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Special Report : “Radioactivity in the Marine Environment and in Fishery Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident”

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Special Report: “Radioactivity in the Marine Environment and in Fishery Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident”

Foreword

Kenji Kagawa*

It has been over five years since the accident at the Fukushima Dai-ichi Nuclear Power Plant of the Tokyo Electric Power Company on 11 March 2011. Before the accident, we at the Marine Ecology Research Institute (MERI) were engaged in research on radioactivity in the ocean. Immediately thereafter, we responded by expanding the marine areas surveyed, increasing the number of monitoring sites, and beginning to monitor radioactivity in marine products. We used our observations to chronologically organize and compare data from before and after the accident to understand and evaluate the current state of radioactive contamination of the ocean. Our results suggest that concentrations of radionuclides in the seawater, marine sediments, and fisheries products of the surveyed marine areas are decreasing for these 5 years. The concerns arising from radioactive contamination, however, cannot be allayed solely by increasing the number of studies, as it is important to renew people’s trust in the safety of these marine environments.

MERI not only conducts surveys but also publishes scientific findings in an endeavor to disseminate accurate and clear scientific information, and it considers this MERI’s mission to prevent the spread of misinformation associated with radioactivity. As part of this initiative, on 24 June 2016 we held a symposium on radioactivity in Tokyo entitled “Radioactivity in the Marine Environment and Fishery Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident.” Dr. M. Kusakabe from MERI opened the symposium, describing the global distribution and fluctuations of each radionuclide in the ocean, while touching on historical events such as nuclear tests, among others. He was followed by Dr. H. Takata, MERI, who discussed the changes in radioactivity in seawater and marine sediments around Japan by summarizing our survey results of over 30 years. Mr. M Yokota, MERI, reported the changes in radioactivity in fisheries products from East Japan. Furthermore, Mr. Y. Nemoto of the Fukushima Prefectural Fisheries Experimental Station discussed the levels of radioactivity in fisheries products and the current conditions of the fishing industry in Fukushima, including information on trial fishing. Finally, Dr. T. Ishimaru, an honorary professor from the Tokyo University of Marine Science and Technology, chaired a panel discussion addressing questions from the audience. There were over 100 participants from the government, fishing industry, electric power industry, and analytical and research institutions, in addition to the general public, and discussions were very interactive.

Here, we summarize the presentations and discussions from the symposium as a special issue of the Report of Marine Ecology Research Institute to aid accurate understanding of the current conditions of radioactivity in the marine environment and marine products. Because there is still widespread misinformation about marine products from East Japan outside the national border, we intend to distribute the English version of this report to international research institutions. Moreover, this report will be available on our website so that we can reach a broader audience and promote comprehensive and accurate understanding of this topic.

MERI was established in 1975 as a research institute using scientific methods to elucidate the impact of thermal

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discharges from power plants on the habitat of marine organisms; since then it has conducted various surveys and researches on the marine environment and marine organisms. We thank you for your ongoing support of our work for over 40 years. In particular, the Fisheries Agency, Nuclear Regulation Authority, associated institutions and associated groups have been extremely supportive in monitoring radioactivity in the ocean. Our research on radioactivity in the ocean has also been extensively evaluated by the International Atomic Energy Agency (IAEA). MERI will continue to contribute to the recovery of the fishing industry in Fukushima along with the recovery and rebuilding from the Great East Japan Earthquake.

In addition to radioactivity, there are many other challenges in the marine environment, such as the effects of climate change and acidification of the ocean. MERI will actively tackle these issues through various initiatives and hopes to maintain your continued trust and support in the future.

Rep. Mar. Ecol. Res. Inst., No.22 (Supplement), 3-16, 2017

Special Report: “Radioactivity in the Marine Environment and in Fisheries Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident”

Distributions of radionuclides in the ocean and their temporal changes

Masashi Kusakabe*[1§]

Abstract: There are two types of radionuclides in the ocean environment: natural radionuclides and artificial radionuclides. The former have existed since Earth was formed; the latter have appeared in the oceans since 1945. Since then, the sources of artificial radionuclides have been atmospheric nuclear testing (the largest source), accidents at nuclear power-related facilities, and planned releases from such facilities. The present study describes the levels of natural and artificial radionuclides in the oceans and the spatiotemporal changes in the artificial radionuclides.

Keywords: natural radionuclides, artificial radionuclides, ocean

1. Introduction

There are many kinds of radionuclides in the environment. They can be divided into the natural radionuclides that have existed since before human beings appeared on Earth, and the artificial radionuclides that have been rapidly increasing in abundance since the end of World War II. The latter arise from causes such as atmospheric nuclear tests and emissions from nuclear power plants and reprocessing facilities. The present study describes the distributions of both types of radionuclides in the ocean environment and their temporal changes up to the time of the accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP) in Fukushima Prefecture, Japan.

2. Natural radionuclides

There are two main origins for the various types of natural radionuclides on Earth. The primordial radionuclides have existed in Earth’s crust since it was formed; other natural nuclides are generated by cosmic rays. Some primordial radionuclides have a decay series, whereas some do not. Therefore, the natural radionuclides in the ocean can be placed into three categories:

- Nuclides that have a decay series
- Nuclides that do not have a decay series
- Nuclides generated by cosmic rays

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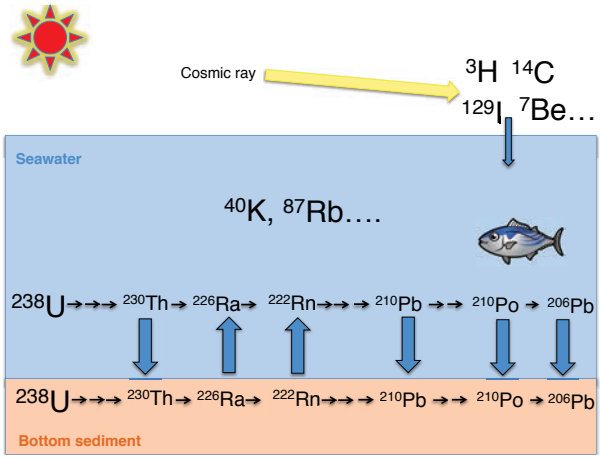

Fig.1 Schematic of the distribution of natural radionuclides in the oceans. The major nuclides are shown. In the figure, the thick upward arrows show the tendencies for nuclides to dissolve out of marine sediments, and the downward arrows show the tendencies for them to be eliminated from sea water.

2.1 Nuclides that have a decay series

In seawater, uranium exists mainly as the uranyl carbonate ion $[UO_2(CO_3)_3^{4-}]$, which dissolves very easily in seawater and is distributed almost uniformly throughout all oceans. There are three isotopes of uranium (^{234}U, ^{235}U, and ^{238}U), and the concentration of ^{238}U (half-life [$t_{1/2}$] = 4.5 × 10^9 years) is the highest: approximately 3 μg/L (0.04 Bq/L). The concentrations of ^{235}U and ^{234}U are 0.002 and 0.04 Bq/L, respectively. ^{238}U decays into ^{234}Th, which then decays through other nuclides to finally become ^{206}Pb, which is stable; this is called the uranium series (Fig. 2). Nuclides that arise through decay are called descendant nuclides, and nuclides prior to decay are called parent nuclides. In seawater, there is also the actinium series that starts with the decay of ^{235}U ($t_{1/2}$ = 7.0 × 10^8 years) and the thorium series that starts with ^{232}Th ($t_{1/2}$ = 1.4 × 10^{10} years). The total amount of radioactivity in seawater from nuclides of the uranium series is an order of magnitude greater than that of the other two series.

If nuclides belonging to the same series had the same chemical properties, and sufficient time had passed, they would have the same radioactivity (this is called radioactive equilibrium). However, in fact, the nuclides that are formed in a decay series have a variety of chemical properties and show various behaviors in the oceans, so their levels of radioactivity are different. For example, thorium (Th), lead (Pb), and polonium (Po) are relatively insoluble in seawater, so they are easily eliminated from seawater as particles, and their concentrations are therefore less than those of their parent nuclides (see Fig. 1). Conversely, uranium and radium (Ra) are soluble in seawater, so they remain in seawater for a long time. At the same time, they dissolve out of marine sediments, so they show higher

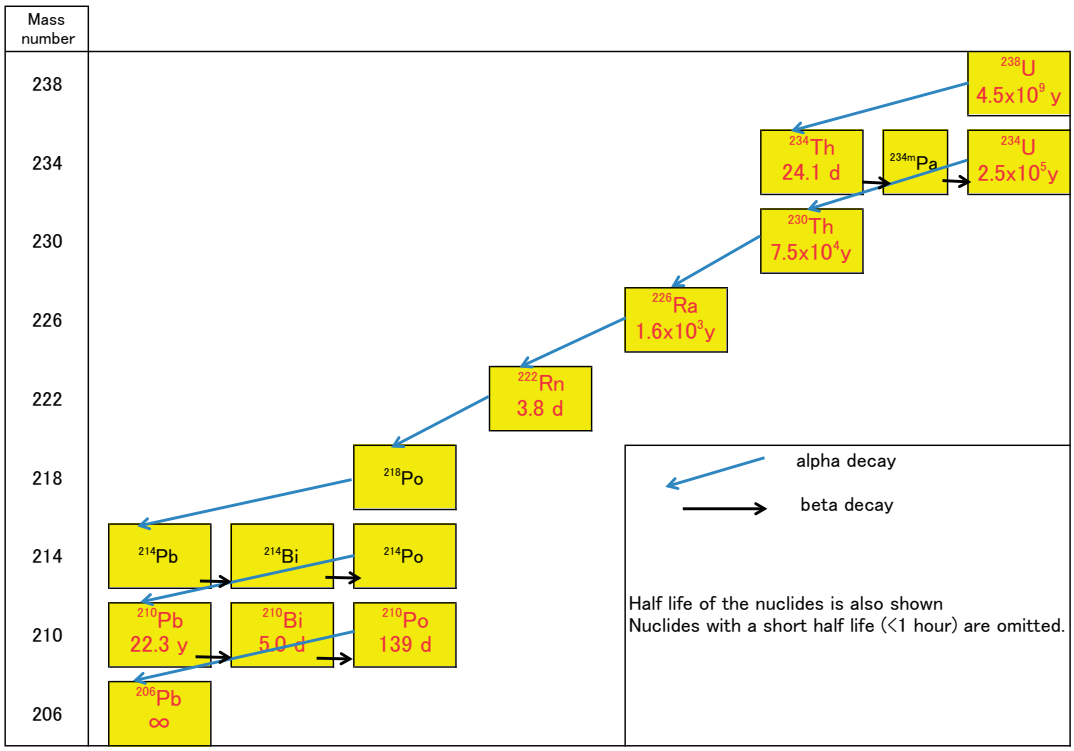

Fig.2 The uranium series. The main nuclides included in the uranium series. Those with small generation rates from their parent nuclides have been omitted.

radioactivity in seawater than do their parent nuclides. Furthermore, radon (Rn), which is a gas, partially escapes to the atmosphere from seawater. Moreover, ^{222}Rn that has come from the land via the air decays to generate ^{210}Pb, ^{210}Bi, and ^{210}Po, which enter the ocean environment.

2.2 Nuclides that do not have a decay series

One of the major nuclides without a decay series is potassium-40 (^{40}K, $t_{1/2}$ = 1.3 × 10^9 years). ^{40}K decays into one of the stable nuclides ^{40}Ar or ^{40}Ca. It has the highest radioactivity (11–12 Bq/L) among the natural radionuclides in seawater. There is also rubidium-87 (^{87}Rb, $t_{1/2}$ = 4.75 × 10^{10} years), but its concentration (0.11 Bq/L) is only about 1/100th that of ^{40}K. In the periodic table, potassium and rubidium belong to the alkali metals, along with sodium (Na), so they dissolve extremely easily in seawater. They therefore have the same distribution as salinity, being distributed approximately evenly throughout all of the oceans. There are a few other nuclides that do not have a decay series, but their concentrations are extremely low.

2.3 Nuclides generated by cosmic rays

Cosmic rays, which come from outside Earth, cause nuclear reactions in elements in Earth's upper atmosphere, creating many radionuclides. These radionuclides are continuously raining down onto the surface of Earth. The main ones are the following:

- Tritium (^{3}H, $t_{1/2}$ = 12.3 years)
- Beryllium-7 (^{7}Be, $t_{1/2}$ = 53 days)
- Carbon-14 (^{14}C, $t_{1/2}$ = 5730 years)
- Iodine-129 (^{129}I, $t_{1/2}$ = 1.6 × 10^6 years)

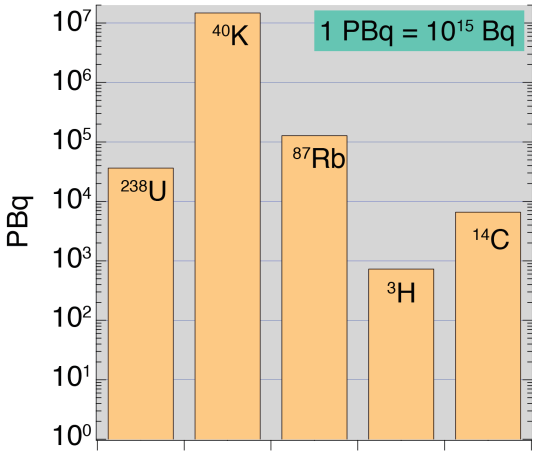

Fig.3 Amounts of the main natural radionuclides existing in the oceans.

Some of the nuclides shown above are readily incorporated into the biogeochemical cycle of the corresponding stable elements. For example, in the atmosphere, ^{14}C becomes $^{14}CO_2$ (carbon dioxide) and dissolves in seawater. Some $^{14}CO_2$ is incorporated into organic compounds through photosynthesis, whereas most of the rest circulates with the ocean currents in the form of $H^{14}CO_3^-$. This is why it is possible to quantitatively describe the movement of seawater by studying the distribution of ^{14}C.

Figure 3 shows the total amounts of the main natural radionuclides in the oceans. As explained above, ^{40}K is the most abundant, exceeding 10^7 PBq (1 PBq = 10^{15} Bq). ^{87}Rb is also present in substantial amounts. ^{238}U is the third most abundant, and the uranium-series nuclides that follow from it (not shown in the figure) are also important.

These various natural radionuclides circulate in the ocean with their own biological and chemical

Table 1 ^{40}K concentration in foods

food	^{40}K (Bq／kg)
dried kelp (kombu)	2,000
dried mashuroom (shiitake)	700
tea	600
dry milk	200
brown seaweed	200
spinach	200
beef	100
fish	100
milk	50
rice	30
bread	30
wine	30
beer	10
sake	1

Imai *et al* . (1999)

Table 2 Reference activity concentrations of natural radionuclides in food

	Activity concentration (mBq/kg)					
	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{228}Th
Milk products	5	40	60	0.3	5	0.3
Meat products	15	80	60	1	10	1
Grain products	80	100	100	3	60	3
Leafy vegetable	50	30	30	15	40	15
Roots and fruits	30	25	30	0.5	20	0.5
Fish prodcus	100	200	2,000	-	-	-

Adapted from UNSCEAR (1993)

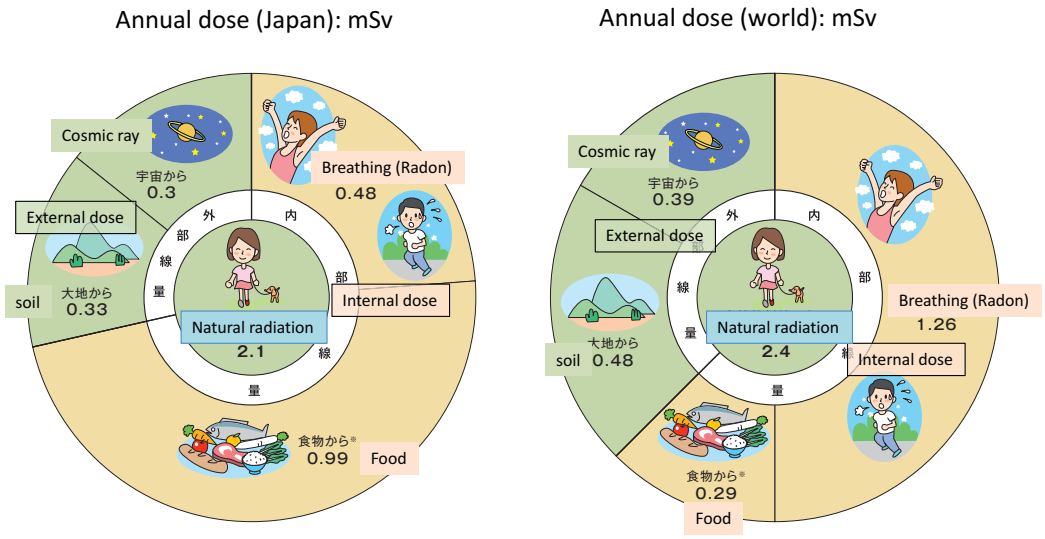

Fig.4 Radiation doses received from natural radionuclides. From: Federation of Electric Power Companies, *Graphical flip-charts of nuclear- and energy-related topics, 2015*.

properties and are partially incorporated into marine organisms. Meanwhile, the natural radionuclides on the land and in the air are incorporated into agricultural products and ultimately arrive on our dinner tables. Tables 1 and 2 show the major natural radionuclides contained in our food. The concentration of ^{40}K, several tens to several hundreds of becquerels per kilogram, is overwhelmingly high compared to other nuclides. Among the nuclides shown in Table 2, the three on the left are the uranium-series nuclides, and the three on the right are from the thorium series. Note that the concentration of ^{210}Po in fish (2000 mBq/kg) is particularly high. This is because Po has biological and chemical properties that allow it to easily remain in the body. The ratio of the concentration of an element in fish to that in seawater is called the concentration factor: the recommended value for the concentration factor of Po is 2×10^3 L/kg, which is in the relatively high group (International Atomic Energy Agency [IAEA], 2004).

Although somewhat beyond the scope of this document, it is worth looking at the radiation doses that we receive from these natural radionuclides (Fig. 4). If we compare the global averages and the averages for Japan, two differences are evident. The exposure of Japanese people to radon is low, whereas the exposure through food is high. Radon (^{222}Rn, $t_{1/2}$ = 3.8 days) is a member of the uranium-series nuclides, generated by α decay from its parent nuclide radium (^{226}Ra, $t_{1/2}$ = 1602 years). It is one of the chemically stable noble gases, similar to others such as helium and neon. In addition, the radon isotope ^{220}Rn (so-called thoron, $t_{1/2}$ = 54.5 seconds) is generated from radium (^{228}Ra and ^{224}Ra) in the thorium series. Radon and thoron decay through the decay series, until finally becoming the stable ^{206}Pb and ^{208}Pb, respectively. If radon or thoron is inhaled as a gas, the descendant nuclides that result from α decay with a short lifetime are deposited in the organs and tissues that form the respiratory tract, conferring high-energy radiation in these regions, with biological consequences. The differences in the effects of radon shown in Fig. 4 are thought to result from differences in living environments. Specifically, wooden buildings that do not contain much ^{238}U do not generate radon, and furthermore the good ventilation within such a building makes it difficult for radon gas to accumulate. The relatively large radiation exposure from food comes from ^{210}Po, which is contained in fish (Table 2). This is because ^{210}Po, which emits α radiation, is a large source of radiation in the gastrointestinal tract, especially the mucosa of the small intestine, and the intake radiation conversion coefficient is 1.2×10^{-6} Sv/Bq, about a hundred times that of ^{137}Cs, which is 1.3×10^{-8}.

