JOINT NORWEGIAN-RUSSIAN EXPERT GROUP
for investigation of Radioactive Contamination in the Northern Areas

10 YEARS OF JOINT MONITORING OF RADIOACTIVE SUBSTANCES IN THE BARENTS SEA

2006–2015

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Preface:

This report presents the results obtained in 2006-2015 by the «Joint Norwegian-Russian monitoring programme of radioactive contamination in the northern areas». The report has been written by the current working group for the monitoring programme under the Joint Norwegian-Russian Expert Group for investigation of radioactive contamination in the northern areas.

Authors list:

Louise Kiel Jensen[1], Vyacheslav Shpinkov[2], Hilde Elise Heldal[3], Justin P. Gwynn[1], Bredo Møller[4], Vladimir Bulgakov[5], Margarita Katkova[5], Georgiy Artemyev[5]

[1]Norwegian Radiation Protection Authority, FRAM - High North Research Centre for Climate and the Environment. Hjalmar Johansens gate 14, 9007 Tromsø, Norway

[2]Federal Service for Hydrometeorology and Environment Monitoring, Novovagankovsky st., 12, Moscow, Russia, 123995

[3]Institute of Marine Research, Nordnesgaten 50, 5005 Bergen, Norway

[4]Norwegian Radiation Protection Authority, Svanhovd, 9925 Svanvik

[5]Research and Production Association «Typhoon», Pobedy st. 4, Obninsk, Russia, 249038

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Contents

1. Introduction

1.1. Radioactive contamination in the Barents Sea area

The Barents Sea has some of the richest fishing grounds in the world. The area has also been exposed to different sources of radioactive contamination for more than half a century. A detailed overview of all past and present sources is given in e.g. AMAP (2015). The main sources have been global fallout following atmospheric nuclear weapons testing in the 1950s and 1960s, long-range transport of contamination from the European reprocessing plants Sellafield and La Hague and the Chernobyl accident. In recent decades, there has been a slow decrease in the activity concentrations of most anthropogenic radionuclides in the Barents Sea as a result of decreasing discharges from the European reprocessing plants, the reduced impact of fallout from the Chernobyl accident, radioactive decay of radionuclides and their dilution in the water masses.

There are, however, numerous *potential* sources for radioactive contamination to the area. These include the Andreeva and Gremikha temporal storage sites for spent nuclear fuel and radioactive wastes, the Kola Nuclear Power Plant, three bases for nuclear powered vessels (Rosatomflot, Severomorsk and Severodvinsk) and large quantities of dumped solid radioactive waste (Figure 1). In addition, there are three sunken nuclear submarines with spent nuclear fuel in the Norwegian, Barents and Kara Seas. In Stepovogo Fjord, on the eastern coast of Novaya Zemlya, «K-27» was intentionally dumped at 33 meters depth in 1982. «K-159» was in the process of being decommissioned when it was lost while under tow at the entrance of the Murmansk fjord in 2003. «K-159» represents the largest single source for potential radioactive contamination in Arctic areas. Komsomolets («K-278»), which also had two nuclear warheads on board, sank in the Norwegian Sea to a depth of 1700 m after an on-board fire in 1989. Recent publications have shown that any leakages from these sunken nuclear submarines would not have any significant impacts on the marine ecosystem and that activity concentrations in fish in the Barents Sea would be well below the maximum permitted level for cesium-137 (Cs-137) 600 Bq/kg set by the Norwegian authorities after the Chernobyl accident (Heldal *et al.,* 2013; Hosseini *et al.,* 2016). However, any increases in radioactive contamination in the Barents Sea may have important socioeconomic consequences if consumers respond by decreasing their demand for seafood products from the area. This effect was seen in Japan after the Fukushima Daiichi accident (Wakamatsu & Miyata, 2016). In order to reassure fishery industries and consumers alike, there is a need for up-to-date information that can only be provided by regular monitoring of the levels of radionuclide contamination in the Barents Sea.

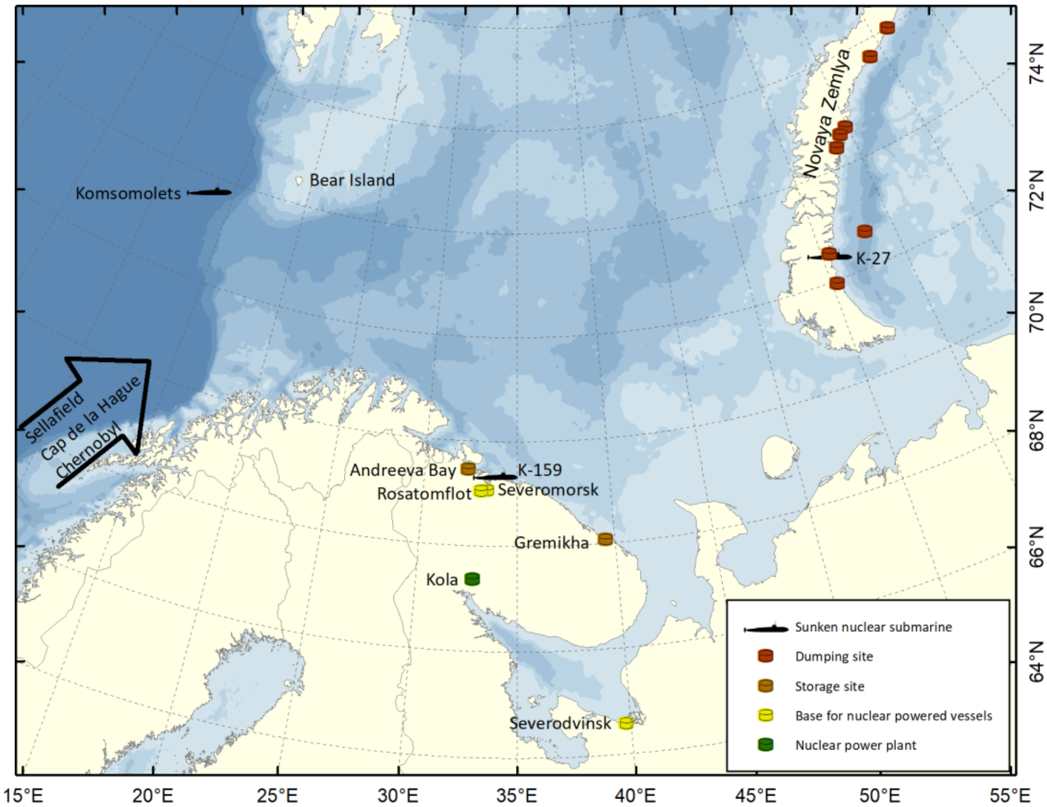

Figure 1. Potential sources of radioactive contamination in the Barents Sea area. The supply of long-range marine transport of contamination from European reprocessing plants and the Chernobyl accident is indicated. Illustration: Kjell Bakkeplass, IMR.

1.2. The joint Norwegian-Russian monitoring programme

Cooperation between Russia and Norway on investigations of radioactive contamination of the marine environment began in 1992, when the first of three joint expeditions to the Kara Sea and fjords on the eastern coast of Novaya Zemlya was carried out (e.g. JNREG, 1996; Salbu *et al.,* 1997). The «Joint Norwegian-Russian monitoring programme of radioactive contamination in the northern areas» (hereafter «the joint monitoring programme») was established in 2006. The main aim was to develop and implement a joint and integrated monitoring programme through the development of common observation targets (radionuclides and sample types) and methodological principles. Through such an initiative, data produced by both countries would be directly comparable and allow for common understanding of the levels of radioactive contamination in the Barents Sea area. To initiate the joint monitoring programme, a set of Norwegian and Russian sampling stations in coastal areas and in the open Barents Sea were agreed (Figure 2).

