}Am, ^{238}Pu, $^{239+240}$Pu and ^{241}Pu in sediment samples collected in the River Nitelva was carried out by Harwell Scientifics Ltd under a contract with NRPA. Samples were dried and ground prior to analysis. An aliquot of the sample was removed and spiked with ^{242}Pu and ^{243}Am tracers of known activity. The sample was then digested with *aqua regia*, filtered and the filtrate evaporated to dryness. The residue was dissolved in 2 M HNO_3 and the Fe reduced to Fe(II) with ascorbic acid. Pu and Am were then isolated and separated from each other using a TRU resin column. Pu was subsequently purified using anion-exchange chromatography before being electrodeposited and the activity counted by alpha spectrometry. Any americium present was separated from the rare earth elements using anion-exchange chromatography. The purified americium was electrodeposited and the activity determined using alpha spectrometry. Activities of plutonium alpha isotopes and ^{241}Am were determined relative to the tracer spikes. A method blank and reference material were also analysed as part of the data quality control.

The ^{241}Pu fraction was leached from the electrodeposited disc with plutonium and extracted into trioctyl phosphine oxide in toluene. This organic extract was mixed directly with a liquid scintillation cocktail and investigated with a Wallac 1220 Quantulus low-level liquid scintillation counter. The ^{241}Pu activity was determined relative to the plutonium (alpha) activity which was simultaneously measured with the liquid scintillation counter.

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