3. Artificial radionuclides

The three sources of artificial radionuclides in the oceans are as follows:

- Atmospheric nuclear tests
- Accidents at nuclear power-related facilities

Table 3 Amounts of radionuclides released to the environment

nuclides	half life	PBq*		
		nuclear test	Chernobyl accident	FDNPP accident
^{89}Sr	50.5 d	117,000	～115	-
^{90}Sr	28.8 yr	622	～10	0.09～0.9（ocean）
^{131}I	8.02 d	675,000	～1,760	200（atmosphere） 11.1（ocean）
^{134}Cs	2.06 yr	～0	～54	15～20（atmosphere） 3.6（ocean）
^{137}Cs	30.2 yr	948	～85	15～20（atmosphere） 3.6（ocean）
^{239}Pu	24.1 yr	6.52	0.03	～0
^{240}Pu	6.56 yr	4.35	0.042	～0
^{241}Pu	14.3 yr	142	～6	～0

Adopted from UNSCEAR (2000), Casacuberta *et al*. (2013), Kobayashi *et al*. (2013), Tsumune *et al*. (2013), Aoyama *et. al*. (2016), Bu *et al*. (2014)

* 1PBq＝10^{15}Bq

Table 4 Release of ^{137}Cs to the ocean by nuclear tests

	Arctic Ocean	Atlantic Ocean	Indian Ocean	Pacific Ocean	sum
northern hemisphere	7	157	21	222	407
southern hemisphere	0	44	63	89	196
sum	7	201	84	311	603

Adapted from IAEA (2005)

unit：PBq

・Emissions from nuclear power-related facilities

The following subsections provide an overview of each of these.

3.1 Artificial radionuclides from atmospheric nuclear tests

From 1945 to 1963, there were more than 500 nuclear tests in the atmosphere. The total amount of artificial radionuclides emitted into the oceans from these tests is the largest of the three sources listed above. For example, the amount of ^{137}Cs due to nuclear testing is more than ten times that from the Chernobyl accident, and more than 40 times that from the Fukushima Daiichi reactor accident (Table 3). Atmospheric nuclear

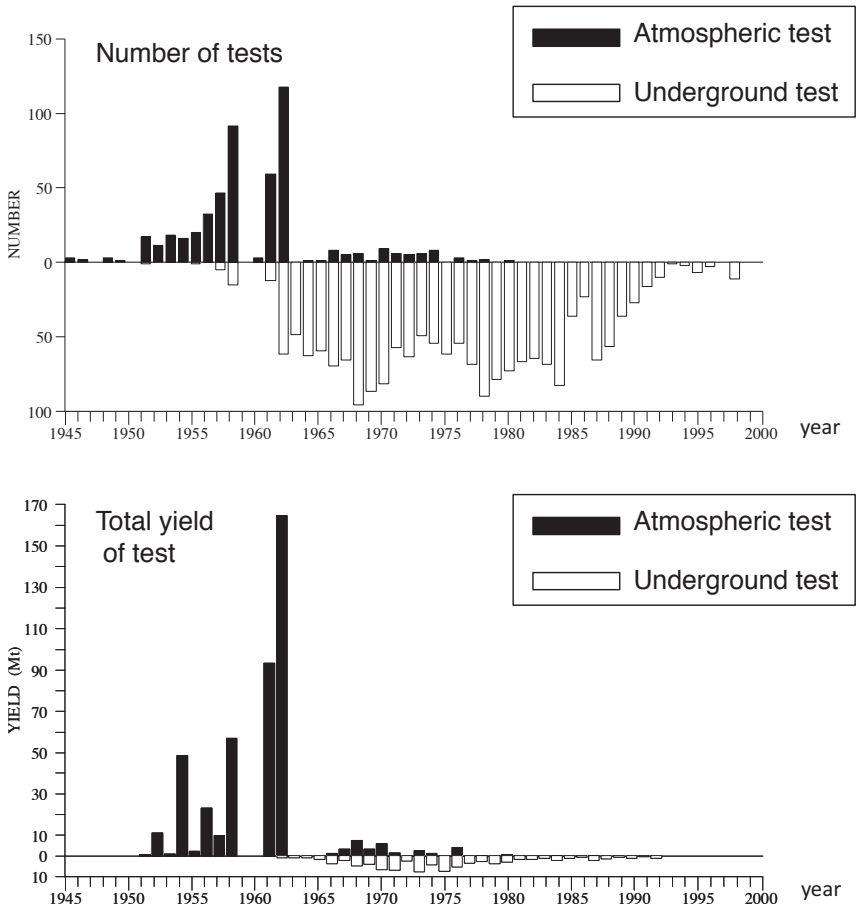

Fig.5 History of nuclear testing. The information is to be added to the UNSCEAR 2000 report.

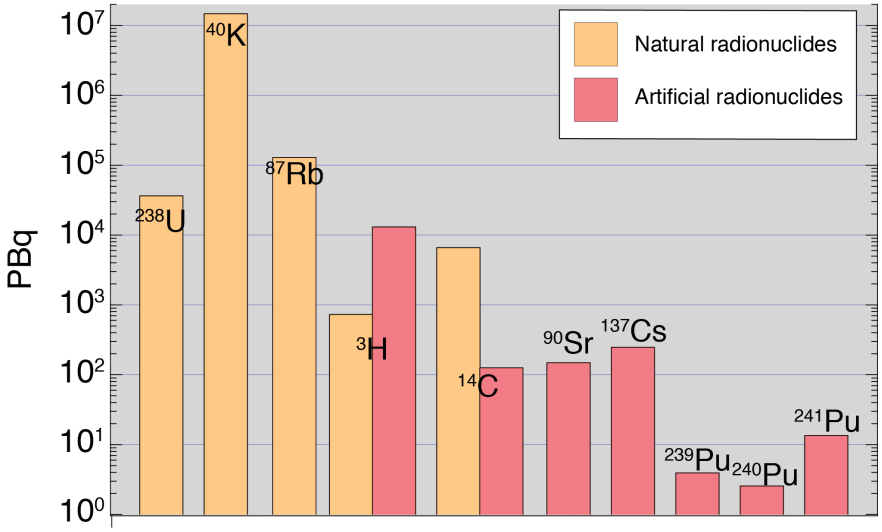

Fig.6 Comparison of the amounts of the main artificial radionuclides and natural radionuclides in the oceans in 2000. Adapted from Figure 3 and Aarkrog (2003).

tests continued until the signing of the Partial Test Ban Treaty in 1963. Some countries did not sign the treaty and continued testing, but the number of atmospheric tests after the signing was much lower (Fig. 5), and the radionuclide emissions have been greatly reduced. Therefore, the pollution due to artificial radionuclides in the oceans was the most serious in the early 1960s. Using ^{137}Cs as an example, the region with the most pronounced pollution from nuclear testing was the Pacific Ocean, which accounted for about half of what was emitted into the oceans (Table 4). Since 1963, the nuclides in the oceans derived from nuclear tests have been decreasing as they undergo radioactive decay, but they persist. Figure 6 presents the amounts of the main artificial radionuclides in the oceans as of 2000, along with the natural radionuclides. Out of approximately 600 PBq of ^{137}Cs emitted, levels had declined to about 1/3 of this by 2000. At the same time, even in 2000, almost 40 years after the end of atmospheric nuclear tests, artificial tritium ($t_{1/2}$ = 12 years) still exceeded the pre-testing natural amount.

The concentration of ^{137}Cs in the surface layers of the ocean due to nuclear testing is decreasing owing to radioactive decay and mixing with seawater from other

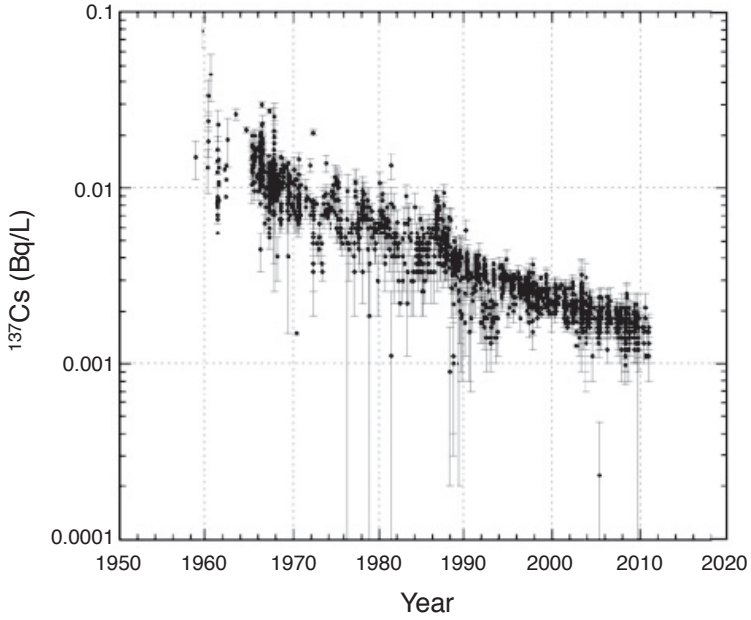

Fig.7 History of ^{137}Cs sea surface concentrations in the northwest portion of the North Pacific. The information is to be added to Povinec *et al*. (2013).

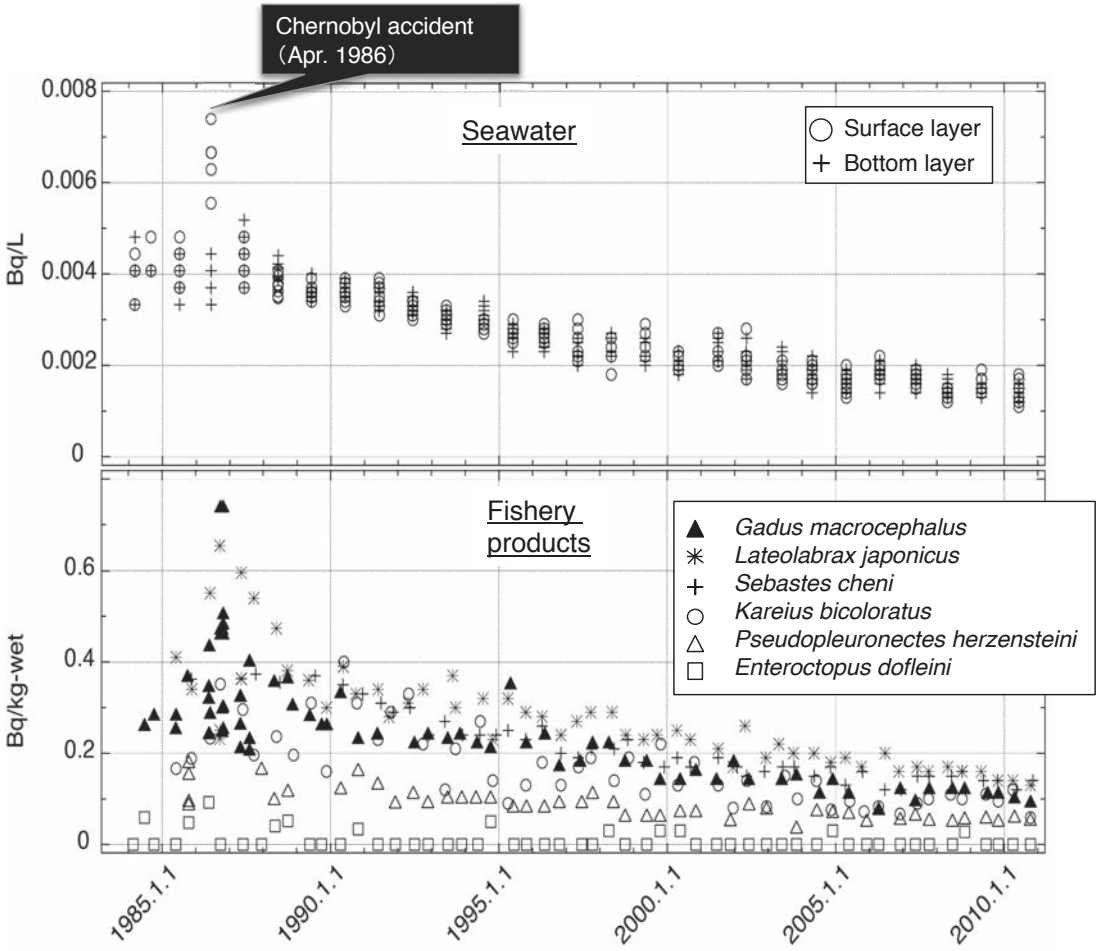

Fig.8 Temporal changes in the ^{137}Cs concentrations in sea water and marine animals in the sea off the coast of Fukushima Prefecture (1984-2010). Adapted based on the results of studies by the Marine Ecology Research Institute.

areas that have relatively less pollution. Figure 7 shows the change over time of ^{137}Cs concentration in the northern Pacific Ocean. In the early 1960s, it reached several tens of millibecquerels per liter; since then it has been decreasing exponentially. Since 1984, the Marine Ecology Research Institute of Japan has conducted detailed studies of radioactivity in the waters offshore of Japan's nuclear power plants; for example, off the coast of Fukushima Prefecture (Fig. 8). It is evident that the effects of the 1986 Chernobyl accident (to be discussed later) reached as far as the Pacific, and that there were 1 to 2 mBq/L of ^{137}Cs in the seawater even before the Fukushima Daiichi reactor accident.

Radionuclides from the nuclear tests existed in the surface layers of the oceans immediately after their emission. As time passed, they were mixed with deeper water and transported downward. The vertical distribution of ^{90}Sr and ^{137}Cs in the northern Pacific (Fig. 9) shows that these isotopes reached a depth of 500 m over approximately 30 years after 1963. However, the $^{239+240}$Pu that was emitted at the same time was carried even deeper. The apparent half-lives of these nuclides in the surface layers of the oceans have been observed for the entire Pacific Ocean (Table 5). The apparent half-lives of ^{90}Sr and ^{137}Cs in the surface oceans were mostly in a range from 13 to 14 years. In contrast, those of $^{239+240}$Pu were only about half that. These marked differences in vertical distribution patterns and apparent half-lives are ascribed to the respective chemical characteristics. The downward movement of elements in seawater is not only because of the diffusion of the dissolved elements themselves but is also closely tied to the precipitation of particles. Qualitatively, if a dissolved element (or an element in the form of suspended fine particles) in seawater tends to be immediately incorporated into settling particles, it will have a short half-life.

Reactions between dissolved elements and

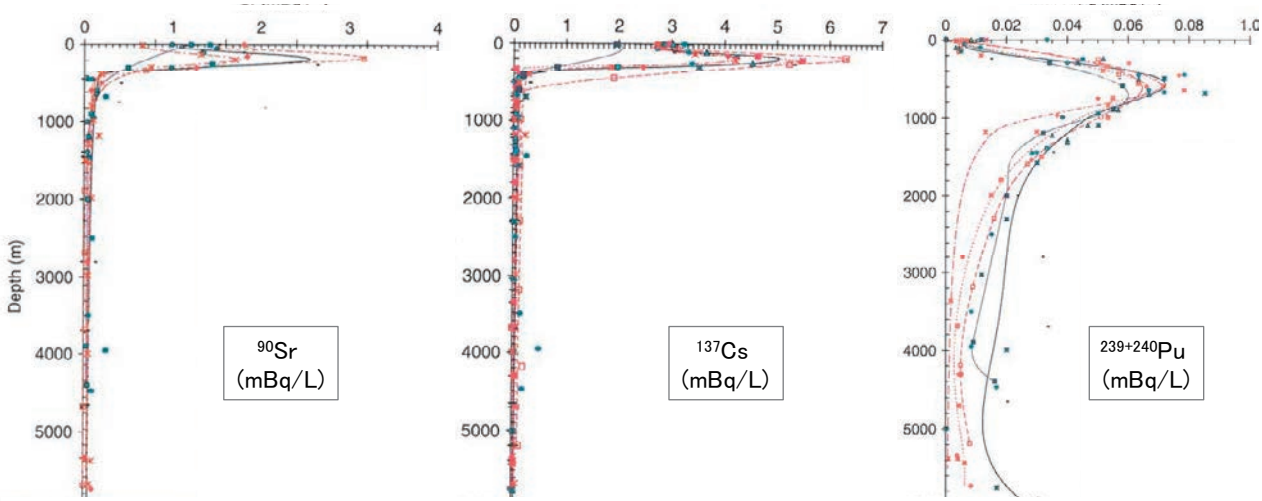

Fig.9 Vertical distributions of ^{90}Sr, ^{137}Cs, and $^{239+240}$Pu concentrations in sea water in the North Pacific (1973-1997). Adapted from Aoyama (2010) with the addition of some text.

Table 5 Apparent half-lives of artificial radionuclides in the surface water of the Pacific Ocean

	half-life (yrs)		
	^{90}Sr	^{137}Cs	$^{239+240}$Pu
North Pacific	12 ± 1	13 ± 1	7 ± 1
Equatorial Pacific	21 ± 2	23 ± 1	10 ± 1
South Pacific	18 ± 1	22 ± 1	12 ± 4
entire Pacific	13 ± 1	14 ± 1	7 ± 1

Adoped from Povinec *et al* . (2005)

Table 6 K_d values for open ocean and ocean margin

Element	Recommended K_d values	
	Open ocean	Ocean margin
Sr	2×10^2	8×10^0
I	2×10^2	7×10^1
Cs	2×10^3	4×10^3
Pu	1×10^5	1×10^5

Adoped from IAEA (2004)

particles in seawater are dynamic, including reactions between particles of various sizes (for example, Bacon, 2004), so that it is not easy to accurately describe these interactions kinetically. Here, for a first approximation, we use the distribution coefficient (K_d)—that is, the ratio of the concentration of a nuclide in particles to the concentration of the nuclide in seawater—as an index of the ease of incorporation of an element into particles. K_d is calculated using the following equation:

$$K_d = \frac{\text{Concentration of nuclide in particles}}{\text{Concentration of nuclide in seawater}}$$

Table 6 shows the values of K_d recommended by the IAEA. K_d increases in the order Sr < Cs < Pu. These values represent that Pu is the easiest to remove from the oceans, and Sr is the hardest of these three nuclides. In fact, experiments using equipment that collects settling particles (sediment traps) have confirmed that settling particles play an important role in the downward migration of Pu in the oceans (Livingston and Anderson, 1983). Thus, by understanding the biological and chemical properties of nuclides, it is possible to predict the future distribution of artificial radionuclides in the oceans.

The impact of the nuclear tests has also been recorded in marine sediments (especially in areas of shallow seas). In the marine sediments of the East China Sea, sediment layers from 1963, as determined from natural radionuclides, show a concentration peak for $^{239+240}$Pu and ^{137}Cs due to the nuclear tests (Fig. 10). This type of vertical distribution is not evident in deep-sea sediments because the sedimentation rate in the deep sea is not high enough for sufficient time resolution.