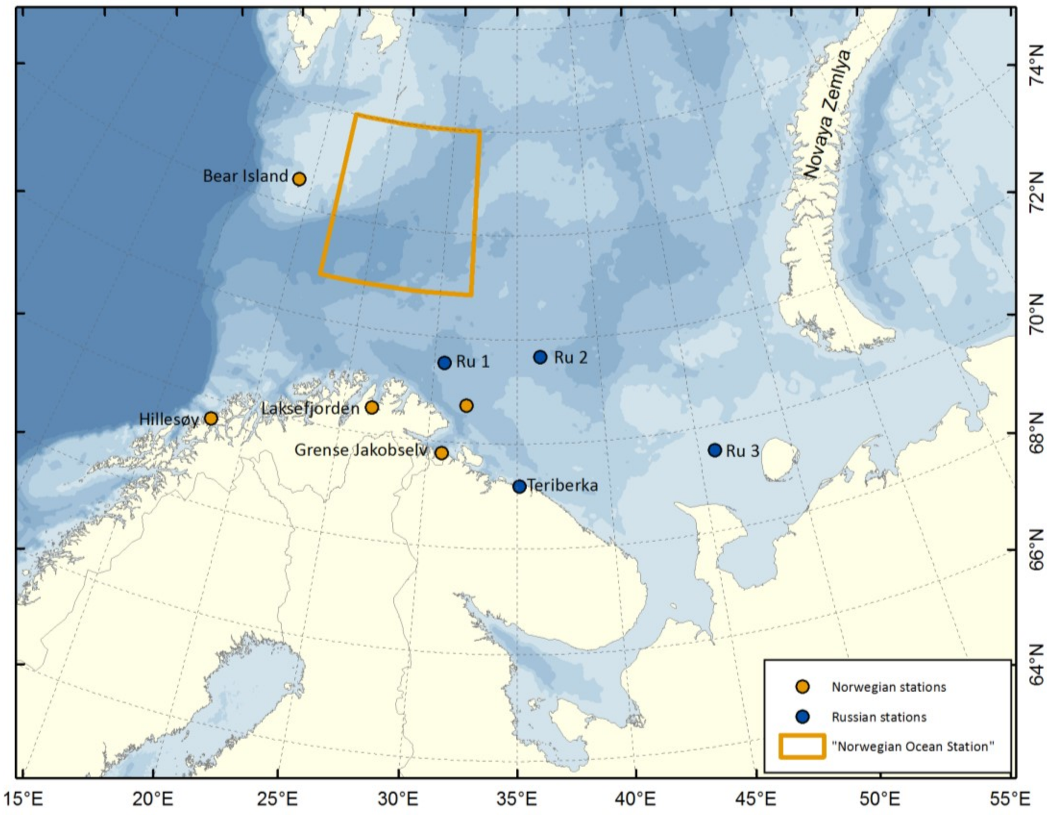

Figure 2. Marine monitoring stations included in the Joint monitoring programme 2006-2015. The «Norwegian Ocean Station» has been defined as the average of all data obtained from any sampling stations located between 72°50'-76°00' N and 22°00'-32°00' E. Ru 1-Ru 3 indicate different Russian stations. Illustration: Kjell Bakkeplass, IMR.

This report summarises the experiences and results of the monitoring programme after 10 years (2006-2015) and provides a current assessment of the levels of radioactive contamination in the Barents Sea area. In addition, the report describes how the original joint monitoring programme has been developed over recent years to meet new challenges.

The organisation of the project

The work under the Joint Norwegian-Russian Expert Group on Investigation of Radioactive Contamination of the Northern Areas is coordinated by Roshydromet on the Russian side and the Norwegian Radiation Protection Authority (NRPA) on the Norwegian side. This expert group works under the Joint Norwegian-Russian Environmental Commission coordinated by the Ministry for Climate and the Environment on the Norwegian side and the Ministry of Natural Resources and Environment on the Russian side.

The expert group coordinates a range of projects within governmental cooperation, including monitoring of decommissioning activities, risk assessments, environmental monitoring and joint expeditions to specific sites of interest.

The project is funded by the Norwegian Ministry of Foreign Affairs by the Nuclear Action Plan.

1.2.1. National organisation

In Russia, the monitoring programme is organised by the Research and Production Association «Typhoon» (RPA «Typhoon») jointly with the Murmansk Department for Hydrometeorology and Environment Monitoring (Murmansk Hydromet) and Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO). Sample treatment and analysis is carried out at the laboratories of RPA «Typhoon» in Obninsk.

In Norway, monitoring of radioactive contamination in the marine environment is organised under the national monitoring programme, Radioactivity in the Marine Environment (RAME) (Skjerdal *et al.,* 2015). This programme is coordinated by the NRPA and run in close cooperation with the Institute of Marine Research (IMR). All Norwegian data are reported both to the Joint Norwegian-Russian monitoring programme and RAME. All sampling, sample preparation and analyses for the joint Norwegian-Russian monitoring programme are performed by the NRPA and IMR.

1.2.2. Bilateral cooperation and communication

The joint monitoring programme is coordinated by RPA «Typhoon» and the NRPA. The respective working group is led by RPA «Typhoon» and the NRPA, but also includes members from Roshydromet and IMR.

The joint monitoring programme is organised through three-year work plans that follow the programme of the Joint Norwegian-Russian Environmental Commission. National coordinators and contributors to the joint monitoring programme are in regular contact to exchange information and experience and to plan work in the ongoing year.

1.2.3. Recent developments of the programme

Since the implementation of the working programme 2015-2017 the joint monitoring programme has been gradually expanded. In order to widen the marine spatial coverage of the programme, a coastal station was established in Umba in the White Sea (Figure 3). The monitoring site at Umba is located close to the city of Severodvinsk and a number of potential sources of radioactive contamination to the environment, including shipyards involved in construction and repair of nuclear-powered ships and temporary radioactive waste storage facilities. As there is an active water exchange between the White Sea and the Barents Sea, the White Sea may act as source of radioactive contamination to the Barents Sea as well as receiving radioactive contamination from the Barents Sea. Furthermore, the collection of samples at this location, including water from the Umba river can provide an indication of the supply of radioactive contamination of the central part of the Kola Peninsula.

The open ocean sampling on the Russian side has been adjusted to mirror the Norwegian sampling and is now done every third year. A new station in the vicinity of the sunken submarine K-159 is included from 2016 and sampled annually.

In the context of the joint monitoring programme, there has been a desire to establish terrestrial and freshwater monitoring sites on both the Kola peninsula and in Pasvik. In Norway, monitoring of berries, mushrooms and freshwater fish has been established for some years in Pasvik, while sampling of soil and freshwater is to be started. In Russia, a monitoring site at Verkhnetulomsky has been chosen with sampling to begin in 2017. The site at Verkhnetolomsky was selected as a terrestrial and freshwater sampling site due to its accessibility and its location half way between the Kola nuclear power station and the Norwegian settlement of Kirkenes. The terrestrial and freshwater ecosystems in the area around Verkhnetulomsky closely reassemble that of the Pasvik valley in Norway, allowing for the sampling of the same species of plants and fish at both locations.