3.2 Artificial radionuclides from accidents at nuclear power-related facilities

Large amounts of artificial radionuclides have been released to the environment because of accidents

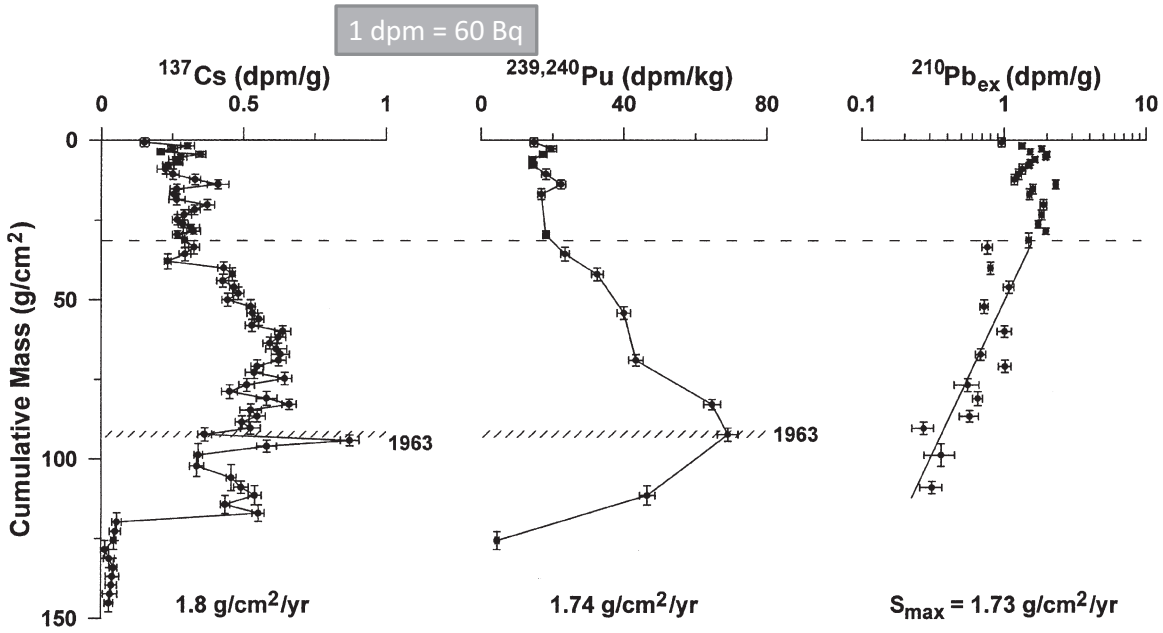

Fig.10 Vertical distributions of ^{137}Cs, $^{239+240}$Pu, and ^{210}Pb concentrations in marine sediments of the East China Sea. The vertical axis does not show depth but rather the accumulated mass of marine sediments, considering factors such as water content. Adapted from Su and Huh (2002).

at nuclear power plants and nuclear fuel reprocessing facilities. The types of nuclides released depend on the accident, so a general comparison is difficult. With respect to the total amount of nuclides released and the range of impacts to the environment, however, the most serious accident was the one at the former Soviet Union's Chernobyl power plant in 1986 (Table 7). The amount of ^{137}Cs released (Table 3) from this accident was approximately 85 PBq, whereas that from the FDNPP accident was 19 to 24 PBq. There is a outstanding difference of the Chernobyl accident from others in terms of extent of the impact. After the Chernobyl accident, ^{137}Cs traveled through the atmosphere and appeared in the surface waters of the ocean off the coast of Fukushima on the opposite side of the globe (Fig. 8). The nuclides from the accident did not show up in the bottom water near Japan, and those in surface water disappeared in the following year, so the radiological impact to the marine environment near Japan could be regarded as minimal. It is worth noting that the ^{137}Cs concentration in some marine animals increased following the accident and persisted into the following year (Fig. 8, bottom). The actual value of the concentration increase was not of a level to endanger human health, but it is interesting in terms of the behavior of Cs in the marine environment.

Kusakabe *et al*. (1988) also found ^{137}Cs from the Chernobyl accident in settling particles in the intermediate depths of the North Pacific. The accident occurred on 26 April 1986, and large amounts of radionuclides were released into the atmosphere. Around 7 May they reached the upper atmosphere of the northwestern North Pacific, and some settled to the sea surface. Data from sediment traps showed that the nuclides reached a depth of approximately 780 m in at most one or two months, with a settling velocity of 60–190 m/day. Because Cs is usually an element that dissolves relatively easily in seawater, this relatively fast settling velocity implies that the ^{137}Cs derived from the accident had a chemical form that was relatively hard to dissolve, or that it was incorporated into particulate matter, perhaps via plankton, and transported as settling particles.

The most important accident in Japan in terms of artificial radionuclides was evidently the one that occurred at FDNPP. Its impact on the ocean environment and fishery products is detailed by Takata *et al*. and Yokota *et al*. (this special issue). Here, briefly, the scale of the FDNPP accident can be appreciated by comparing it with that of the nuclear tests. Basically, the impact of

the FDNPP accident on the ocean environment was limited to the North Pacific. Before the accident (in 2010), ^{137}Cs in the North Pacific from nuclear tests amounted to 69 PBq. The FDNPP accident added 3.5 PBq by direct discharge, and 12–15 PBq via the atmosphere. As a result, the amount of ^{137}Cs in the waters of the North Pacific increased by 22–27% from the accident (Aoyama *et al*., 2016). It is expected that the concentration of ^{137}Cs in the future will decrease with a half-life of more than 10 years, as shown in Table 5, as the result of seawater movement into other areas, precipitation of ^{137}Cs onto marine sediments, and radioactive decay.

3.3 Artificial radionuclides discharged from nuclear power-related facilities

There have been some radionuclides discharged from nuclear power-related facilities; in particular, facilities related to nuclear fuel processing. Generally, care is taken to try to ensure that there is no significant effect on local ecology but there have probably been cases in the past where the amounts emitted exceeded the currently accepted levels. Among these, the largest sources of radionuclides were two reprocessing facilities in Europe: Sellafield (formerly Windscale, as in Table 7) in England and La Hague in France. Table 8 shows the change over time (1970–1998) in the ^{137}Cs and ^{90}Sr discharged from these two reprocessing facilities. The cumulative amount of ^{137}Cs discharged from Sellafield into the ocean for over 28 years has been approximately 40 PBq. Considering radioactive decay, the corrected amount for the year 2000 is 23 PBq. Through the middle of the 1970s, the annual discharge rate reached a maximum of 5.2 PBq/year, but it had been reduced to 0.008 PBq/year by 1998. Since 2000, the rate has been further reduced, to less than 0.005 PBq/year in 2013 (Fig. 11). The total amount of ^{137}Cs discharged from La Hague is less than 3% that of Sellafield.

The Irish Sea, which faces Sellafield, has less active water exchange with other seawater than does the water off the coast of Fukushima Prefecture. Furthermore, because of persistent discharge of waste with high radionuclide level until the middle of the 1980s, the concentration of ^{137}Cs in the water of the Irish Sea remained high (Fig. 12). The seawater of the English Channel that is affected by La Hague has a concentration that is three orders of magnitude lower than that of the Irish Sea. It is believed that the difference in concentration is because of the differences in the amounts discharged and in the seawater mixing. The ^{137}Cs from Sellafield flows northward on the ocean currents to enter the North Sea (Fig. 13). The increase in concentration seen in the Baltic Sea after 1986 was mainly because of ^{137}Cs that was transported through the atmosphere from the Chernobyl accident.

Table 7 Amount of radionuclides released during accident at nuclear power-related facilities

nuclides	place	Chelyabinsk	Windscale	Three Mile Islans	Chernobyl	Fukushima Pref.
	country	Soviet Union	England	United States	Soviet Union	Japan
	year	1957	1957	1979	1986	2011
^{90}Sr		4	7×10^{-5}		～10	0.09～0.9（ocean）
^{131}I			0.74	5.55×10^{-4}	～1,760	200（atmosphere） 11.1（ocean）
^{137}Cs		0.03	0.022		～85	5～20（atomosphere） 3.6（ocean）
^{239}Pu			1.6×10^{-6}		0.03	～0
^{240}Pu					0.042	～0
^{241}Pu					～6	～0
		The facilities were located inland. Few impact to the ocean.	Impact mainly in inland	Major nuclides released: ^{85}Kr and ^{133}Xe	^{137}Cs to the ocean: 15～20 PBq	^{137}Cs to the ocean through the atmosphere ：12～15

Adapted from UNSCEAR（2000）, Casacuberta *et al*.（2013）, Kobayashi *et al*.（2013）

unit：PBq（$=10^{15}$Bq）

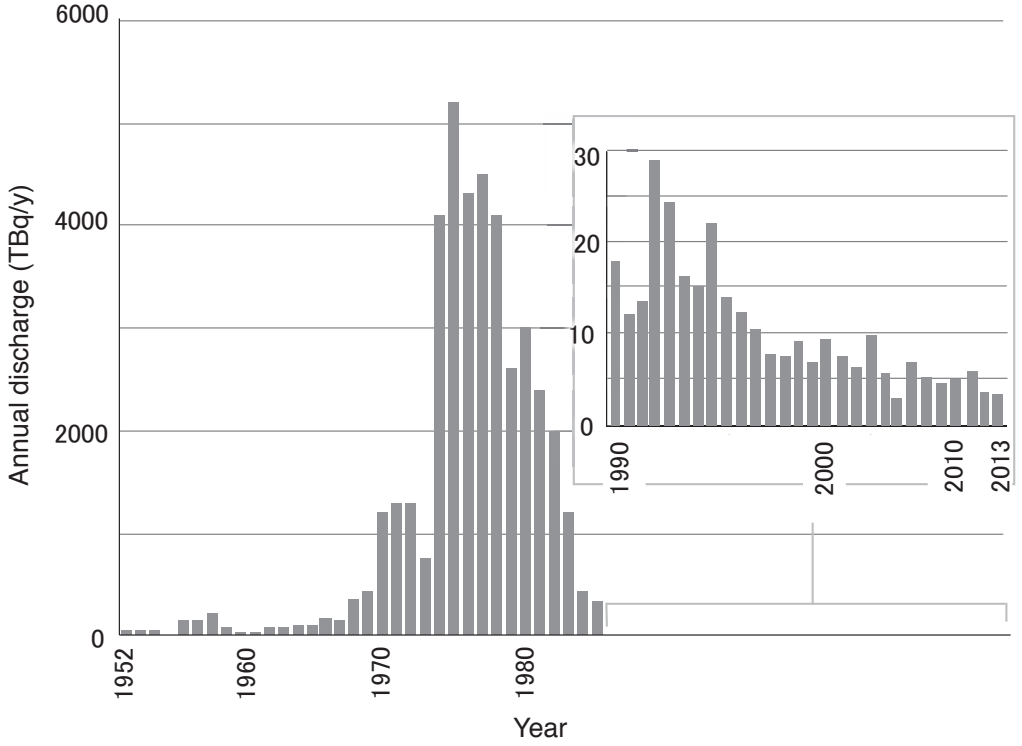

Fig.11 History of emitted amounts per year of ^{137}Cs at Sellafield. Adapted from the Environmental Protection Agency (2015).

The effects of the discharge from Sellafield have been recorded in nearby marine sediments. The concentration of ^{137}Cs in the surface sediment was approximately 400 Bq/kg-dry in 1992, whereas it exceeded 1000 Bq/kg-dry in deeper layers (Fig. 14; MacKenzie *et al*., 1998). This pattern of vertical distribution is not seen in the studies outside the 30-km radius from the FDNPP conducted by the Marine Ecology Research Institute of Japan under contracts from the Nuclear Regulatory Agency of the Japanese Government (see Takata *et al*. [this issue] for details). The difference in vertical distribution patterns can be attributed to the differences in oceanic material cycling; that is, whereas the Fukushima coast directly faces the

Table 8 Annual dicharge rates of ^{137}Cs and ^{90}Sr at Sellafield (England) and La Hague (France)

year	Sellafield				La Hague			
	^{137}Cs	^{90}Sr	^{137}Cs ac*	^{90}Sr ac*	^{137}Cs	^{90}Sr	^{137}Cs ac*	^{90}Sr ac*
1970	1,200	230	600	112	89	2	45	1
1975	5,230	466	2,936	255	34	38	19	21
1980	2,970	352	1,871	217	27	29	17	18
1985	325	52	230	36	29	47	21	33
1990	24	4	19	3	13	16	10	13
1995	12	28	11	25	5	30	4	27
1998	8	18	7	17	3	3	3	3
sum	38,837	5,528	22,912	3,193	961	1,106	566	746

Adopted from Aarkrog (2003)

Sum was calculated baed on the data of every year from 1970 to 1998

unit : 10^{12}Bq

* Radioactivity was corrected for decay to the year 2000

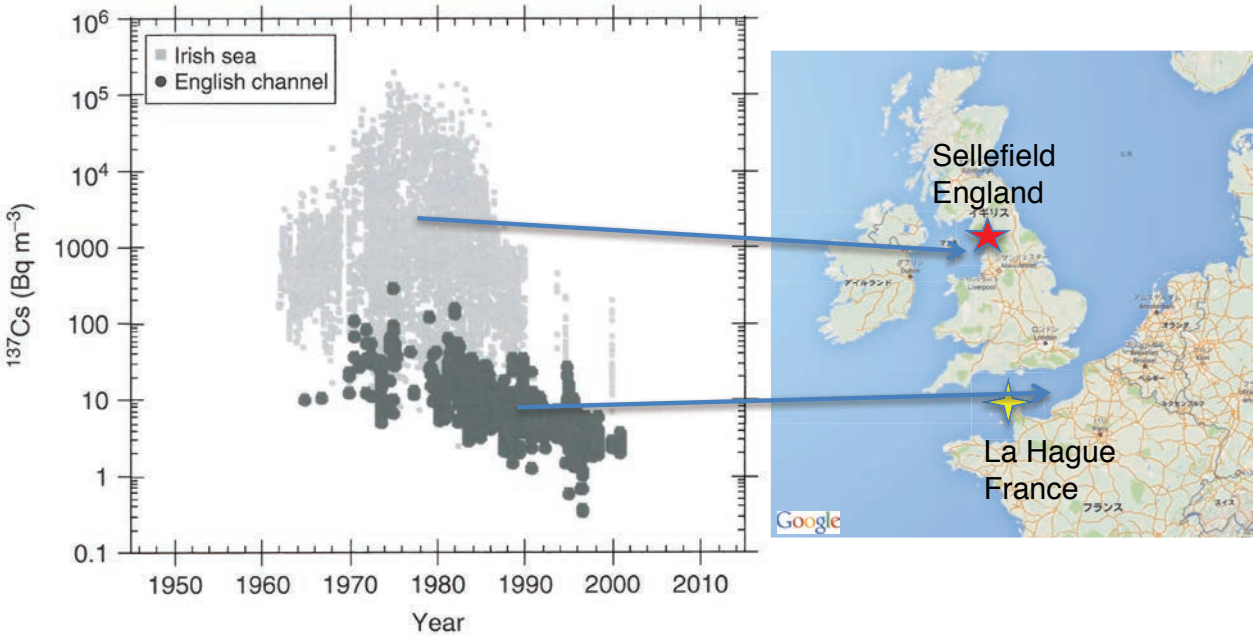

Fig.12 History of ^{137}Cs concentrations in the surface water of the Irish Sea and the English Channel. The map shows the locations of the two fuel reprocessing facilities (see the main text) as well as the Irish Sea and the English Channel. The data are from Inomata (2010). Concentrations are shown as Bq/m^3, but this is equivalent to mBq/L.

open ocean, the sea off the coast of Sellafield is semi-enclosed. Future comparative studies of these two areas should allow more precise predictions regarding the recovery of the ocean near Fukushima.

4. Summary

- Humans have always been living surrounded by various types of natural radionuclides. At the same time, certain radionuclides have accumulated within their bodies.
- The largest source of radioactive pollution in the ocean environment is atmospheric nuclear tests.
- The largest accident at a nuclear power-related facility occurred at the Chernobyl nuclear power plant.
- Planned discharges during daily operations at nuclear fuel processing facilities are currently extremely low compared to the two preceding sources.

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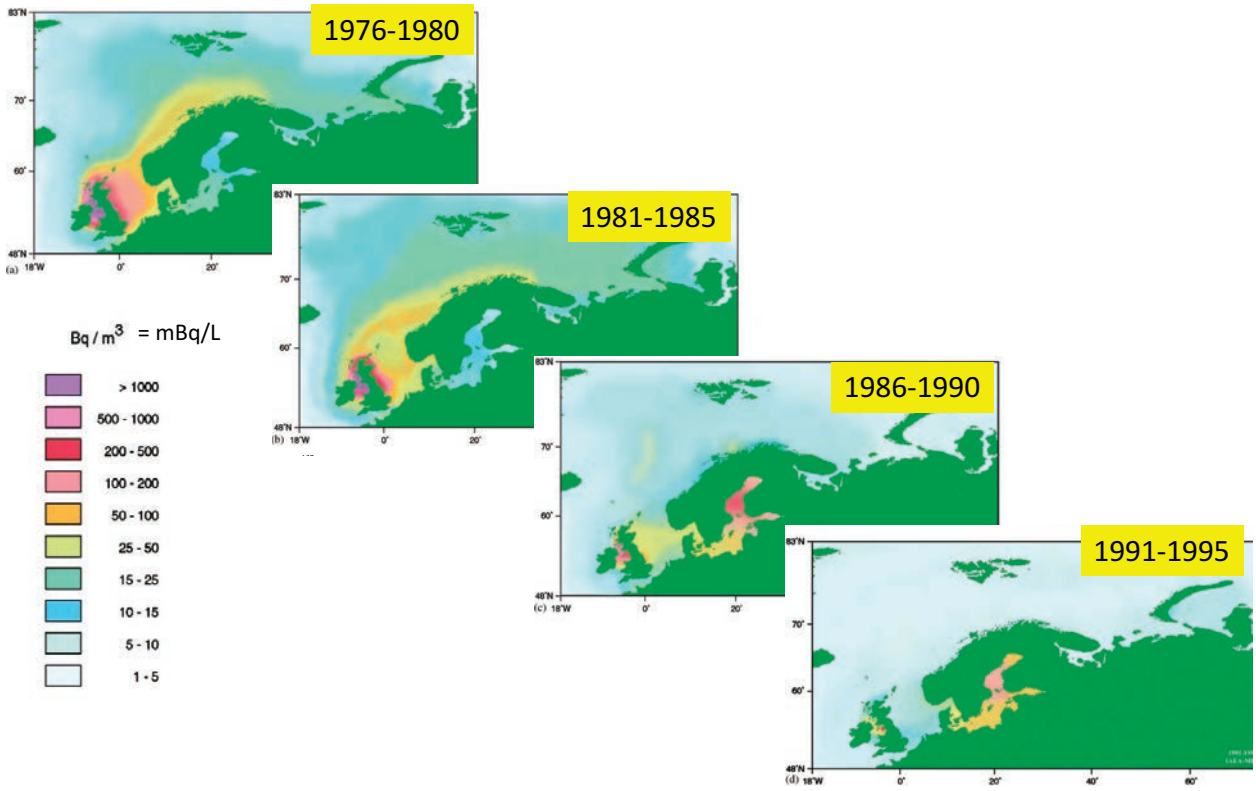

Fig.13 History of ^{137}Cs concentration in the surface water of the northeastern Atlantic. Adapted from Povinec *et al*. (2003).