An overview of the present sampling stations included in the joint monitoring programme is shown in Figure 3.

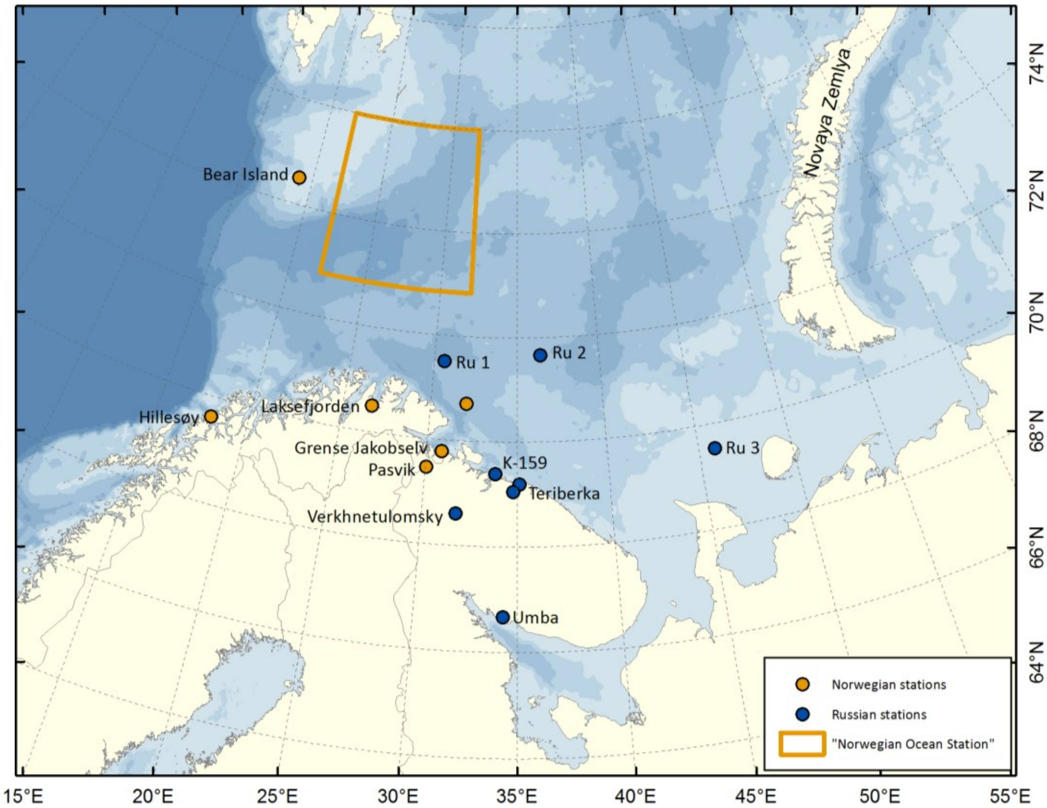

Figure 3. Current sampling stations in the joint monitoring programme as of 2017. The «Norwegian Ocean Station» has been defined as the average of all data obtained from any sampling stations located between 72°50'-76°00' N and 22°00'-32°00' E. Ru 1-Ru 3 indicate different Russian stations. Illustration: Kjell Bakkeplass, IMR.

In 2016, Norway and Russia agreed to include air monitoring data within the joint monitoring programme (Figure 4). Specifically, an agreement was made between the NRPA and Murmansk Hydromet to share data from air monitoring stations on a quarterly basis. Air monitoring provides important information on the levels of radioactivity in the air that may allow for the estimation of source quantities and locations resulting from any accidental releases.

Data from air monitoring stations in Northern Norway (Svanhovd, Viksjøfjell and Skibotn) and from the Kola Peninsula (Murmansk and Kandalaksha) are now reported to the joint monitoring programme. The inclusion of air monitoring data within the joint monitoring programme further strengthens Norwegian-Russian cooperation on emergency preparedness through greater mutual understanding of such monitoring practices in each country.

Figure 4. Inger Margrethe Eikelmann (NRPA) demonstrates to Russian colleagues how the air monitoring station at Svanhovd functions. Photo: Hilde Elise Heldal, IMR.

1.2.4 Coordination with other Norwegian-Russian monitoring efforts

The Joint Norwegian-Russian Environmental Commission is currently developing a monitoring programme for the Barents Sea to cover the entire marine ecosystem. This monitoring programme is developed by the Hav-3/Mop-3 working group (Korneev *et al.,* 2016). Marine indicators for all human pressures are under development, including radioactive contamination. For radioactive contamination, the marine indicators include activity concentrations in seawater, sediment, cod and seaweed. Results for these indicators obtained by the joint monitoring programme will be used in the Joint Norwegian-Russian Environmental Commission's monitoring programme.

2. Sampling, analytical methods and data handling

2.1. Russian stations

Sampling at the coastal monitoring station in Teriberka in the Murmansk Region includes annual sampling of surface seawater, surface layer sediments and marine biota (algae, fish and mussels). The sampling of water, sediments, bladder wrack (*Fucus vesiculosus*) (Figure 5), and mussels *(Mytilus* *edulis)* is performed by RPA «Typhoon» and Murmansk Hydromet. Data on mussels are not included in this summary report. Cod (*Gadus morhua*) and other fish samples, as well as tangle (*Laminaria hyperborea*) are taken by Murmansk Hydromet. Where more than one sample of a fish species was available, these were pooled into a single muscle sample weighing typically 2-3 kg before analysis. Otherwise, muscle samples from individual fish were analysed.

*Figure 5. Bladder wrack (*Fucus vesiculosus*). Photo: Louise Kiel Jensen, NRPA.*

*Figure 6. Sampling of bladder wrack (*Fucus vesiculosus*) at Grense Jakobselv in September 2017. Photo: Hilde Elise Heldal, IMR.*

Sampling of surface water at three open sea stations was carried out by PINRO on an annual basis until 2015.

All the water, sediments and biota samples taken are analysed for anthropogenic radionuclides content at the laboratories of RPA «Typhoon».

2.2. Norwegian stations

Coastal samples are collected from the stations at Hillesøy close to Tromsø and Grense Jakobselv close to the border with Russia. At these stations, samples of bladder wrack (*F. vesiculosus)* and seawater are collected by the NRPA and samples collected in August/September are reported to the joint monitoring programme (Figure 6 and 7). In addition, coastal sediments are sampled on an annual basis by IMR at two stations in Laksefjorden, Finnmark.

Samples of seawater and sediments are collected from the open Barents Sea every third year during research cruises conducted by IMR. The sampling locations may vary somewhat and in an attempt to standardise the data, a representative "Norwegian Ocean Station" has been defined as the average of all data obtained from any sampling stations located between 72°50'00"-76°00'00" N and 22°00'00"-32°00'00" E. Samples obtained during these monitoring cruises are analysed jointly by the NRPA and IMR.

Figure 7. Sampling of seawater at Grense Jakobselv in September 2017. Photo: Hilde Elise Heldal, IMR.

In addition, samples of cod (*G. morhua*) are taken for IMR by Norwegian fishing vessels in the Bear Island area and along the coast of eastern Finnmark each spring and autumn. Each sample is a pooled sample of muscle from either 25 or 100 individuals.

An overview of the sampling stations included in the joint monitoring programme 2006-2015 is shown in Figure 2.