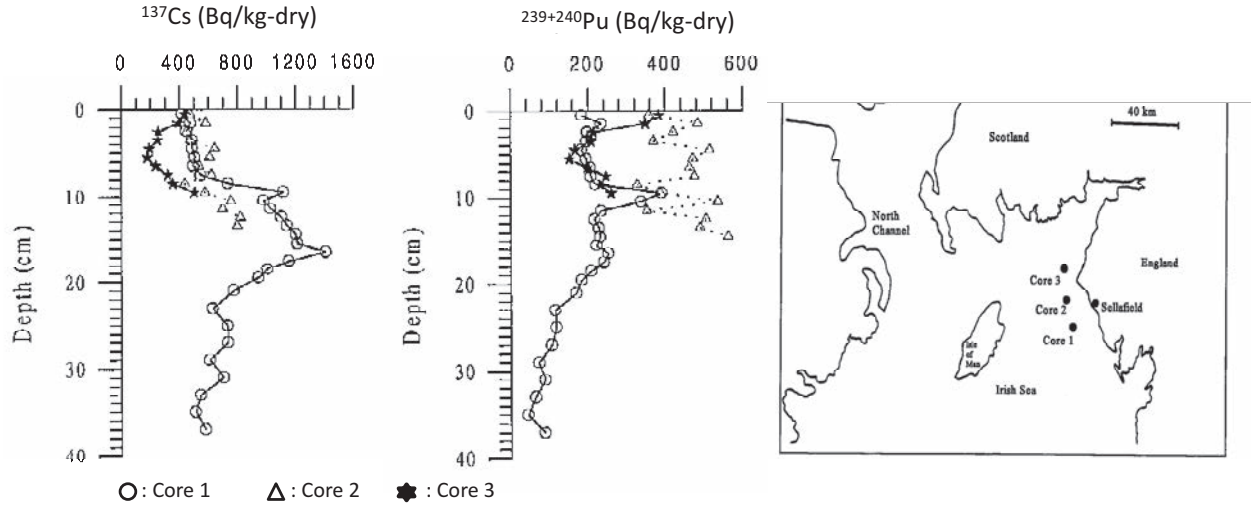

Fig.14 Distribution of ^{137}Cs in marine sediments because of Sellafield. Samples are collected in January 1992. Adapted from MacKenzie *et al*. (1998).

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Rep. Mar. Ecol. Res. Inst., No.22 (Supplement), 17-25, 2017

Special Report: "Radioactivity in the Marine Environment and in Fisheries Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident

Long-term Distribution of Radioactive Cesium in the Coastal Seawater and Sediments of Japan

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Abstract: A radioactivity survey was launched in 1983 to determine background levels of artificial radionuclides such as ^{90}Sr and ^{137}Cs in marine environments offshore of nuclear power stations throughout Japan and one nuclear fuel reprocessing plant. In addition, an environmental radioactivity monitoring study, with a particular focus on the waters off Fukushima and nearby prefectures, was initiated shortly after the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident. Here, we report on spatiotemporal changes of radiocesium in the waters off FDNPP, as well as on long-term (>30-year) temporal changes in radionuclides in the marine environment off the nuclear power stations and the fuel reprocessing facility. We determined that ^{137}Cs concentrations decreased over the period 1983–2010, with the exception of a spike corresponding to the Chernobyl nuclear accident in 1986. Levels of radiocesium prior to the FDNPP accident (2006–2010) indicated that ^{137}Cs concentrations ranged from 1.3 to 2.5 mBq/L (mean: 1.6 mBq/L). Post-accident monitoring revealed a heavy burden of artificial radionuclides in Japanese coastal areas, as ^{137}Cs concentrations in surface seawaters of the northwestern North Pacific Ocean increased markedly. On the other hand, concentrations of ^{134}Cs, which has a short half-life (around 2 years), decreased sharply due to seawater dispersion by coastal currents. Although concentrations of ^{137}Cs in coastal seawater within 10 km of FDNPP remained high even 5 years after the FDNPP accident, concentrations in seawater >30 km from FDNPP have almost returned to background values.

Concentrations of ^{137}Cs in sediments declined slightly over the period 1983–2010, but maximum values were observed at all monitoring stations near the FDNPP in September 2011 (8.0–580 Bq/kg-dry), several months after the accident; almost all concentrations exceeded pre-accident 5-year averages (2.1 Bq/kg-dry) for Japanese coastal regions. However, five years of monitoring after the accident reveal a trend of exponential decline.

Keywords: seawater, sediment, ^{134}Cs, ^{137}Cs, Fukushima Dai-ichi Nuclear Power Plant

Introduction

The Marine Ecology Research Institute (MERI) has been conducting surveys of anthropogenic radionuclides in marine environments offshore of commercial nuclear power plants throughout Japan since 1983. Because of the large amount of radioactive nuclides released as a result of the accident at the Fukushima Dai-ichi Nuclear Power Plant (hereafter "FDNPP") in March 2011, MERI instituted a survey specifically focusing on the distribution and behavior of man-made radionuclides in seawater and marine sediments at sites close to FDNPP (hereafter "FDNPP monitoring"); results of this survey have previously been reported in extensive detail (Takada and Suzuki, 2003; Kusakabe *et al*., 2013; Watabe *et al*., 2013;

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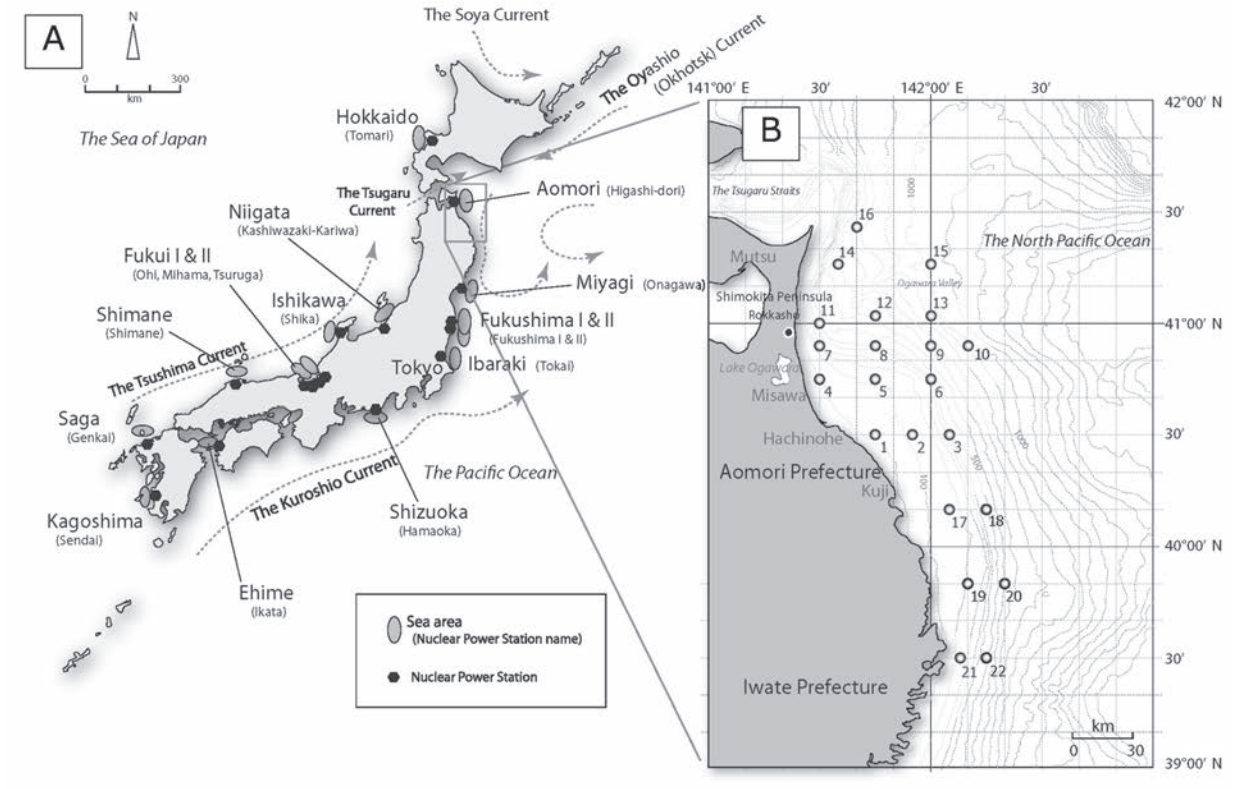

Fig.1 Location of the marine areas included in this study. A: 15 coastal marine regions (four sampling stations in each region) adjacent to commercial nuclear power plants. B: 22 offshore sampling stations in waters adjacent to the nuclear fuel reprocessing facilities.

Oikawa *et al*., 2013a, b, 2014; Kusakabe, 2014; Takata *et al*., 2013, 2015, 2016; Isono *et al*., 2015a, b). Here, we provide a summary of the trends in the concentrations of artificial radioactive nuclides in Japanese coastal waters and sediments since 1983 including the Nuclear Regulation Authority's monitoring data for radioactive Cs (^{134}Cs, ^{137}Cs) concentrations in marine systems over the period 1983–2015.

Methods

Sampling

Sampling procedures have been summarized in detail elsewhere (Oikawa *et al*., 2014; Isono *et al*., 2015a). Briefly, we collected seawater and sediment samples from 15 coastal regions in which commercial nuclear power plants are located, with four sampling stations established within each region (Fig. 1A). Since 1991, prior to regular operation of the nuclear fuel reprocessing facilities in the village of Rokkasho, Aomori Prefecture, surveys involving 22 sampling stations have been conducted in the waters off Aomori and Iwate Prefectures (Fig. 1B). In addition, there has been an ongoing marine environmental monitoring project in the waters offshore of FDNPP since March 2011, shortly after the nuclear accident. As of 2015, the FDNPP monitoring area included 32 sampling stations in coastal areas 30–90 km from FDNPP, along with 10 stations in the open ocean (Fig. 2A) and seven stations within a 10-km radius of FDNPP (Fig. 2B).

Seawater samples were collected annually in May/June; samples consisted of 60–200 L of seawater collected with Van Dorn or Niskin water samplers. Water samples were collected from each station in the surface layer (1-m depth), from a depth of 50–100 m, and from 10–40 m above the seafloor. Seawater samples were not filtered. Two milliliters of 6 M hydrochloric acid or 15 M nitric acid were added per liter of seawater

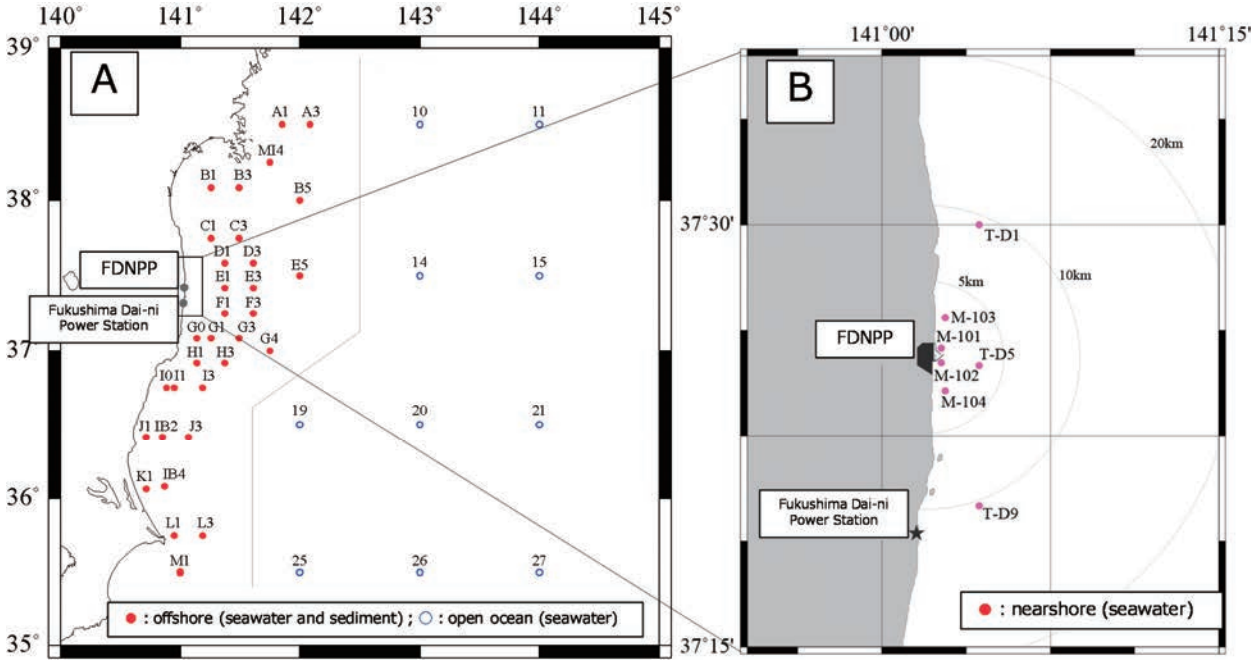

Fig.2 Monitoring area. A: 32 sampling stations in the coastal area located 30-90 km from the FDNPP and 10 stations in the open ocean. B: seven nearshore sampling stations within a 10-km radius of the FDNPP.

to each sample, after which samples were stored under cool, dark conditions until analysis. Surface sediment samples were collected using an Ekman–Birge grab sampler or a box corer (Rigo stainless steel box [45-cm sides] capable of taking pillar-shaped samples at sediment depths up to about 40 cm) or a multiple corer (Rigo acrylic pipe with an inside diameter of 8 cm [eight rows]). We collected about 2.5 kg of sediment from the layer about 3 cm below the surface. The sediment samples were either refrigerated or frozen until analysis.

Analysis

Cesium-137 in the seawater samples was chemically separated and quantified by gamma-ray spectrometry. After drying, measured quantities of seabed sediment were placed in plastic containers, and ^{137}Cs concentrations were determined via gamma-ray spectrometry. The lower detection limits for both ^{134}Cs and ^{137}Cs in all samples were 0.3–1.0 mBq/L for seawater and about 0.7 Bq/kg-dry for seabed sediments. See Oikawa *et al*. (2013a) for additional details of the analytical methods.

Results and Discussion

Cs-137 in seawater offshore of commercial nuclear power plants

Temporal changes in ^{137}Cs concentrations in both surface and bottom layers of seawater in the 15 coastal regions offshore of commercial nuclear power plants for 1983–2015 are presented in Figure 3. Prior to the FDNPP accident, low levels of ^{137}Cs in seawater were detected using beta-ray measurement following sample pre-concentration. However, ^{134}Cs, with a half-life of 2 years, was also released in the accident; the activation product of ^{134}Cs has approximately the same radiation level (activity ratio ≈ 1) as that of ^{137}Cs, which is a fission product. Because beta rays of ^{134}Cs and ^{137}Cs cannot be distinguished, gamma-ray spectrometry was applied to all samples collected since 2012, as this approach can differentiate ^{134}Cs and ^{137}Cs. Cesium levels in some of the samples from 2011, for which the beta-ray approach was used, are reported as $^{134+137}$Cs.

Although ^{137}Cs, which originated primarily from atmospheric nuclear-weapons testing in the Northern Hemisphere between 1945 and 1965, continues to be detected in the surface layers of the North Pacific

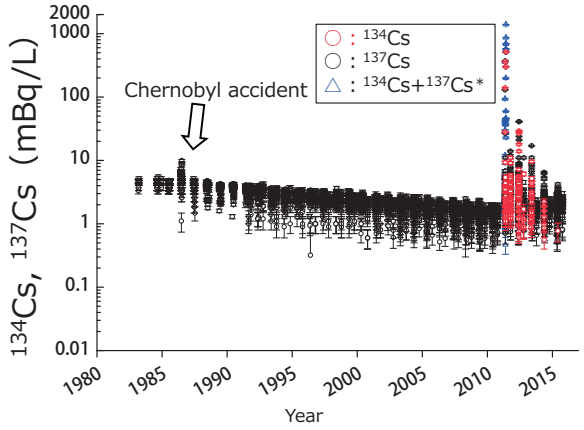

Fig.3 Concentrations of ^{137}Cs in surface waters of the marine areas adjacent to nuclear power plants over the period 1983–2015. Samples based on beta measurements in 2011 included ^{134}Cs in addition to ^{137}Cs; thus, these data are shown as "$^{134+137}$Cs". Vertical bars indicate counting errors (1σ). ND = not detected and therefore not plotted.

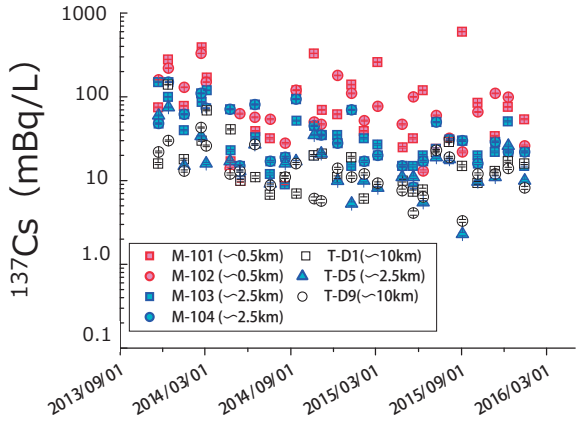

Fig.4 Temporal variation in ^{137}Cs concentrations in seawater in nearshore areas within 10 km of the FDNPP over the period November 2013 to February 2016. Vertical bars indicate counting errors (1σ). Figures in quotation marks next to measurement points indicate distance from the FDNPP.

Ocean, its concentration has gradually declined throughout the survey regions, with theexception of a spike in May–June 1986 due to the April 1986 Chernobyl nuclear power-plant accident. Because the beta-ray measurement method was used at that time, the presence of ^{134}Cs was unconfirmed; however, surveys in the following year (1987) showed that levels of ^{137}Cs were the same as those prior to the Chernobyl

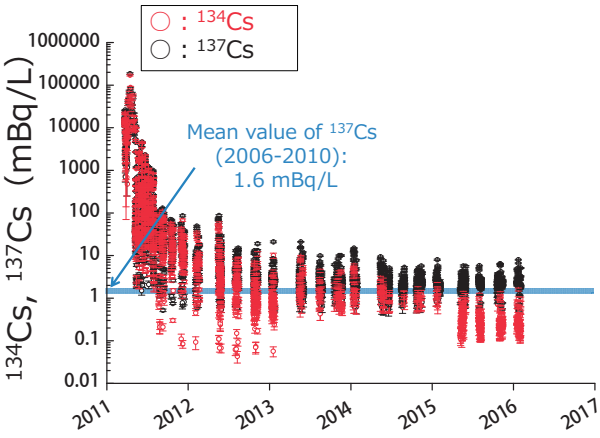

Fig.5 Temporal variations in ^{137}Cs concentrations in seawater offshore of sites over the period March 2011 to February 2016. Vertical bars indicate counting errors (1σ).

accident, declining thereafter at a rate similar to the pre-accident rate. In addition, the mean concentration of ^{137}Cs in seawater based on all data over the 5-year period from 2006 to 2010 (i.e. before the FDNPP accident) was 1.6 mBq/L (range: 1.1–2.5 mBq/L), and the effective environmental half-life was estimated to be 12–20 years, which is shorter than the physical half-life of ^{137}Cs (30.1 years) (Oikawa *et al.*, 2013b). Concentrations of ^{137}Cs increased in the waters off Miyagi, Fukushima Dai-ichi, Fukushima Dai-ni, and Ibaraki monitoring areas in 2011 due to the FDNPP accident, but subsequently decreased exponentially between 2011 and 2015.

Cs-137 in seawater following the FDNPP accident

Temporal variations in ^{137}Cs concentrations in surface seawater within a 10-km radius of the FDNPP are shown in Figure 4. Concentrations of ^{137}Cs in surface seawater ranged from 5.3 mBq/L (station T-D5) to 140 mBq/L (station M-101) in January 2015 and from 8.2 mBq/L (station T-D9) to 54 mBq/L (station M-101) in January 2016, or about one to two orders of magnitude greater than pre-accident levels (1.3–2.5 mBq/L).

Temporal variations in ^{137}Cs concentrations in coastal areas 30–90 km from FDNPP are shown in Figure 5; the unbroken line in this figure represents the mean ^{137}Cs concentration (1.6 mBq/L) in the waters

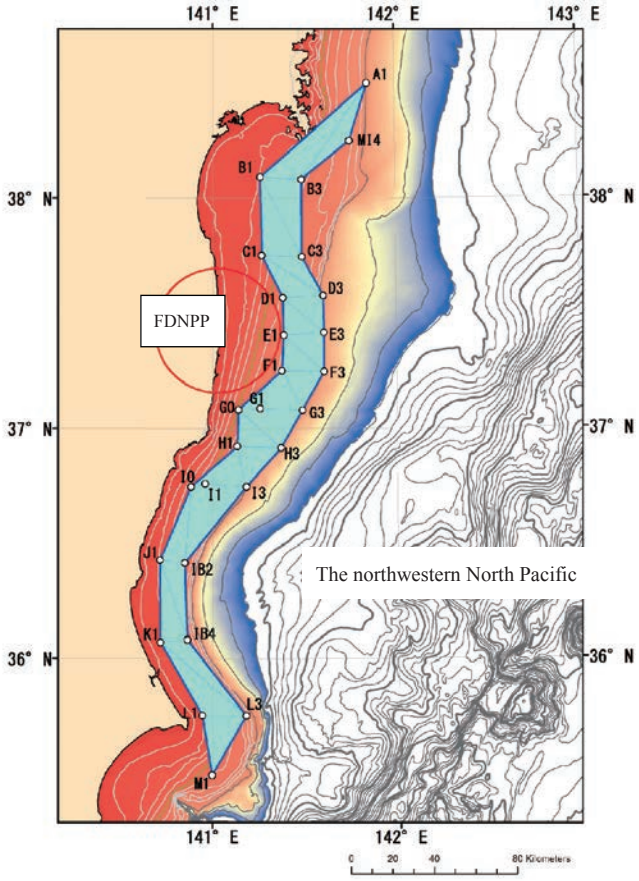

Fig.6 Area used to calculate the ^{137}Cs inventory in seawater (light blue area); circles indicate the 27 stations used for this calculation. Data taken from a report by Takata *et al*. (2016).

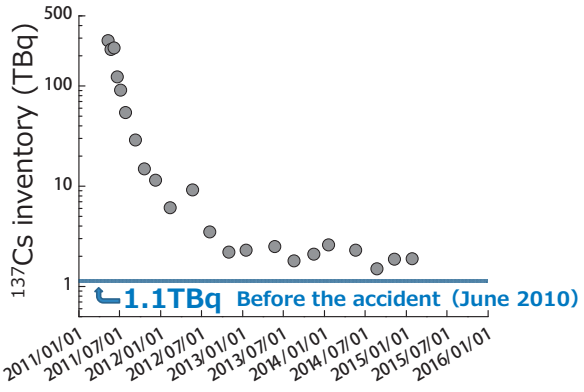

Fig.7 Temporal changes in ^{137}Cs inventories in offshore waters. Data taken from a report by Takata *et al*. (2016).

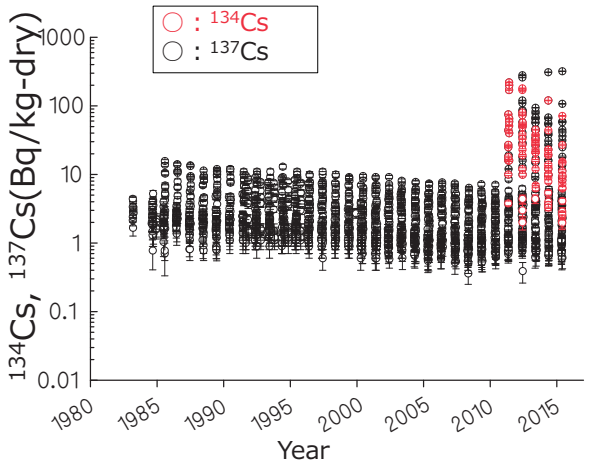

Fig.8 Cs-137 concentrations in sediment samples (0–3 cm depth) collected from 15 coastal marine regions (including each of the four sampling stations in each region) adjacent to commercial nuclear power plants over the period 1983–2015. ND = not detected and therefore not plotted. Vertical bars indicate counting errors (1σ).

offshore of Miyagi, Fukushima, and Ibaraki prefectures over the 5-year period preceding the accident (2006–2010). The highest concentration of ^{137}Cs in the surface seawater after the accident, recorded on 15 April 2011, was 186,000 mBq/L, or approximately five orders of magnitude greater than pre-accident levels. Concentrations then decreased exponentially over time, falling to about 10 mBq/L within 2 years, and maximum levels have not exceeded 10 mBq/L since 2014. Annual mean values of ^{137}Cs concentrations in seawater during the FDNPP monitoring were 2.44 mBq/L in 2014 and 2.35 mBq/L in 2015, and they continue to exhibit a downward trend towards the mean pre-accident background level (1.6 mBq/L).

We conducted a water-column inventory of ^{137}Cs (Bq/m) by measuring ^{137}Cs concentrations at various depths from the surface to the sea bottom at 27 coastal stations (Fig. 6). On the basis of the estimated surface area (6160 km^2) and volume (753 km^3) of the offshore waters on which we focused (30–90 km from the FDNPP), we examined the temporal changes in ^{137}Cs inventories in this area; details of this calculation are described by Takata *et al*. (2016). In May 2011 (2 months after the accident), we estimated a ^{137}Cs inventory of 283 TBq in this region, equivalent to

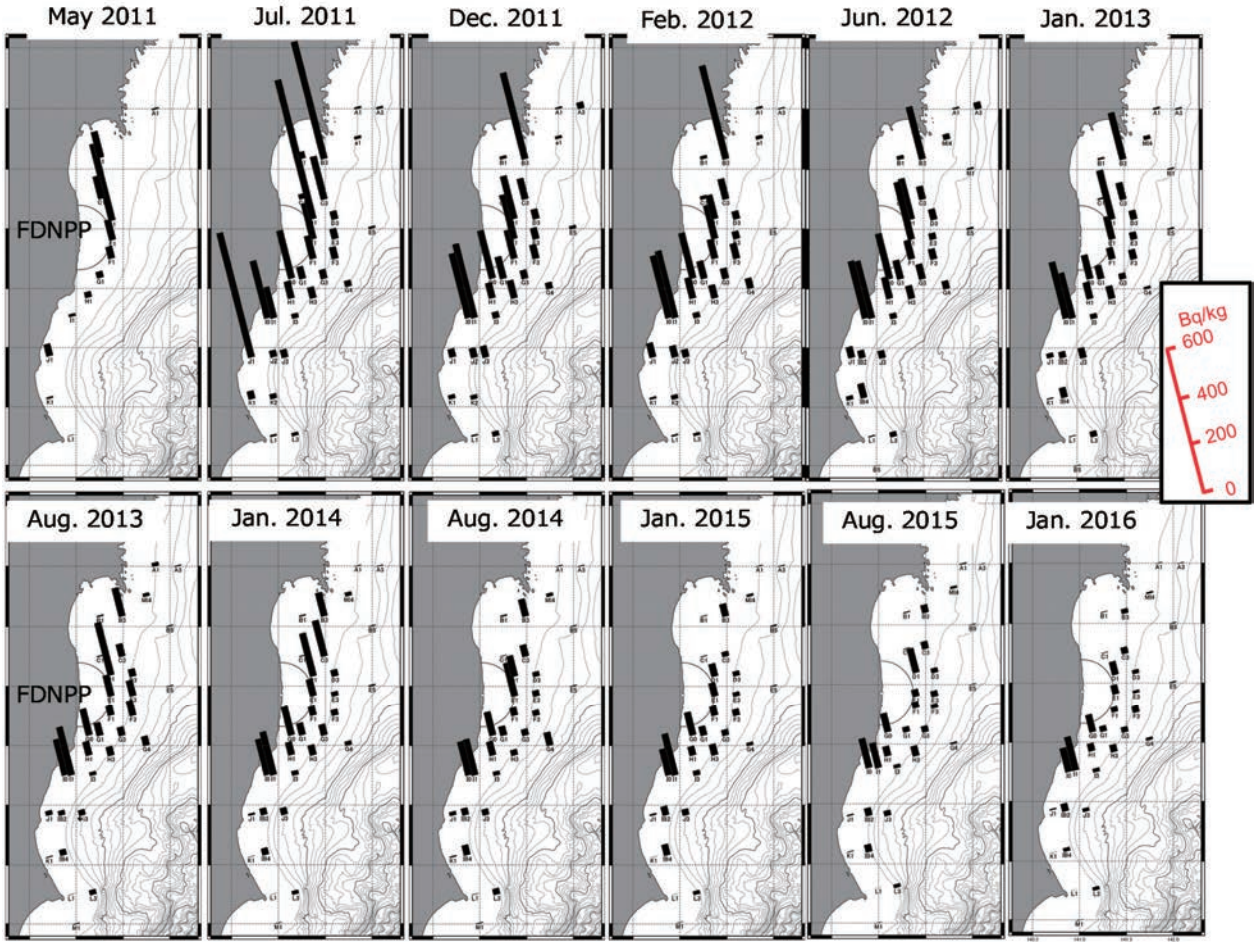

Fig.9 Cs-137 concentrations in sediment samples (0–3 cm depth).

approximately 1.5–1.8% of the total amount of ^{137}Cs that entered the ocean as a result of the accident (approximately 15.5–18.5 PBq; Aoyama *et al*., 2016) (Fig. 7). Our estimated inventory of 283 TBq is over two orders of magnitude higher than the pre-accident inventory of 1.1 TBq, but the inventory declined by an order of magnitude to 14.9 TBq over the subsequent six months (May–October 2011). From October 2011 to February 2015, the inventory fell to 1.89 TBq, thus approaching the pre-accident level; however, relatively high concentrations of ^{134}Cs and ^{137}Cs are still being recorded at nearshore stations, and thus continuous monitoring remains a priority.

Cs-137 in sediments offshore of commercial nuclear power plants

Temporal variations in ^{137}Cs concentrations in sediments over the period 1983–2015 are presented in Figure 8. Concentrations of ^{137}Cs are highly heterogeneous in sediments because of the changes in range of grain sizes and the surface areas of sediment particles; for example, Cs tends to accumulate more in muddy sediments than in sandy sediments. As such, ^{137}Cs concentrations were slightly higher in the predominately muddy sediments off Hokkaido, Niigata, and Fukui prefectures than in the sandy sediments that are more common in other regions (Oikawa *et al*., 2013b). Cesium-137 levels in sediments have, however, generally declined slightly since 1983; even the Chernobyl accident, which raised ^{137}Cs concentrations in surface waters for a year, had no effect on sediment concentrations (Oikawa *et al*., 2013b). We estimated the 5-year (2006–2010) average ^{137}Cs concentration in sediments to be 2.1 Bq/kg-dry (range: 0.72–8.0 Bq/kg-dry).

Cs-137 in sediments following the FDNPP accident

Sampling of the seabed began in May 2011, two

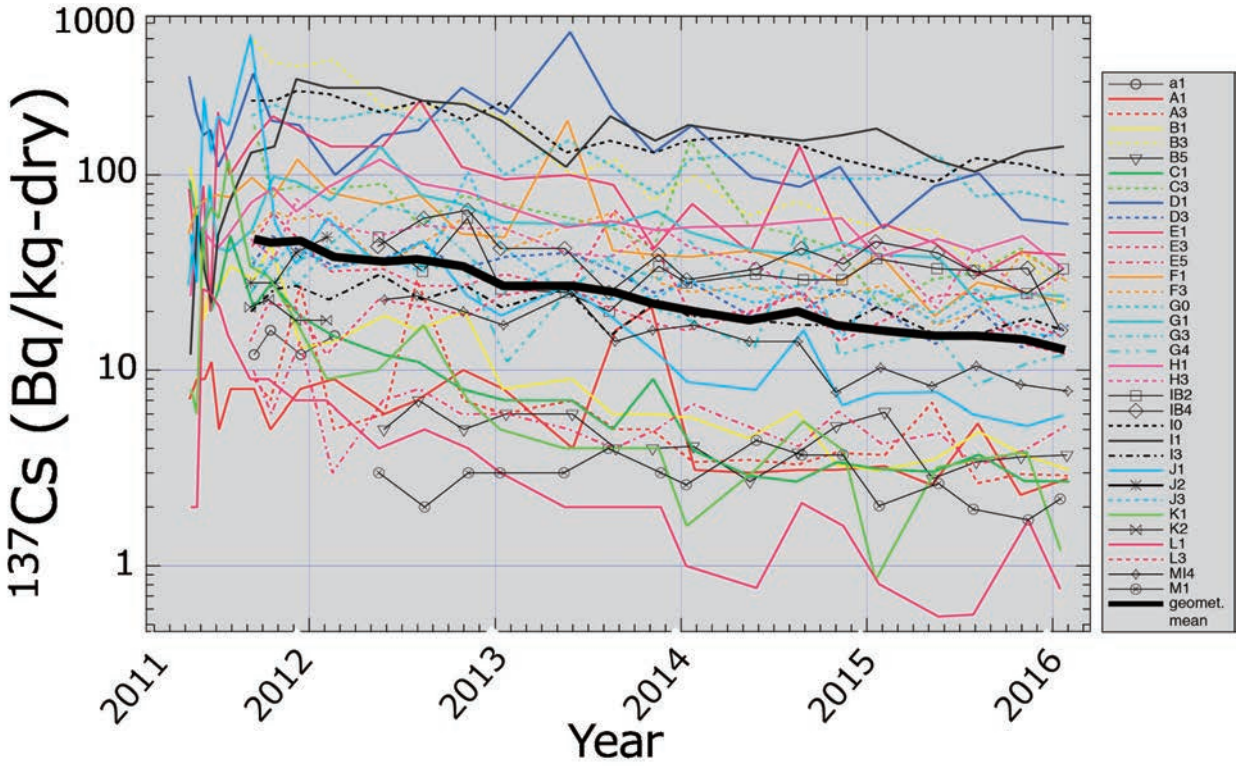

Fig.10 Temporal variations in ^{137}Cs concentrations in sediment samples (0-3 cm depth) collected from the seabed of the marine monitoring area offshore of the FDNPP. Bold (black) line indicates the geometric mean value of all measurement points collected during each sampling cruise.

months after the FDNPP accident, with subsequent sampling conducted at 2- to 3-month intervals. Concentrations of ^{137}Cs were highest at each station in September 2011 (8.0–580 Bq/kg-dry), with almost all samples having concentrations exceeding the 5-year pre-accident average (2.1 Bq/kg) for coastal regions of Japan. However, concentrations declined exponentially during 2011–2016.

Spatiotemporal variations in ^{137}Cs concentrations from May 2011 to January/February 2016 are shown in Figures 9 and 10. Concentrations varied considerably with sampling date over the first half-year, but there was generally much less temporal variation in concentrations. There was no obvious correlation between ^{137}Cs concentration and the proximity of the sampling location to the accident site; for example, the lowest ^{137}Cs concentrations occurred off Miyagi Prefecture in the north and off Chiba Prefecture in the south (stations A1, A3, L1 and L3). Close proximity of a sampling station to FDNPP did not necessarily result in a high ^{137}Cs concentration; between May and July 2011, when sampling was restricted to areas relatively close to the coast, concentrations were higher at the northern stations (e.g., B1, C1 and D1) than at the other stations, and they were also consistently high at stations D1, E1, G0, I0, I1 and J1 (Kusakabe *et al*., 2013). High concentrations (100–200 Bq/kg-dry) were subsequently observed at stations D1, E1, G0, I0 and I1. In contrast, concentrations at station B3, in Sendai Bay, exhibited a decreasing trend, thought to be caused by the lateral transport of surface-layer ^{137}Cs down through the water column and into the bottom sediments, and/or because of bioturbation of sediments (Kusakabe, 2014).

Despite sporadic peaks at each station, the geometric mean of the ^{137}Cs concentration has decreased steadily, from 47 Bq/kg in September 2011 to 13 Bq/kg in January/February 2016. Cs-137 penetrates sediments to depths beyond 3 cm from the sediment surface, and thus may have been transported from the surface layers (Black and Buesseler, 2014; Buesseler, 2014; Otosaka

and Kato, 2014). Desorption/dissolution of ^{137}Cs from sediments is believed to occur at a much lower rate than adsorption does; concentrations would therefore decrease more slowly in sediments than in seawater. For this reason, monitoring of radiocesium levels in marine sediments should remain a top priority.

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Rep. Mar. Ecol. Res. Inst., No.22 (Supplement), 27-36, 2017

Special Report: “Radioactivity in the Marine Environment and in Fisheries Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident”

Trend of Radioactivity in Fisheries Products

Mizurou Yokota*[1§], Takayuki Watanabe*[1], Hirotaka Nomura*[1], Yutaka Akimoto*[1] and Hiromitsu Onchi*[1]

Abstract: We measured activities of radioactive cesium (^{134}Cs and ^{137}Cs) in fisheries products (38,241 samples, 355 species) obtained from September 2011 to March 2016. The samples were caught in marine areas off Eastern Honshu Japan, but not including areas off Fukushima Prefecture, and from freshwater areas in Eastern Honshu, but not including Fukushima Prefecture. Activities that exceeded the national standard limit (100 Bq/kg) were detected in some samples of marine organisms from the Pacific Ocean off eastern Japan from Aomori Prefecture to Chiba Prefecture, and of freshwater organisms in areas of eastern Japan likely affected by surface contamination of radioactive substance. Of all the samples, the percentage containing radioactive cesium concentration above the national standard limit has declined over time since the March 2011 disaster at the Fukushima Dai-ichi nuclear power plant. This percentage has been 0% for marine products since September 2014 and less than 1% for freshwater products since October 2015.