2.3. Selection of data

The joint monitoring programme focuses on radionuclides that are most relevant in terms of dose and on sample types that show temporal and spatial trends. Both Norway and Russia provide data on cesium-137 (Cs-137), strontium-90 (Sr-90) and plutonium-239,240 (Pu-239,240) in one or more sample type (seawater, sediment, fish and seaweed).

2.4. Analytical methods and comparability of results

In 2012, a joint Norwegian-Russian expedition was carried out to Stepovogo Fjord on the eastern coast of Novaya Zemlya (JNREG, 2014; Gwynn *et al.,* 2016). The main partners in the joint monitoring programme (RPA «Typhoon», IMR and NRPA) all participated in the expedition. The analytical methods used for analysing samples collected during the expedition are the same as used in the joint monitoring programme, and are described in the final report from the expedition (JNREG, 2014). During the course of this expedition, a large volume sediment sample was obtained, homogenised and split for use as an intercomparison exercise between the different participants. The different analyses of this sediment showed good overall agreement between the results obtained by the partners (RPA «Typhoon», IMR and NRPA) and the IAEA who were also involved in the expedition (JNREG, 2014).

3. The results from 10 years of the joint monitoring programme

3.1. Radionuclides in seawater

3.1.1. Cs-137

Activity concentrations of Cs-137 in seawater in the Barents Sea area have been low during the monitoring period (less than 3 Bq/m^3), with a decreasing trend over the past 10 years (Figure 8). Activity concentrations observed at open ocean stations were comparable to values for coastal stations. Data reported under the joint monitoring programme shows good agreement with data from Icelandic and Greenlandic waters in the same time period (AMAP, 2015).

The values and trend observed in the Barents Sea during the last 10 years reflects the overall reduction in the long-range transport of Cs-137 to the area. In comparison, activity concentrations of Cs-137 in seawater in the southwestern Barents Sea in the early 1980s reached nearly 50 Bq/m^3 (Kershaw & Baxter, 1995; Matishov *et al.,* 2005), as a result of peak discharges of this radionuclide from the European reprocessing facilities at Sellafield and La Hague in the mid-1970s.

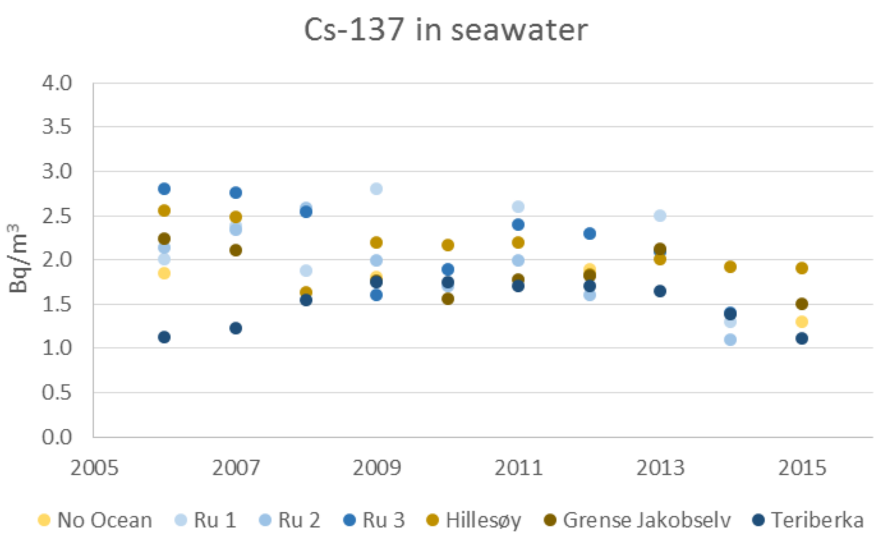

Figure 8. Activity concentrations (Bq/m^3) of Cs-137 in seawater from Norwegian and Russian sampling stations. See Figure 2 for the location of sampling stations.

3.1.2. Sr-90

Activity concentrations of Sr-90 in seawater in the Barents Sea during the monitoring period were of a similar range to those observed for Cs-137, although with less of an obvious decreasing time trend over the last 10 years (Figure 9). The values reported under the joint monitoring programme are within the range of values observed by Leppänen *et al.* (2013) for the area for 2008 and 2009 (0.1±0.1 to 10.4±0.7 Bq/m^3 (n=25)).

In comparison, Kershaw and Baxter (1995) reported activity concentrations of Sr-90 in the Barents Sea in 1981 of between 3.7 and 6.0 Bq/m^3 (n=4), that reflected the period of peak discharges of this radionuclide from European reprocessing facilities. Cs-137/Sr-90 activity ratios at this time were reported to be between 3.8 and 7.9 (Kershaw & Baxter, 1995), whereas during the time-span of the joint monitoring programme, this ratio has been closer to 1. The change in Cs-137/Sr-90 activity ratios observed in seawater follows the reduction in the ratio of Cs-137 and Sr-90 discharged from Sellafield from the mid-1970s until today (see e.g. Gray *et al.* (1995) and annual reports on discharges and environmental monitoring from Sellafield Ltd (http://www.sellafieldsites.com).

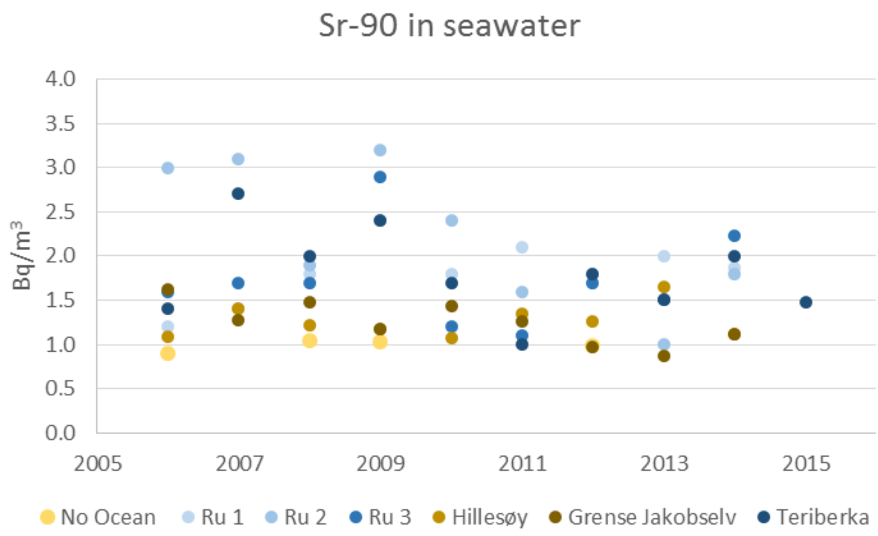

Figure 9. Activity concentrations (Bq/m^3) of Sr-90 in seawater from Norwegian and Russian sampling stations. See Figure 2 for the location of sampling stations.

3.1.3. Pu-239,240

Activity concentrations of Pu-239,240 in seawater in the Barents Sea during the monitoring period ranged from 2 to 11 mBq/m^3 (Figure 10). Only three samples have been analysed by Norway, and the results are in the lower range. These levels are comparable to data reported for other locations in the Barents Sea in the Norwegian national monitoring programme RAME during the same period (Gäfvert *et al.,* 2007; Gäfvert *et al.,* 2011; Gwynn *et al.,* 2012).

In comparison, Strand *et al.* (1994) reported activity concentrations of Pu-239,240 in seawater between 1.8 and 16 mBq/m^3 for the Barents and Kara Seas in the early 1990s, which are similar to the values found during the monitoring period. Although the values reported under the joint monitoring programme show some variation between years, there is an indication of a decrease in the activity concentrations over time.