Keywords: radioactive cesium, fisheries products, marine areas, freshwater areas, Fukushima, nuclear power plant

Introduction

The March 2011 accident at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) contaminated marine areas near Japan with airborne radioactive materials and/or radioactive substance-contaminated runoff. The accident led to detection of radioactive cesium (^{134}Cs and ^{137}Cs) in some commercial fish. When radioactive cesium enters an organism’s body, it tends to take in the muscle and other edible parts. This tendency makes monitoring radioactive cesium activities in marine and freshwater organisms an urgent task from the standpoint of food safety. The standard limit of the Japanese Ministry of Health, Labour, and Welfare for radioactive cesium in general food products was set at 100 Bq/kg on 1 April 2012. The Marine Ecology Research Institute (MERI) has been commissioned by the Japanese Fisheries Agency with the task of surveying the effects of radioactive substances in fisheries products collected from marine areas off Eastern Honshu in Japan (not including those off Fukushima Prefecture, where commercial fisheries have voluntary suspended operations since the nuclear disaster) and freshwater areas in Eastern Honshu (but not including those in Fukushima Prefecture). We began these surveys in September 2011 and they continue to the present day. The results of these surveys have been published on the website of the Fisheries Agency (Fisheries Agency, 2016), and trends in radioactive cesium activities in commercial fish up to March 2015 have been reported by Yokota *et al*. (2013, 2014, 2015a, 2015b). In this report, we describe the trends in radioactive cesium activities in fisheries products from marine and freshwater areas up to March 2016.

Methods

Survey

The fisheries products were collected by 14

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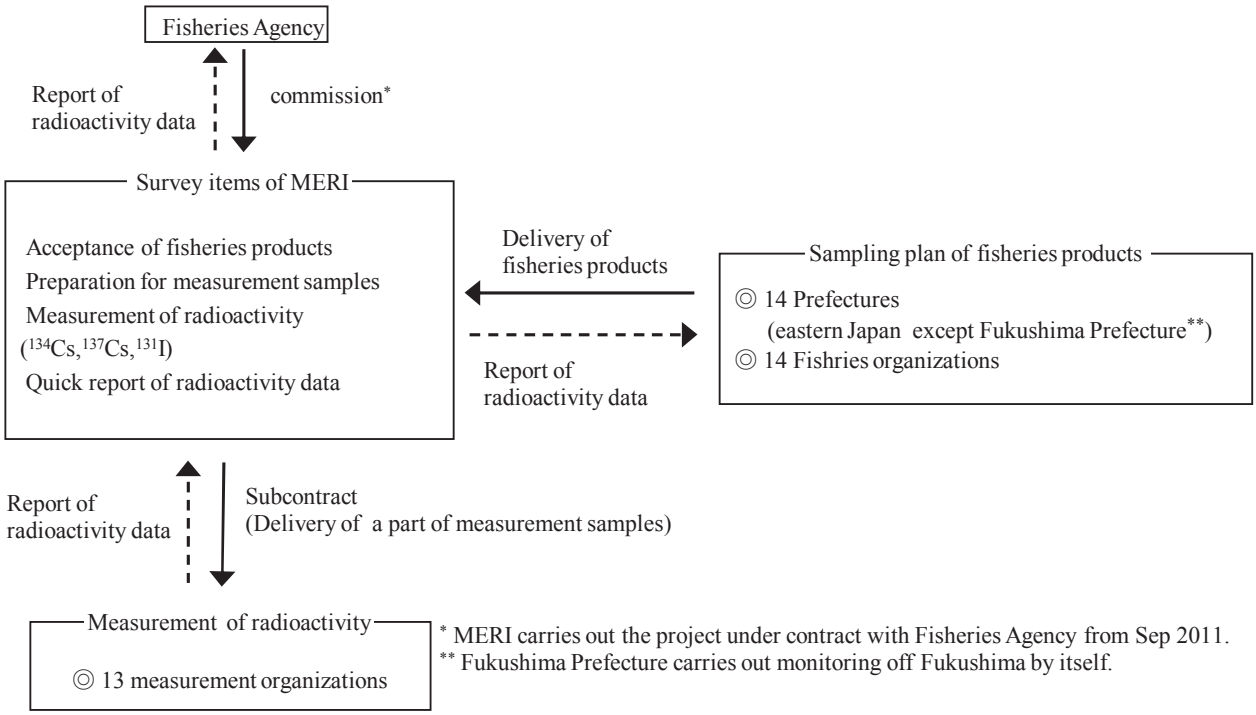


Fig.1 Flow of the project commissioned by Fisheries Agency.

Fisheries Organizations and 14 prefectures in eastern Japan. The samples were then sent to the MERI Central Laboratory in accordance with the collection plans of these groups (Fig.1). The fisheries products were first minced in sample preparation rooms and then sent to the analysis office in the Central Laboratory or to outside institutes for analysis of radioactivity. MERI quickly notified the relevant entities of the results of fisheries products analyses, which were then released to the public. MERI analyzed and summarized the effects of radioactive substances on fisheries products based on the data.

Analytical methods

After identifying the species of each fish, its muscle, liver, ovaries, testes, and other edible parts were collected (Fig.2). In principle, the edible parts from several individuals were mixed together and minced to produce a fresh sample for analysis. Some of the sample were sent to outside institutes for radioactivity analysis. In principle, about 2,000 g of a sample was placed in a 2-L Marinelli container. If this was not possible, about 100 g were placed in a 100-mL U-8 container.

Radioactivity analyses were performed by gamma-ray spectrometry using a germanium semiconductor detector (SEIKO EG&G Co. or Canberra Japan KK.) to measure the activities of ^{134}Cs (half-life of about 2 years) and ^{137}Cs (half-life of about 30 years) in the samples. In principle, radioactivities were calculated per kg of wet weight (Bq/kg-wet), except for seaweeds, which were sent in a dried state (Fig.3). The methods of analysis of the Japanese Ministry of Education, Culture, Sports, Science, and Technology (1992) were followed. In principle, analyses were performed within 24 hours after delivery to an analytical institute. The measurements of radioactivity took one hour for both the 2-L Marinelli containers and the 100-mL U-8 containers.

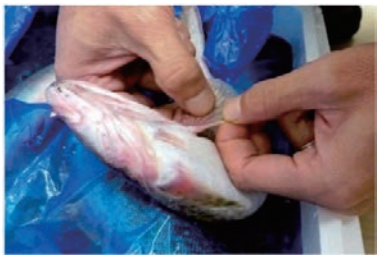
Results and Discussion

Marine organisms

Of the 30,059 samples (313 species) that underwent radioactivity analyses from September 2011 to March 2016, radioactive cesium activities exceeding

1. Acceptance of fisheries products

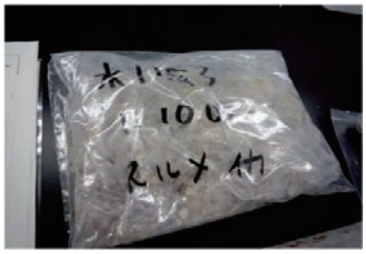
4. Extraction of edible part



2. Identification of fish species

5. Mincing of edible part

3. Mesurement of length and weight of fisheries products



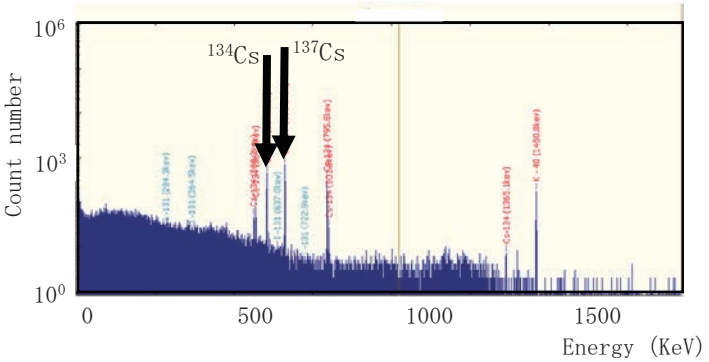
6. Sample for measurement of radioactivity

Fig.2 Preprocessing to analyze the radioactivity of fisheries products.

1. Packing minced sample to a container

2. Setting a sample to γ-ray detector

3. Counting γ activity



4. An example of γ spectrum of a sample

Fig.3 Radioactivity measurement.

Table 1 The number of sample of marine products with $^{134+137}$Cs concentration of >100Bq/kg-wet. Data from the Fukushima offshore were excluded. Measurement samples in Sep 2011 - Mar 2016 were used for data analysis.

Type of fisheries products	Measurement part	The number of samples with >100 Bq/kg-wet	The total number of samples of five years
Fish	Muscle	62	23,586
	Whole	-	1,191
	Liver	-	890
	Testicle	-	205
	Ovary	-	451
	Heart	-	3
	Mixture	-	54
Squid	Muscle	-	917
	Whole	-	5
	Liver	-	81
Octopus	Muscle	-	633
Shrimp	Muscle	-	117
Crab	Whole	-	7
	Mixture	-	187
Squilla	Muscle	-	15
Shellfish	Muscle	-	210
	Soft body part	-	522
Sea cucumber	Muscle	-	29
Urchin	Gonad	-	30
Ascidian	Muscle	-	300
Krill	Whole	-	100
Mysid shrimp	Whole	-	1
Seaweed	Whole	-	431
Whale	Muscle	-	84
Other	Fish meal	-	6
	Fish oil	-	2
	Broth	-	2
Total		62	30,059

"-" represents no samples exceeded the 100 Bq/kg-wet level.

100 Bq/kg-wet were detected in the muscle of 62 fish samples (15 species) (Table 1). Apart from fish, radioactive cesium activities exceeding 100 Bq/kg-wet were not detected in any other marine organism, including species of squid, octopus, shrimp, crab, mantis shrimp, shellfish, sea cucumbers, sea urchins, ascidians, krill, Mysidacea, seaweeds, and whales.

Marine fish with radioactive cesium activities exceeding 100 Bq/kg-wet were collected in coastal areas on the Pacific Ocean side of eastern Japan (not including Fukushima), including Aomori, Iwate, Miyagi, Ibaraki, and Chiba prefectures (Fig.4). Most of the samples (58 of 62) of marine fish with radioactive cesium activities exceeding 100 Bq/kg-wet were collected off Miyagi and Ibaraki prefectures, which border on Fukushima (Table 2). All 15 species with

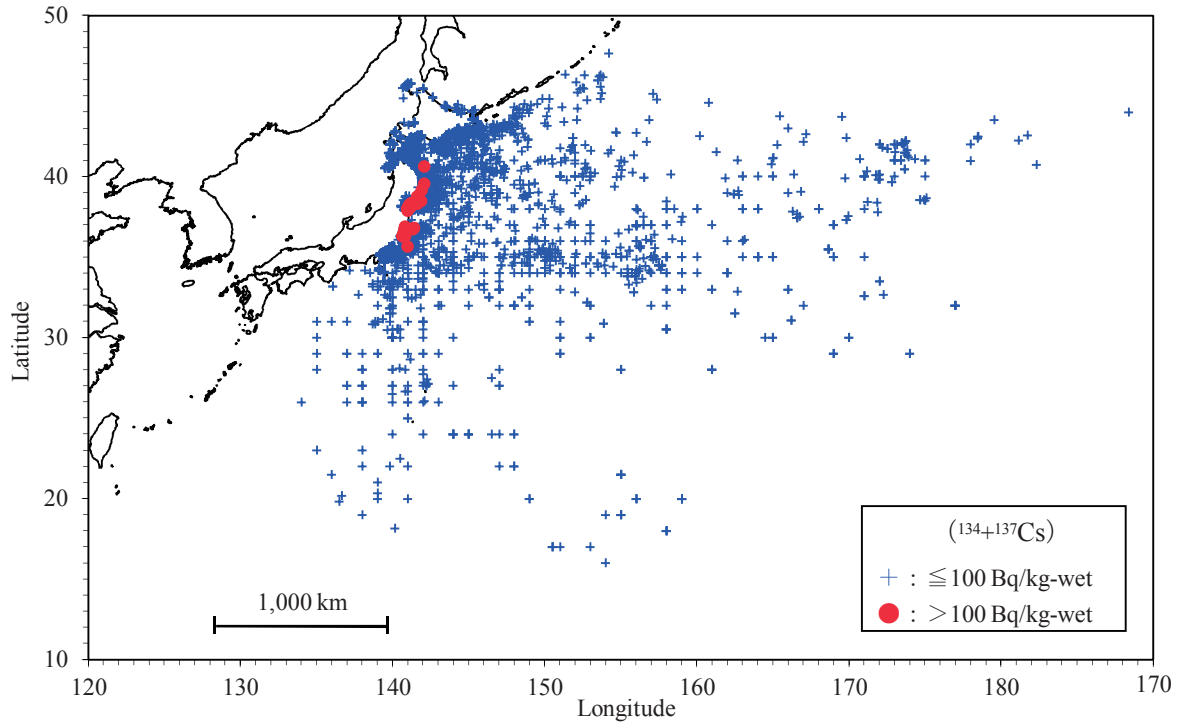


Fig.4 Distribution of radiocesium concentration in marine products (Sep 2011 - Mar 2016). Data from the waters off Fukushima Prefecture were excluded.

Table 2 Marine products with $^{134+137}$Cs concentration of >100Bq/kg-wet. Data from the Fukushima offshore were excluded. Measurement samples in Sep 2011 - Mar 2016 were used for data analysis.

Fish species	Offshore area					The total number of >100 Bq/kg-wet (The total number of samples)	Maximum value (Bq/kg-wet)
	Aomri	Iwate	Miyagi	Ibaraki	Chiba		
Acanthopagrus schlegelii	-	-	16	-	-	16 (188)	3,300
Lateolabrax japonicus	-	-	7	7	1	15 (1,667)	1,000
Okamejei kenojei	-	-	-	3	-	3 (379)	520
Paralichthys olivaceus	-	-	5	2	-	7 (2,034)	400
Sebastes schlegelii Hilgendorf	-	1	-	-	-	1 (209)	400
Microstomus achne	-	-	-	1	-	1 (612)	260
Pseudopleuronectes yokohamae	-	-	-	2	-	2 (835)	180
Hexagrammos otakii	-	-	-	1	-	1 (642)	170
Sebastes cheni	-	-	-	1	-	1 (147)	170
Gadus macrocephalus	1	-	4	3	-	8 (5,367)	160
Takifugu pardalis	-	-	1	-	-	1 (183)	140
Nibea mitsukurii	-	-	-	3	-	3 (129)	130
Sebastes thompsoni	-	-	-	1	-	1 (147)	120
Seriola quinqueradiata	-	1	-	-	-	1 (655)	110
Oncorhynchus kisutch	-	-	1	-	-	1 (37)	110
Total	1	2	34	24	1	62 (13,231)	

"-" represents no samples exceeded the 100 Bq/kg-wet level.

radioactive cesium activities exceeding 100 Bq/kg-wet appear in coastal areas shallower than 30 m. Moreover, the two species that exhibited radioactive cesium activities of 1,000 Bq/kg-wet or higher, *Acanthopagrus schlegelii* and *Lateolabrax japonicas*, can migrate to the brackish waters of rivers. The presence of high radioactive cesium activities in *A. schlegelii* and *L. japonicus* was likely influenced by the fact that the concentration factor of cesium is about 25 times higher in freshwater fish than in marine fish (IAEA, 2010). It may therefore be more difficult for fish in brackish areas to eliminate radioactive cesium.

The radioactive cesium activities detected in marine organisms collected off the Pacific Ocean side of Eastern Honshu (not including Fukushima) from April 2011 to March 2016 decreased over time. None of the samples has exhibited radioactive cesium activities exceeding 100 Bq/kg-wet since September 2014, and the radioactive cesium activities of most samples have fallen to 50 Bq/kg-wet or lower (Fig.5). Furthermore, the monthly percentage of samples with radioactive cesium activities exceeding 100 Bq/kg-wet (mean number of samples tested per month: 500) decreased from about 10% soon after the FDNPP accident to 0% in September 2014 (Fig.6).

Freshwater organisms

Of the 8,182 samples (42 species) that underwent radioactivity analysis from September 2011 to March 2016, radioactive cesium activities exceeding 100 Bq/kg-wet were detected in the muscle or whole bodies of 209 fish samples (15 species) (Table 3). Apart from fish, radioactive cesium activities exceeding 100 Bq/kg-wet were not detected in any other freshwater organisms, including species of shrimp, crab, and shellfish.

After radioactive substances emitted into the atmosphere from the FDNPP were deposited on the

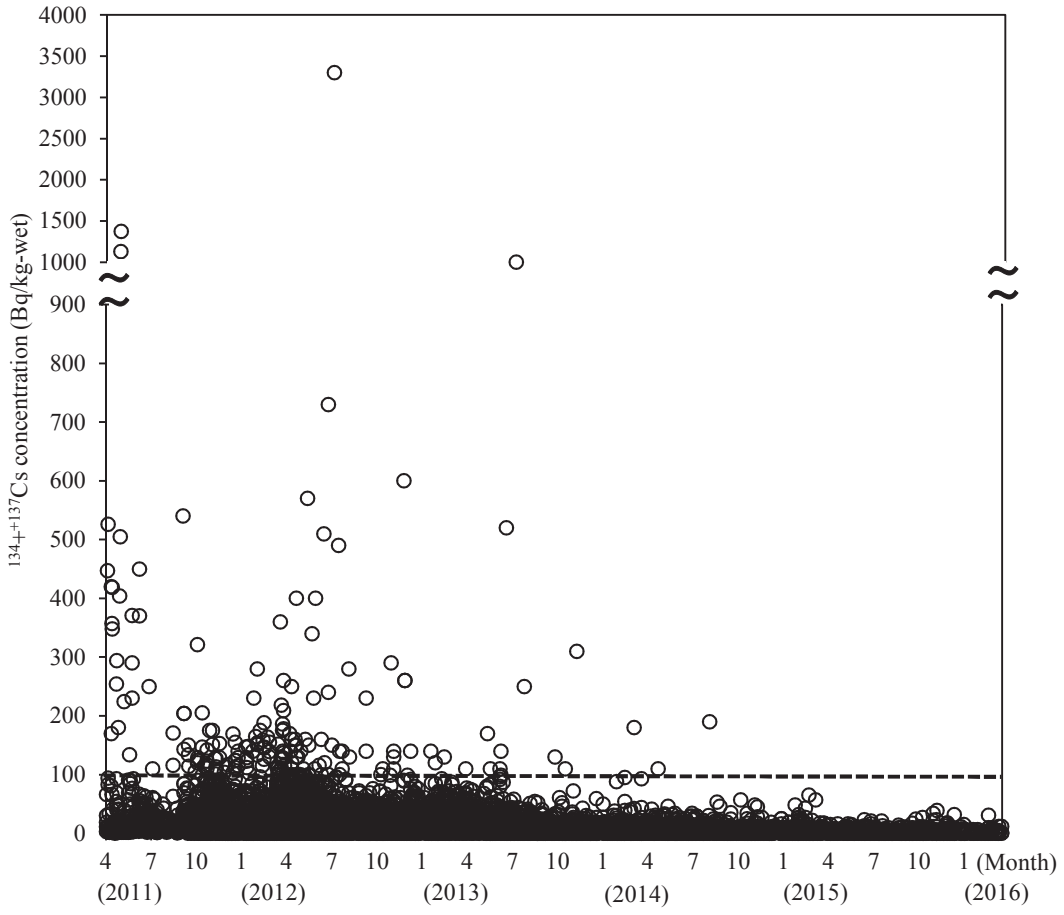


Fig.5 Temporal change of $^{134+137}$Cs concentration in marine products caught in the Pacific area of eastern Japan. Data adapted from Fisheries Agency (2016).

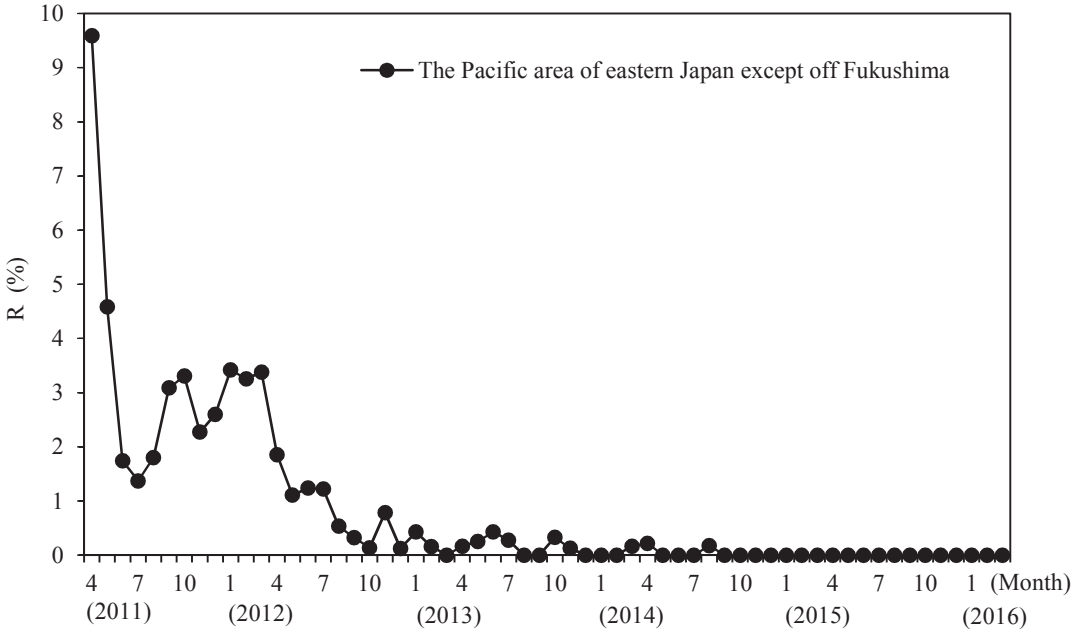


Fig.6 Temporal change of ratio (R) of samples with >100 Bq/kg-wet. The ratio were calculated based on the following equation using data adapted from Fisheries Agency (2016); R (%) = [The number of samples with concentration of >100 Bq/kg-wet] / [The number of all samples] x 100.

Table 3 The number of sample of freshwater products with $^{134+137}$Cs concentration of >100Bq/kg-wet. Data from the Fukushima offshore were excluded. Measurement samples in Sep 2011 - Mar 2016 were used for data analysis.

Type of fisheries products	Measurement part	The number of samples with >100 Bq/kg-wet	The total number of samples of five years
Fish	Muscle	180	5,400
	Whole	29	2,236
Shrimp	Whole	-	163
Crab	Whole	-	35
	Mixture	-	6
Shellfish	Soft body part	-	341
Softshell turtle	Whole	-	1
Total		209	8,182

"-" represents no samples exceeded the 100 Bq/kg-wet level.

ground, spatial radiation dose rates measured at a height of 1 m that exceeded 0.1 μSv/h were found over an extensive area (Japan Map Center et al., 2016). Freshwater fishes with radioactive cesium activities exceeding 100 Bq/kg-wet were collected from freshwater areas in Iwate, Miyagi, Ibaraki, Tochigi, Gunma, Chiba, Saitama, and Kanagawa prefectures of eastern Japan (Table 4). Samples with radioactivities exceeding 100 Bq/kg-wet were not collected from freshwater areas in prefectures on the Sea of Japan side, where there was little fallout of the airborne radioactive substances after the nuclear disaster. The distribution of radioactive cesium activities exceeding 100 Bq/kg-wet in freshwater fish was largely consistent with spatial radiation dose rates near the surface (Fig.7).

Sixty-six of the 209 freshwater fish samples with

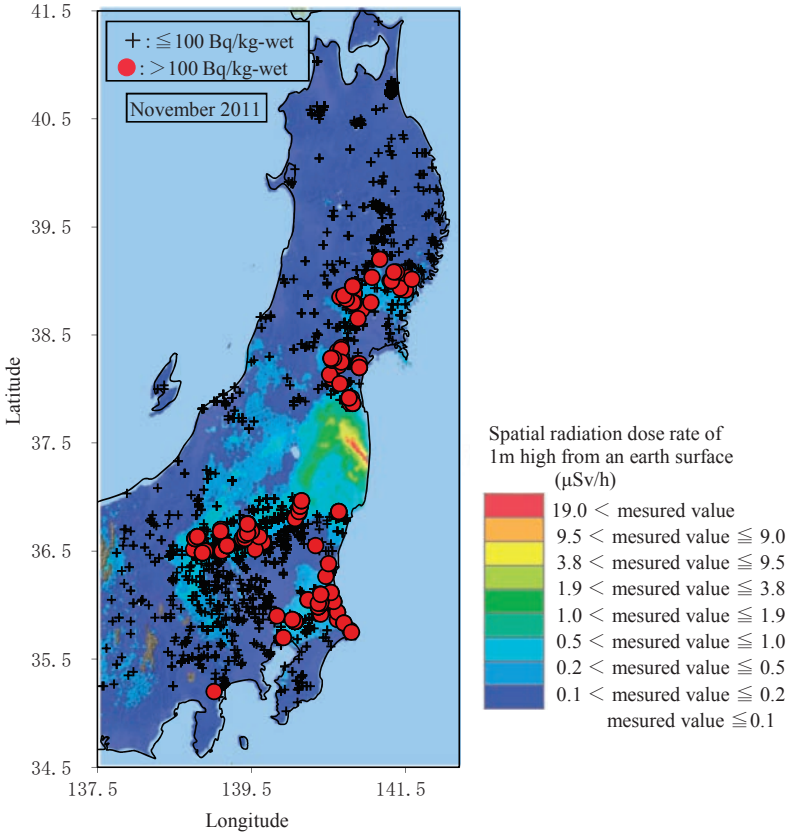


Fig.7 Distribution of radiocesium concentration in freshwater products (Apr 2012 - Mar 2016). Data from Fukushima Prefecture were excluded. Spatial radiation dose rate (Japan Map Center et al., 2016) were measured at 1m high from an earth surface at Nov 2011.

Table 4 Freshwater products with $^{134+137}$Cs concentration of >100Bq/kg-wet. Data from the Fukushima Perfecture were excluded. Measurement samples in Sep 2011 - Mar 2016 were used for data analysis.

Fish species	Prefecture								The total number of >100 Bq/kg-wet (The total number of sumples)	Maximum value (Bq/kg-wet)
	Iwate	Miyagi	Ibaraki	Tochigi	Gunma	Chiba	Saitama	Kanagawa		
Oncorhynchus masou masou	2	-	2	2	12	-	-	-	18 (1,536)	490
Salvelinus leucomaenis	7	18	2	14	18	-	-	-	59 (1,044)	460
Carassius auratus langsdorfii	-	-	5	-	-	17	-	-	22 (315)	400
Hypomesus nipponensis	-	-	-	-	19	-	-	-	19 (482)	370
Cyprinus carpio	-	-	-	-	-	10	-	-	10 (137)	330
Ictalurus punctatus	-	-	20	-	-	-	-	-	20 (46)	320
Tribolodon hakonensis	12	1	-	4	-	-	-	-	17 (970)	310
Salmo trutta	-	-	-	11	-	-	-	-	11 (12)	260
Anguilla japonica	-	1	13	-	-	6	-	-	20 (1,255)	200
Pseudorasbora parva	-	-	-	-	-	2	-	-	2 (143)	170
Plecoglossus altivelis	-	4	-	-	-	-	-	-	4 (894)	140
Oncorhynchus nerka	-	-	-	4	-	-	-	-	4 (50)	140
Silurus asotus	-	-	-	-	-	-	1	-	1 (13)	130
Oncorhynchus mykiss	-	-	-	1	-	-	-	-	1 (245)	120
Micropterus salmoides	-	-	-	-	-	-	-	1	1 (8)	110
Total	21	24	42	36	49	35	1	1	209 (7,150)	

"-" represents no samples exceeded the 100 Bq/kg-wet level.

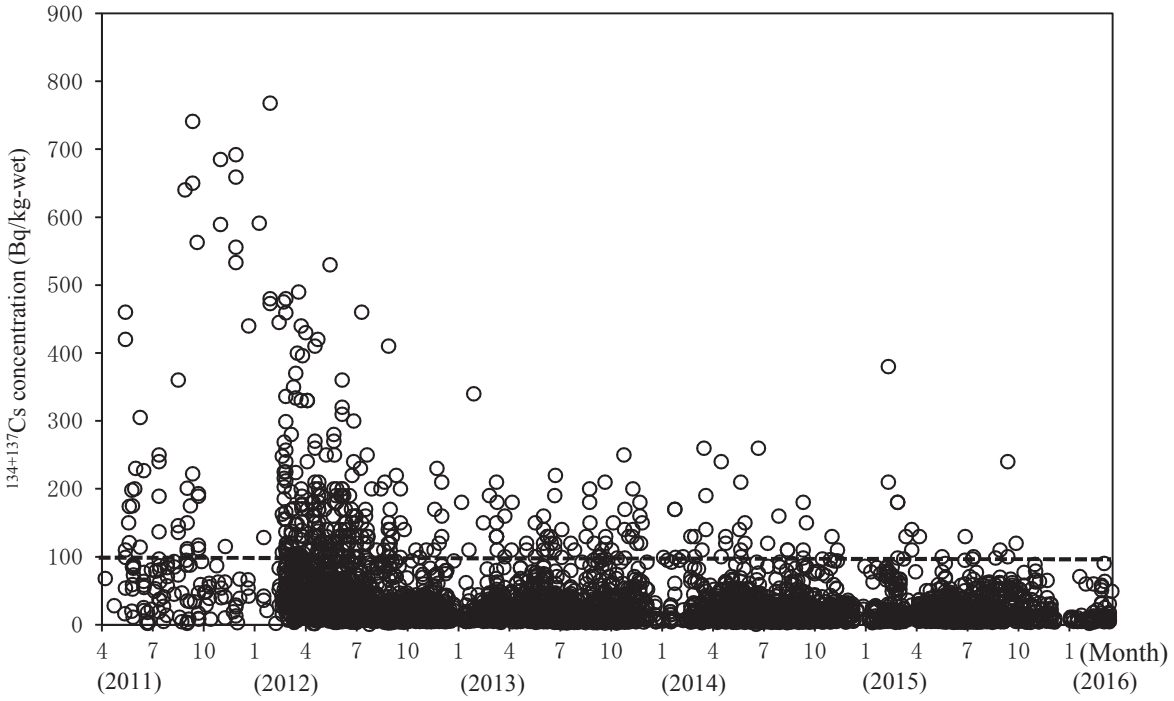


Fig.8 Temporal change of $^{134+137}$Cs concentration of freshwater products caught in eastern Japan. Data adapted from Fisheries Agency (2016).

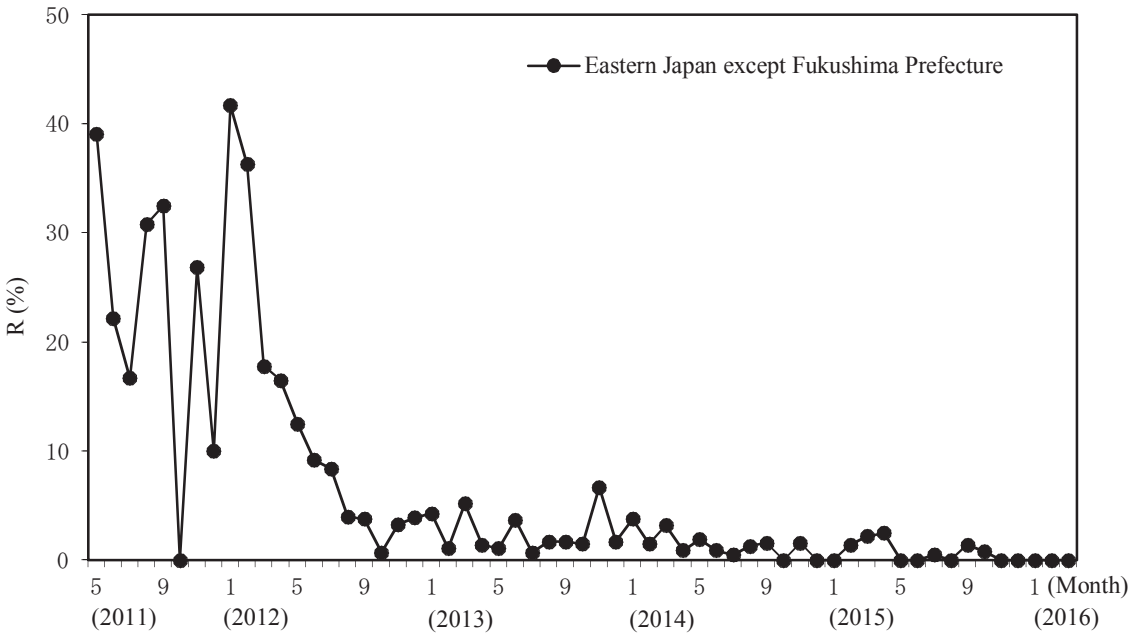


Fig.9 Temporal change of ratio (R) of samples with >100 Bq/kg-wet. The ratio were calculated based on the following equation using data adapted from Fisheries Agency (2016); R (%) = [The number of samples with concentration of >100 Bq/kg-wet] / [The number of all samples] x 100.

radioactive cesium activities exceeding 100 Bq/kg-wet were collected from Miyagi and Ibaraki prefectures, which border on Fukushima; the other 143 samples were obtained from prefectures that do not border Fukushima (Table 4). Of the 15 freshwater fish species with radioactive cesium activities exceeding 100 Bq/kg-wet, 9 species were collected from enclosed waters such as lakes and marshes; 5 species were collected from rivers; and 1 species was collected from both lake/marsh and river environments. The highest radioactive cesium activity measured during the survey was 490 Bq/kg-wet in a specimen of *Oncorhynchus masou* collected from a river.

Radioactive cesium activities detected in freshwater organisms collected in the freshwaters of Eastern Honshu (not including Fukushima) from April 2011 to March 2016 decreased over time. None of the samples has exhibited a radioactive cesium activity exceeding 100 Bq/kg-wet since October 2015, and most of the samples have fallen to 50 Bq/kg-wet or lower (Fig.8). Furthermore, the monthly percentage of samples with radioactive cesium activities exceeding 100 Bq/kg-wet (mean number of samples tested per month: 150) decreased from about 40% soon after the FDNPP accident to below 1% in October 2015 (Fig.9).

Acknowledgements

Data collected from the project commissioned by the Fisheries Agency to survey radioactive substances in fisheries products from 2011 to 2015 were used in this report. We thank the Fisheries Agency, which commissioned the project, and prefectural governments and fisheries organizations for providing the fisheries products used to analyze radioactive substances.

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Special Report: “Radioactivity in the Marine Environment and in Fisheries Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident”

Current Fishery Activities and Levels of Radioactivity in Fisheries Products from Fukushima Prefecture

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Abstract: We surveyed the levels of radioactivity in marine organisms from Fukushima Prefecture, where the Fukushima Daiichi Nuclear Power Plant accident occurred in March of 2011. In June of 2012, fishing trials were initiated for safe species to evaluate the commercial distribution of harvested fish. Over time, the number of targeted species, fishing methods, and fishing areas have increased, and in June of 2016 fishing trials were being conducted for 73 species along the shores of Fukushima Prefecture beyond a distance of 20 km from the Fukushima Daiichi Nuclear Power Plant. Immediately after the Fukushima accident, radioactive cesium (^{134}Cs and ^{137}Cs) activities of at least 100 Bq/kg-wet were detected in many species. However, those activities declined significantly during the five years following the accident. Since April of 2015, radioactive cesium activity has not exceeded the national standard limit (100 Bq/kg), and since July of 2015, the radioactive cesium activities of over 90% of the samples have been below the detection limit. Continuation of the fishing trials, collection and analysis of the scientific data, and sharing of information will all be necessary to reassure distributors and consumers of the safety of commercial fish. In addition, reconstruction of the production and distribution systems for commercially important marine fish is urgently needed to end the current suspension of fishing activities.

Keywords: Fukushima Prefecture, fishing trials, radioactivity

Introduction

Following the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident in March of 2011, radioactive substances were detected in commercial fish harvested from the coastal areas of the Fukushima Prefecture. As a result, the coastal fisheries of Fukushima Prefecture (including the offshore trawl fishery) voluntarily suspended fishing activities and were continuing to do so as of June 2016. Starting immediately after the accident, Fukushima Prefecture began monitoring the levels of radioactivity in commercially important marine fish and evaluating the extent of contamination. Based on the results, a fishing trial was initiated targeting fish species that had been confirmed to be safe. The impact of the accident decreased over time, and the targeted species, fishing methods, and fishing areas have been gradually expanded. As of June 2016, the number of targeted species had increased from the initial 3 to 73. Here, we report the levels of radioactivity in commercially important fish and discuss the efforts of Fukushima Prefecture and members of the fishing industry to restore the fishing industry. Finally, we discuss future challenges.

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Levels of radioactivity in commercial fish

Methods

The sampling of commercial fish from Fukushima Prefecture began on 7 April 2011. Widespread sampling was conducted under the auspices of the Fukushima Prefectural Federation of Fisheries Co-operative Associations (FPFFCA) with the support of fishermen from each coastal fishery cooperative. Periodic monthly sampling was conducted using a research vessel from the Fukushima Prefectural Fisheries Experimental Station (FPFES), and fishermen collected species of fish available throughout the entire region offshore of Fukushima Prefecture with fishing methods that had been in use before the earthquake that caused the accident. Meanwhile, an FPFES research vessel collected trawl samples once a month as a rule at survey locations. Until 30 September 2011, the area within 30 km of the FDNPP was designated an emergency evacuation preparation area, within which no samples could be collected. This restriction was subsequently withdrawn, and the survey areas were expanded accordingly. After April of 2013, sampling of commercial fish was conducted along the entire length of Fukushima Prefecture, except for the region within 5 km of the FDNPP. Within that 5-km radius, the Tokyo Electric Power Company monitored the state of environmental contamination and published the results.