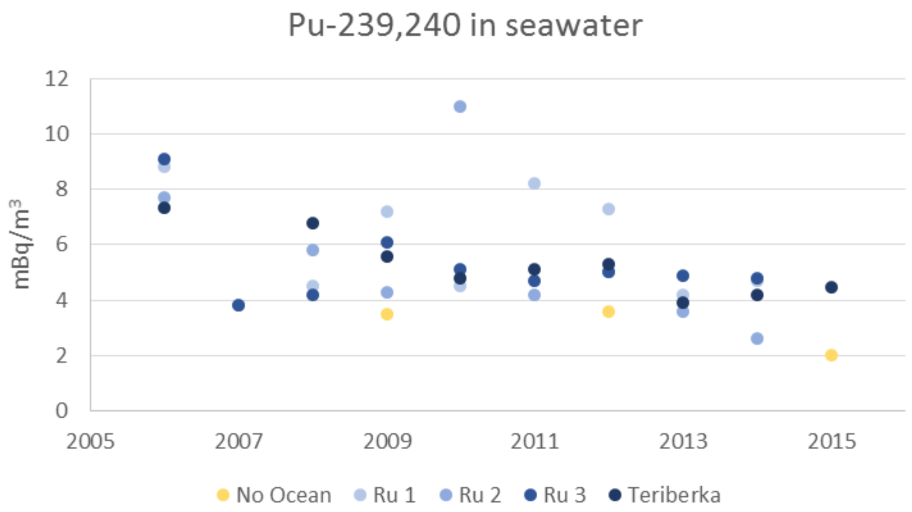

Figure 10. Activity concentrations of Pu-239,240 (mBq/m³) in seawater from Norwegian and Russian sampling stations. See Figure 2 for the location of sampling stations.

3.2. Radionuclides in sediments

3.2.1. Cs-137

The accumulation of radionuclides in sediments depends to a large extent on the grain size and organic matter content of the sediments. As a result, different locations may show distinct differences in radionuclide levels despite similar fluxes of the radionuclide in question to the overlying water column. The activity concentration of Cs-137 in sediments in the Barents Sea collected in the joint monitoring programme were all below 10 Bq/kg d.w. (Figure 11). Although the activity concentrations of Cs-137 differ between the various stations, most likely due to differences in physical properties of the sediment, the values observed for each station have been relatively stable over the monitoring period. The results are comparable to the findings of e.g. (Zaborska *et al.,* 2010; Gwynn *et al.,* 2012; Leppänen *et al.,* 2013).

The results obtained in the joint monitoring programme are also comparable to levels found at 102 stations in the Barents Sea and at the west coast of Spitsbergen in the early 1990s (values ranging from <1.0 to 8.6 Bq/kg d.w.) (Føyn & Sværen, 1997). Thus, levels of Cs-137 in sediments in the Barents Sea have been stable for several decades, while levels in seawater have decreased.

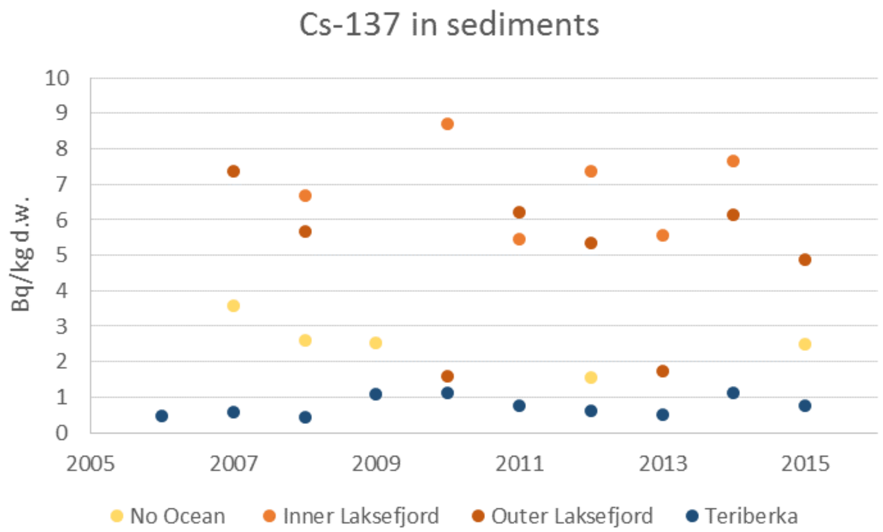

Figure 11. Activity concentrations (Bq/kg d.w.) of Cs-137 in surface sediments from Norwegian and Russian sampling stations. See Figure 2 for the location of sampling stations.

3.3. Radionuclides in biota

The activity concentrations of various anthropogenic radionuclides have been determined in a variety of marine biota within the joint monitoring programme. However, the focus has been on fish and seaweed, and therefore we present only results for these two biota types here. See e.g. (Heldal *et al.,* 2015; Skjerdal *et al.,* 2015) for information about radionuclides in other marine biota. Samples of fish (cod) analysed by Norway are pooled samples typically of 25 individual specimens. Some samples of fish species analysed by Russia consist of individual specimens only. The Norwegian results thus represent an average activity concentration in a fish stock, while the Russian results can represent activity concentrations in individual fish. This difference can introduce some variation between Norwegian and Russian results.

3.3.1. Cs-137 in fish

Due to its wide distribution and commercial importance, Atlantic cod (*G. morhua*) has been chosen as an indicator species under Norwegian Marine Management Plans and has been suggested as a common Norwegian/Russian indicator species by the Hav-3/Mop-3 project (see chapter 1.2.4 for details). Data reported under the joint monitoring programme by Norway is intended to represent different cod fish stocks. Fish caught around Bear Island are thought to represent migrating Barents Sea stock, while the fish caught near the Finnmark coastline are thought to represent stationary coastal stock. Cod caught by Russia at Teriberka are also thought to represent stationary coastal stock. Despite this, the activity concentrations of Cs-137 at the different stations are comparable and low (<0.3 Bq/kg f.w.) for all reported cod samples (Figure 12). These levels are comparable to data reported for other locations in the Barents Sea in the Norwegian national monitoring programme RAME during the same period (Heldal *et al.,* 2015). In the early 1980s, the activity concentration of Cs-137 in cod collected in the Barents Sea was reported to exceed 2 Bq/kg f.w. (Matishov *et al.,* 2005), reflecting the higher activity concentrations of this radionuclide in seawater at this time.

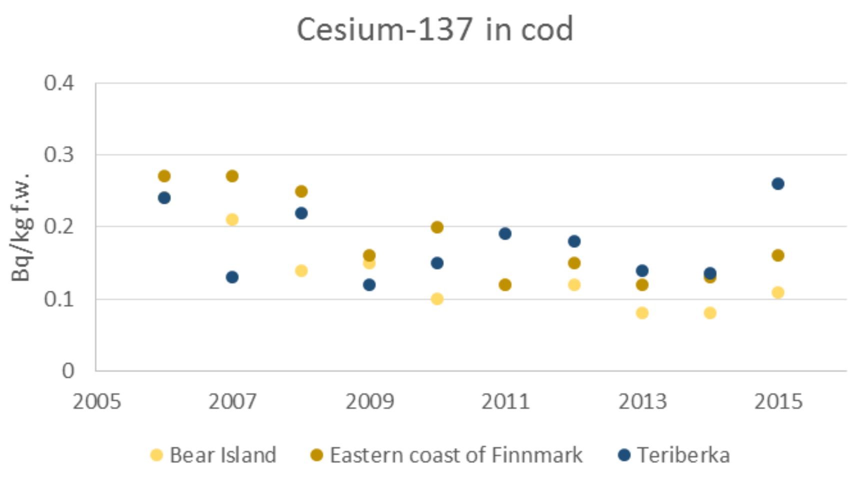

*Figure 12. Activity concentrations (Bq/kg f.w.) of Cs-137 in Atlantic cod (*Gadus morhua*) from Norwegian and Russian sampling stations. See Figure 2 for the location of sampling stations.*

Since 2006, Russia have sampled various other fish species at Teriberka and analysed these for the activity concentrations of Cs-137, Sr-90 and Pu-239,240. The fish species sampled have included: wolffish (*Anarhichas lupus*), herring (*Clupea harengus*) plaice (*Pleuronectes platessa*), redfish (*Sebastes* sp.), pollack (*Pollachius* sp.), haddock (*Melanogrammus aeglefinus*), capelin (*Mallotus villosus*), cusk (*Brosme brosme*), long rough dab (*Hippoglossoides platessoides*) and halibut (*Hippoglossus* sp.).

In general, the activity concentrations of Cs-137 in these different fish species have been below 0.3 Bq/kg f.w. as was the case for cod (Figure 13). Somewhat higher activity concentrations of 0.9 and 1.1 Bq/kg f.w. were observed in two individual samples of pollack (2008) and plaice (2010), respectively. These levels are low, and well below the maximum permitted level for radioactive cesium of 600 Bq/kg set by the Norwegian authorities and the 130 Bq/kg limit set in the Russian sanitary requirements. Overall, the data for Barents Sea fish stocks during the monitoring period corresponds well with data reported for Icelandic fish stocks from 1995 to 2015 (AMAP, 2015).

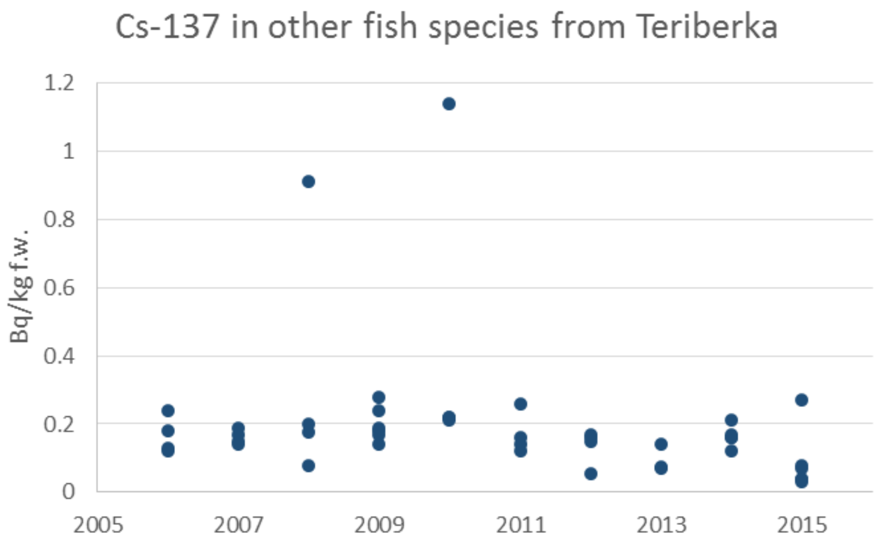

Figure 13. Activity concentrations (Bq/kg f.w.) of Cs-137 in muscle of different individual fish species (see text for specification of species) caught at Teriberka. Samples of individual fish showing higher activity concentrations than 0.3 Bq/kg f.w. were pollack (2008) and plaice (2010).

3.3.2. Sr-90 in fish

Strontium is a chemical analogue to calcium and is known to accumulate in bone rather than muscle of vertebrates, including fish (Vanderploeg *et al.,* 1975). The activity concentrations of Sr-90 reported by Russia for fish species from Teriberka are based on the analysis of muscle, and are typically <0.05 Bq/kg f.w. A somewhat higher activity concentration of 0.23 Bq/kg f.w. was observed in one sample of herring from 2006. This is the only herring analysed for Sr-90 within the monitoring period. In general, our values are below the lower end of the range of Sr-90 activity concentrations reported in perch (*Perca fluviatilis*) from the Baltic Sea (0.07 to 0.14 Bq/kg f.w.) in 2014 (Zalewska *et al.,* 2015).

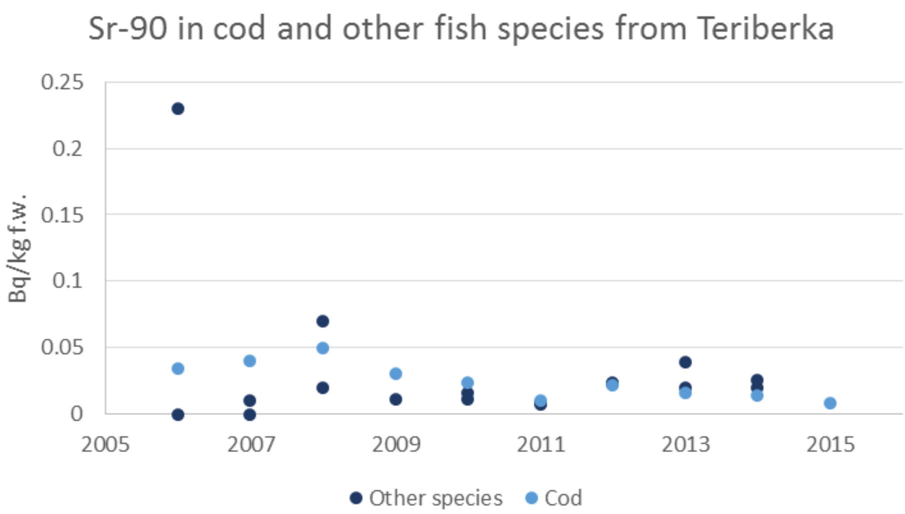

Figure 14: Activity concentrations (Bq/kg f.w.) of Sr-90 in muscle of individual cod and other fish species caught at Teriberka. The one sample showing higher activity concentrations than 0.2 Bq/kg f.w. was a herring.

3.3.3. Pu-239,240 in fish

The activity concentrations of Pu-239,240 in cod and other fish species caught at Teriberka were low and typically <2 mBq/kg f.w. A somewhat higher activity concentration of 12 mBq/kg f.w. was observed in one sample from 2008 (Figure 15). In a study from 1993-1994 from the Barents Sea, Ikäheimonen *et al.* (1997) only detected Pu-239,240 in one out of nine samples from various fish species. The activity concentration in a combined muscle sample from three thorny skate (*Amblyraja radiata*) samples was 7.9±0.9 mBq/kg f.w., which corresponds well with the data reported here.

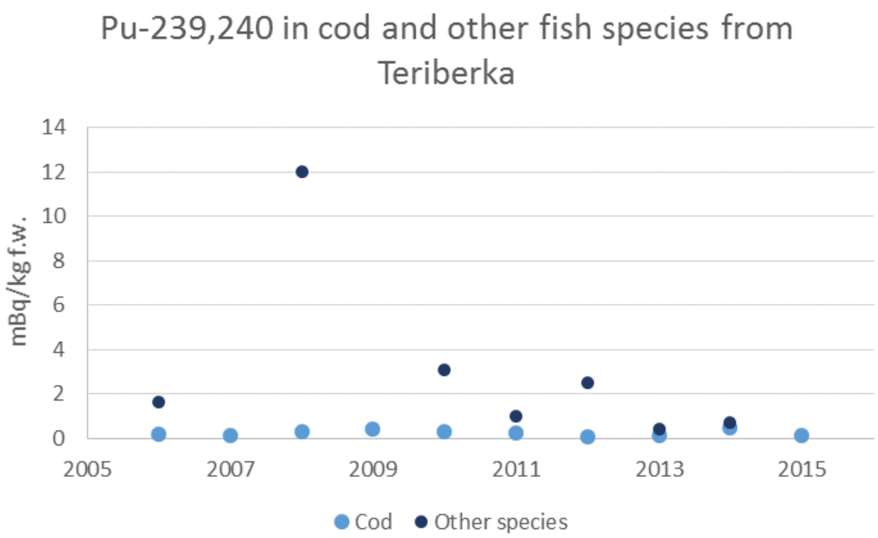

Figure 15. Activity concentrations (mBq/kg f.w.) of Pu-239,240 in muscle of individual cod and other fish species (herring, wolffish, plaice and redfish) caught at Teriberka.

3.3.4. Cs-137 in seaweed

Sessile organisms such as seaweed are often used as indicator species, as they can be repeatedly sampled from the same location and can integrate exposure concentrations over long time spans. The brown seaweed bladder wrack (*F. vesiculosus*) has been chosen as an indicator species under the Norwegian Marine Management Plans and has been suggested as a common Norwegian/Russian indicator species by the Hav-3/Mop-3 project (see chapter 1.2.4 for details). A dried and homogenised sample of *F. vesiculousus* ready for gamma-spectroscopy is shown in Figure 16.

Figure 16. Dried and homogenised sample of Fucus vesiculousus *ready for gamma-spectroscopy. Photo: Hilde Elise Heldal, IMR.*

The activity concentrations of Cs-137 in bladder wrack from both Norwegian and Russian sampling stations were below 1 Bq/kg d.w. (Figure 17). Data has been reported by Russia for the brown seaweed species sugar wrack (*Saccharina latissima*), two-headed wrack (*F. distichus*) and tangle (*Laminaria hyperborea*) as well as for green algae (*Cladophora* spp.) and two different red algae (*Porphyra* sp. and *Rhodymenia* spp.). Activity concentrations of Cs-137 in these other seaweed species were also typically below 1 Bq/kg d.w. (Figure 18).

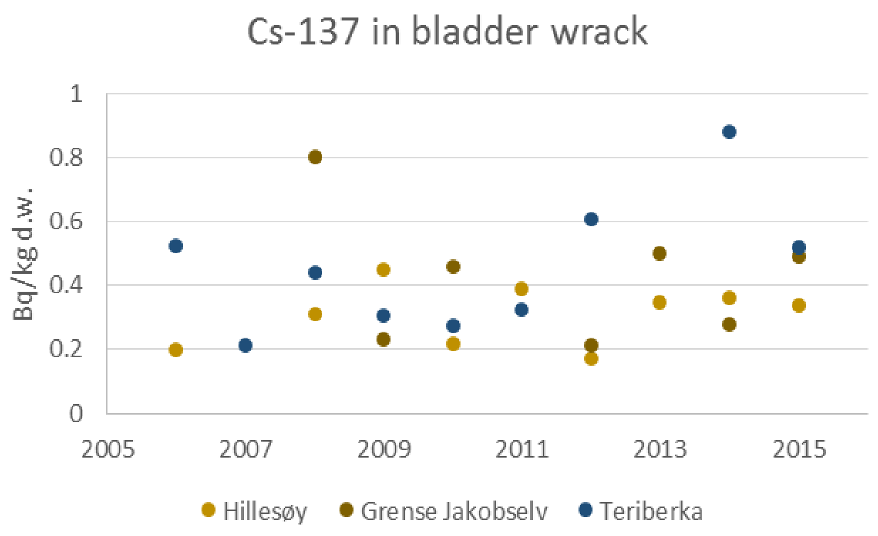

Figure 17. Activity concentrations (Bq/kg d.w.) of Cs-137 in bladder wrack from different Norwegian and Russian sampling stations. See Figure 2 for the location of sampling stations.

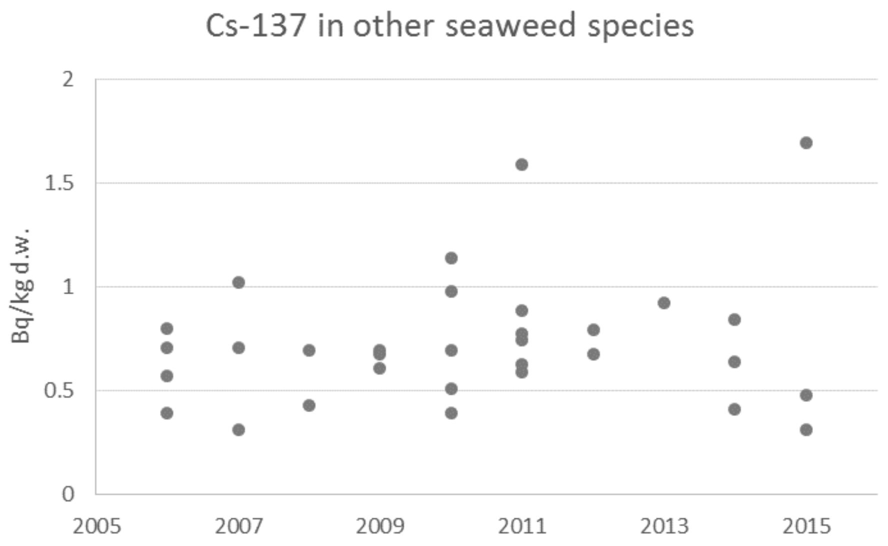

*Figure 18. Activity concentrations (Bq/kg d.w.) of Cs-137 in other seaweed species (sugar wrack, two-headed wrack, tangle, green algae (*Cladophora *spp.) and red algae (*Porphyra *sp. and* Rhodymenia *spp.) from Teriberka.*

Based on activity concentrations of Cs-137 in seawater and bladder wrack from Teriberka, biological concentration factors (BCF) ranging from 17 to 94 have been derived (Figure 19). These values are in good agreement with the IAEA recommend value of 50 for seaweed (IAEA, 2004).

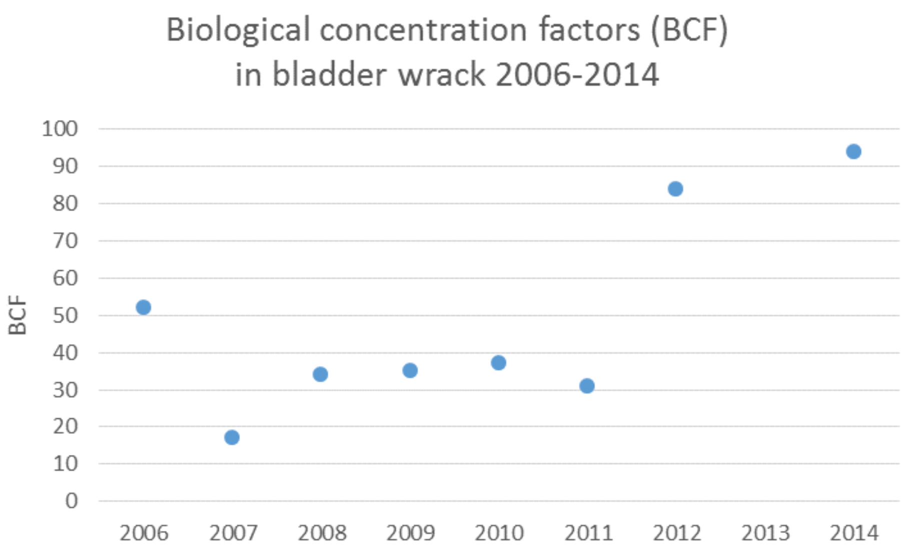

*Figure 19. Derived biological concentration factors (BCF) of Cs-137 in bladder wrack (*Fucus vesiculosus*). The BCFs are based on activity concentration data obtained from Teriberka for bladder wrack and seawater.*

3.3.5. Sr-90 in seaweed

Activity concentrations of Sr-90 in three different species of brown seaweed (bladder wrack, sugar wrack and tangle) collected at Teriberka range from 0.06 to 0.80 Bq/kg d.w. (Figure 20). Norway have not reported Sr-90 in seaweed to the joint monitoring programme. However, samples of bladder wrack collected from various places in Norway during 2004 had activity concentrations of Sr-90 in the range of 0.14 to 0.60 Bq/kg d.w. The highest activity concentrations were observed in samples from the southern Norway (Gäfvert *et al.,* 2006).

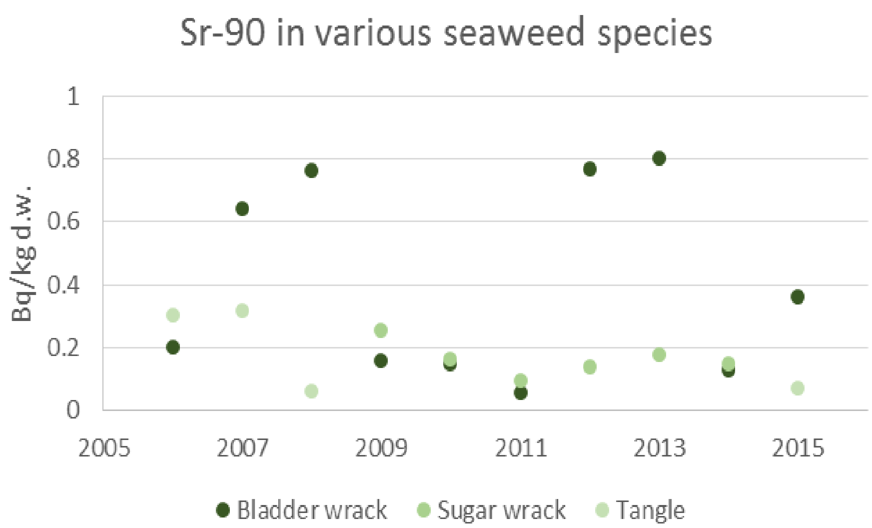

Figure 20. Activity concentrations (Bq/kg d.w.) of Sr-90 in selected seaweed species from Teriberka.

3.3.6. Pu-239,240 in seaweed

Activity concentrations of Pu-239,240 in three different species of brown seaweed (bladder wrack, sugar wrack and tangle) collected at Teriberka ranged from 0.003 to 0.115 Bq/kg d.w. (Figure 21). Norway have not reported data for Pu-239,240 in seaweed to the joint monitoring programme, but the range of Pu-239,240 activity concentrations observed at Teriberka is similar to the range of values (0.04 to 0.20 Bq/kg d.w.) reported for bladder wrack at different coastal sites in Norway between 1980 and 2002 (Gäfvert *et al.,* 2004).

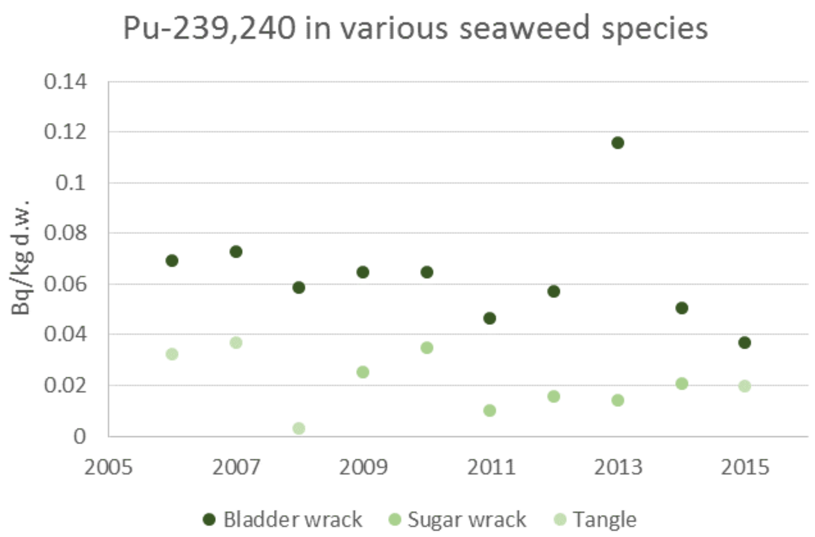

Figure 21. Activity concentrations (Bq/kg d.w.) of Pu-239,240 in selected seaweed species from Teriberka.

4. Conclusions on 10 years of the joint monitoring programme

Data accumulated over the 10 year period of the joint monitoring programme gives a good overview of the levels and trends of radioactive contamination in the Barents Sea marine environment. The data confirms that levels of the anthropogenic radionuclides Cs-137, Sr-90 and Pu-239,240 in seawater, sediments, fish and seaweed are currently low and are continuing to decrease compared to the situation in the 1980s. Since 2015 the data acquired within the joint monitoring programme have been made freely available via the Barentsportal (http://www.barentsportal.com). The data are updated annually as soon as all relevant data is available.

The monitoring data reported by Norway and Russia have shown good agreement in most cases. Further effort to ensure data comparability is an important part of the ongoing work on future cooperation. To support this aim, a series of bilateral workshops on sampling, analysis and quality control have been launched (starting in 2016) to better understand and harmonise methodologies employed on each side of the border.

Figure 22. Workshop on methodology of sampling, sample preparation and instrumentation held at RPA «Typhoon», Obninsk, 18.-19. October 2016. Photo: RPA «Typhoon».

Figure 23. Norwegian and Russian scientists working together with sample collection at Grense Jakobselv in September 2017. Regular meetings and discussions are important for an active and vibrant cooperation. From the left: Louise Kiel Jensen (NRPA), Georgiy Artemev (RPA «Typhoon»), Hilde Elise Heldal (IMR), Inger Margrethe Eikelmann (NRPA), Olga Polianskaia (RPA «Typhoon»), Kirill Shkola (Murmansk Department for Hydrometeorology and Environment Monitoring). Photo: Hilde Elise Heldal, IMR.

The bilateral contacts and trust developed over the years of partnership under the Russian-Norwegian Expert Group on Investigation of Radioactive Contamination of the Northern Areas and the joint monitoring programme in particular have proven their value. This was demonstrated during the weeks following the 2011 Fukushima Daiichi accident, when the situation required prompt exchange of monitoring data between Norway and Russia.

The joint monitoring programme is not static and will be developed further as new challenges arise, as has recently occurred with the inclusion of terrestrial monitoring sites and the reporting of air monitoring data.

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