Sampled marine organisms were brought to the FPFES, and after measuring the body size of individuals and recording the stomach contents of fish, the edible portions of each organism were collected as samples. For example, because whitebait and greeneyes *Chlorophthalmus albatrossis* are eaten whole, the surfaces of the fish were washed, and the whole bodies of the specimens, including their internal organs, were treated as samples. In contrast, fish such as Japanese flounder *Paralichthys olivaceus* are usually eaten as sashimi, and therefore only the muscle tissue of the specimens was used. To avoid underestimating contamination when samples were combined and to quantify the variability of contamination between individual specimens, individuals from which at least 100 g of muscle could be dissected were treated as separate samples. When 100 g of muscle could not be obtained from single individuals, equivalent proportions of tissue from multiple individuals were combined to obtain a total of at least 100 g of muscle tissue.

After collection, the samples were transported to a test facility*1, where the activities of ^{131}I, ^{134}Cs, and ^{137}Cs were measured using a germanium semiconductor detector. For each sample, about 100 g was placed in a U8 container, and the intensity of gamma radiation from each radionuclide was measured for 2000 seconds. Detection limits under these conditions ranged from 7 to 9 Bq/kg-wet for both ^{134}Cs and ^{137}Cs, and total radioactive cesium activities were equated to the sum of the ^{134}Cs and ^{137}Cs activities for each specimen.

Results

Figure 1 shows the number of samples of commercial fish collected each month in 2011, the percentage of samples with levels of radioactivity that exceeded the national standard limit of 100 Bq/kg, and the percentage of samples with levels of radioactivity below the detection limit. Immediately after the accident, analytical procedures were not yet firmly established, and only 100–200 samples were assayed each month. Subsequently, however, the number increased, and in 2016, around 700 samples were assayed each month. In 2011, the radioactivities of 39.8% of the samples exceeded 100 Bq/kg, but after April of 2015, no samples exceeded that limit. In 2011, the radioactivity of only 14.9% of the samples was below the limit of detection, but after July of 2015 the radioactivity of more than 90% of the samples was below the limit of detection. Thus, the impact of the nuclear accident on marine organisms was clearly decreasing.

We divided the coastal area of Fukushima Prefecture into 10 sections, which were oriented from east to west based on the position of the 50-m isobath and from north to south based on latitude. The radioactive cesium activities in marine organisms from each of the 10 sections were then summarized. From April to December of 2011, the samples were

*1 Until June of 2011, the Japan Chemical Analysis Center and Environmental Radioactivity Monitoring Center of Fukushima, Fukushima office, and subsequently the Fukushima Agricultural Technology Centre.

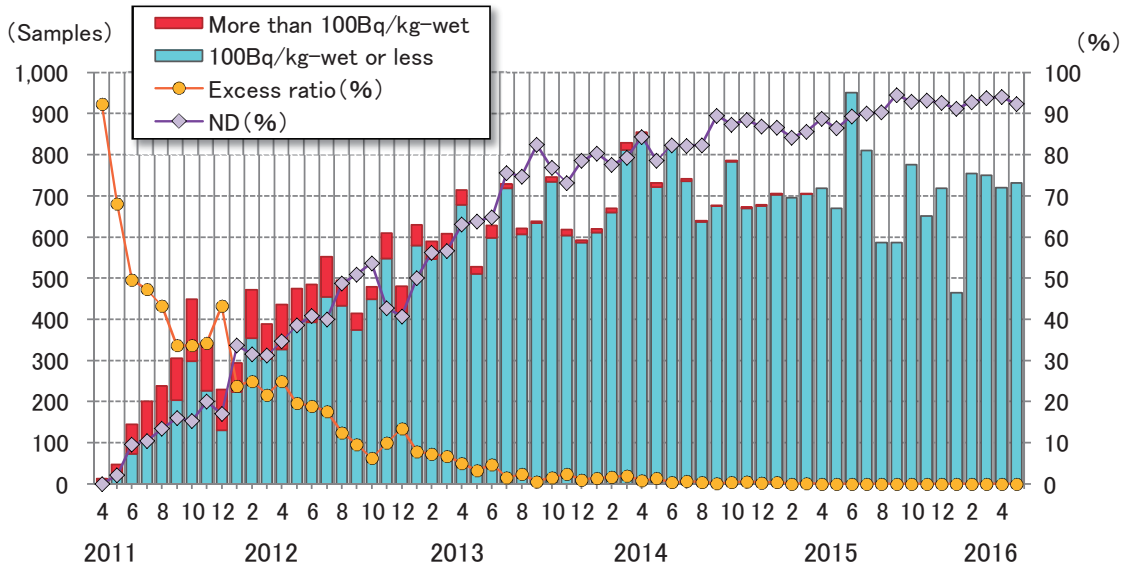

Fig.1 Monthly monitoring results.

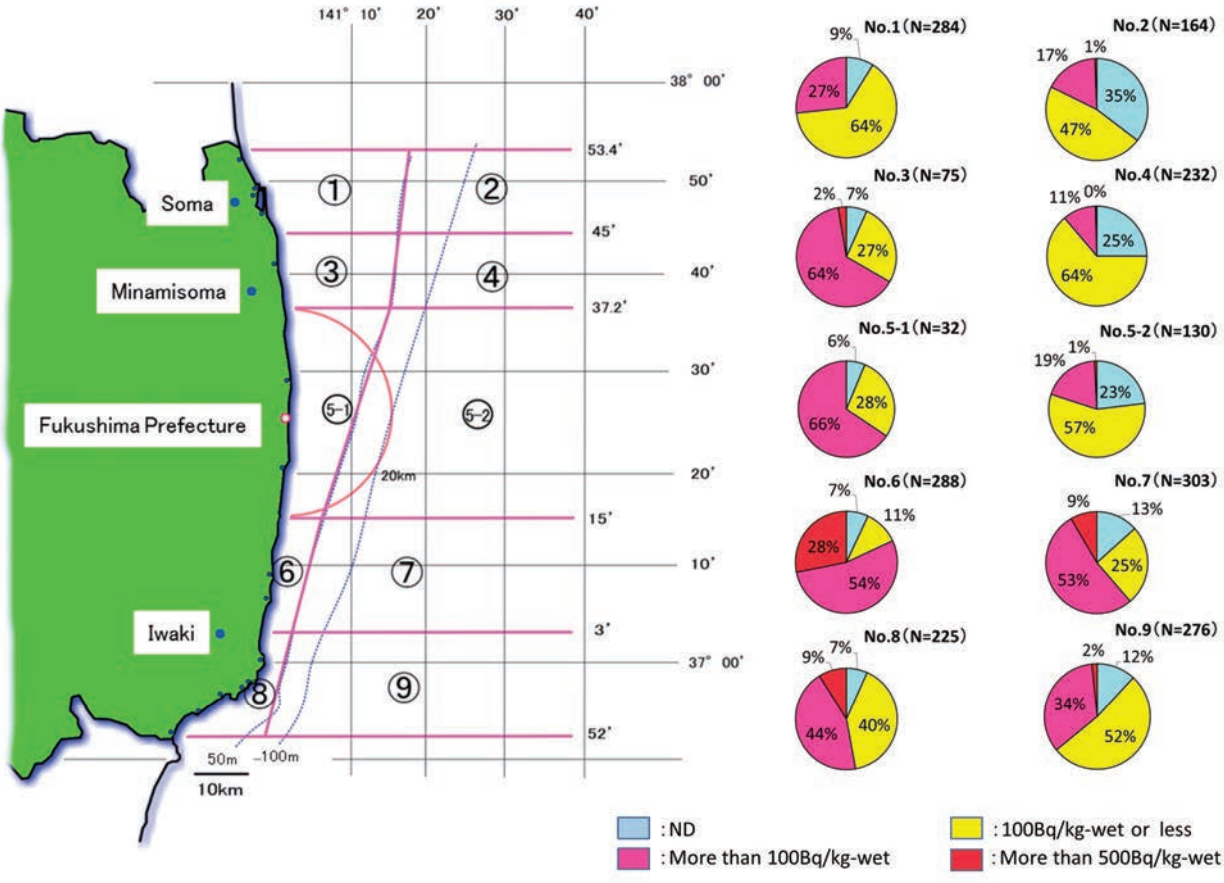

Fig.2 Radioactive cesium concentrations in each area (April to December, 2011).

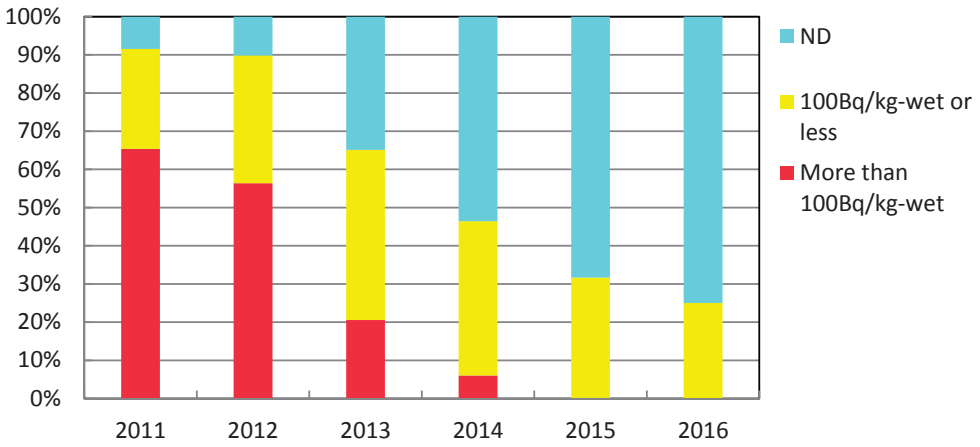

Fig.3 Radioactive cesium concentrations in each year in the area No.6.

categorized as >500 Bq/kg-wet, 100–500 Bq/kg-wet, ≤100 Bq/kg-wet, or below the limit of detection. Figure 2 shows the percentages of samples in each category for each of the 10 sampling areas. In marine area No. 6 (south of the FDNPP and in a water depth ≤50 m), the radioactivities of a high percentage of the samples exceeded 500 Bq/kg. However, the percentage of samples from the same depth interval (≤50 m) on the north side of FDNPP with radioactivities that exceeded 500 Bq/kg-wet was lower than on the south side. In addition, the percentage of radioactivities that exceeded 500 Bq/kg-wet was smaller for samples collected from water deeper than 50 m than from samples taken from shallower water. These results suggest that marine organisms from shallow water south of FDNPP were most contaminated by the accident. However, the activities of radioactive cesium tended to decrease over time, regardless of the area tested, even in area No. 6, where the percentage of samples with radioactivities exceeding 500 Bq/kg-wet was high. Furthermore, in 2016 there were no samples with radioactivities exceeding 100 Bq/kg-wet (Fig. 3).

The activities of radioactive cesium declined with time in all fish species. Cesium radioactivities, for example, were as high as 14,400 Bq/kg-wet in April 2011 in the juvenile of Japanese sand lance *Ammodytes personatus*, but they had decreased greatly by the fishing season of the following year, and after 2013 they were undetectable (Fig. 4). The cesium radioactivities in other fish, such as whitebait, also decreased rapidly with time. We suspect that this trend was related to the short generation times of the fish because less radioactive cesium accumulated in the generations of fish that were not exposed to the high levels of radioactivity immediately after the accident. In addition, the concentrations of radioactive cesium in migratory and offshore species of fish were relatively low or undetectable, even immediately after the accident (Fig, 5, 6). The cesium radioactivities in crustaceans and mollusks decreased rapidly, even in species for which the radioactivities exceeded the standard limits immediately after the accident (Fig. 7, 8).

As of 2016, the number of fish species with detectable (though low) cesium radioactivities was relatively small. The self-imposed criterion of the FPFFCA for shipment of fish is that the radioactivity be less than 50 Bq/kg-wet, which is lower than the national standard limit. In widespread sampling during 2016, the radioactive cesium activities of only rockfish

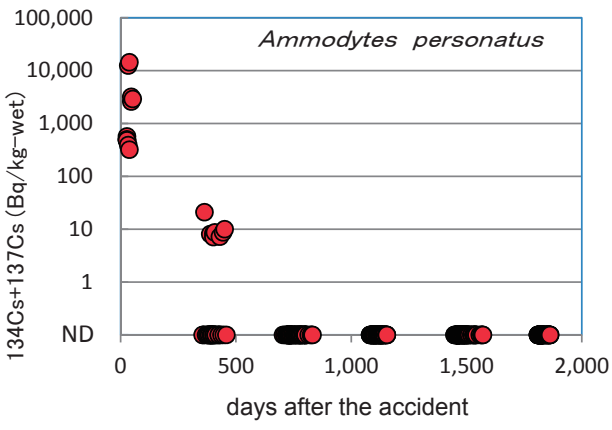

Fig.4 Changes in radioactive cesium concentrations of *Ammodytes personatus*.

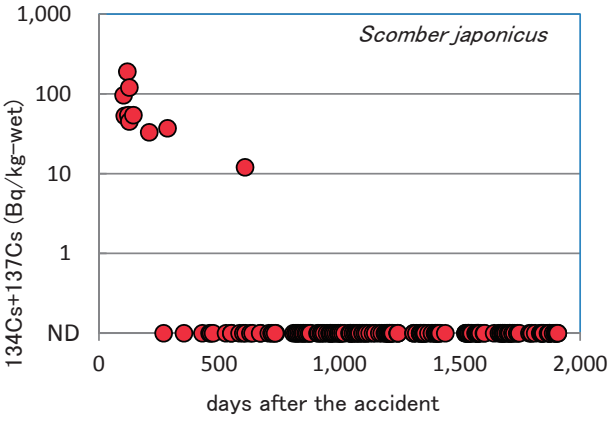

Fig.5 Changes in radioactive cesium concentrations of *Scomber japonicus*.

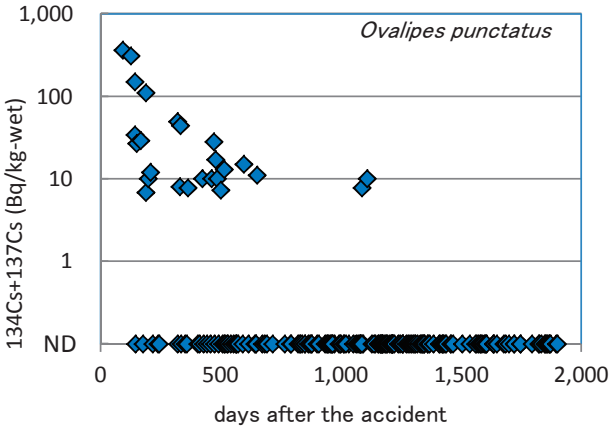

Fig.7 Changes in radioactive cesium concentrations of *Ovalipes punctatus*.

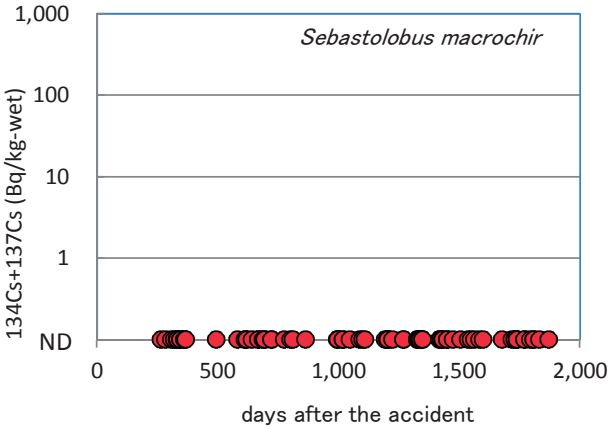

Fig.6 Changes in radioactive cesium concentrations of *Sebastolobus macrochir*.

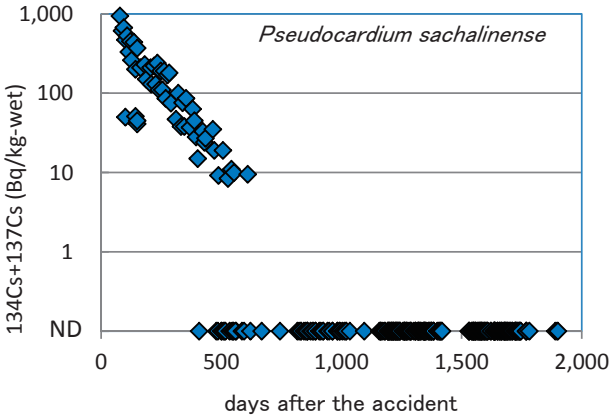

Fig.8 Changes in radioactive cesium concentrations of *Pseudocardium sachalinense*.

Table 1 Restriction on shipping and distribution (offshore Fukushima Prefecture, as of June 2016.)

Restriction on shipping and distribution					
No	Species	No	Species	No	Species
1	*Hexagrammos otakii*	10	*Sebastes schlegelii*	19	*Verasper variegatus*
2	*Cynoglossus joyneri*	11	*Acanthopagrus schlegelii*	20	*Pleuronectes yokohamae*
3	*Ammodytes personatus* （except juvenile）	12	*Okamejei kenojei*	21	*Platycephalus* sp.
4	*Kareius bicoloratus*	13	*Oncorhynchus masou*	22	*Sebastes pachycephalus pachycephalus*
5	*Sebastes thompsoni*	14	*Occella iburia*	23	*Mercenaria stimpsoni*
6	*Ditrema temminckii*	15	*Sebastes cheni*	24	*Stichaeus grigorjewi*
7	*Physiculus maximowiczi*	16	*Lateolabrax japonicus*	25	*Verasper moseri*
8	*Sebastes vulpes*	17	*Platichthys stellatus*	26	*Sebastiscus marmoratus*
9	*Paraplagusia japonica*	18	*Microstomus achne*		

Cancellation of restriction on shipping and distribution					
No	Species	Cancellation date	No	Species	Cancellation date
1	*Ammodytes personatus* （juvenile）	22 June 2012	10	*Gadus macrocephalus* ※	14 January 2015
2	*Hippoglossoides dubius*	9 October 2013	11	*Mustelus manazo*	18 February 2015
3	*Theragra chalcogramma*	17 December 2013	12	*Eopsetta grigorjewi*	24 February 2015
4	*Pleuronectes herzensteini*	16 April 2014	13	*Nibea mitsukurii*	2 April 2015
5	*Helicolenus hilgendorfi*	28 May 2014	14	*Pleuronichthys cornutus*	2 April 2015
6	*Chelidonichthys spinosus*	9 July 2014	15	*Hemitripterus villosus*	22 June 2015
7	*Strongylocentrotus nudus*	9 July 2014	16	*Takifugu pardalis*	3 December 2015
8	*Hyporhamphus sajori*	9 July 2014	17	*Paralichthys olivaceus*	9 June 2016
9	*Takifugu snyderi*	15 October 2014	18	*Conger myriaster*	9 June 2016

※ Limited area（The whole area cancellation was 24 May 2015）

Sebastes cheni, stone flounder *Kareius bicoloratus*, slime flounder *Microstomus achne*, and Japanese sea perch *Lateolabrax japonicus* exceeded the 50 Bq/kg-wet limit. Fish species that maintained detectable activities of radioactive cesium included species that inhabited areas that were severely affected by the accident and that did not move away from the areas afterward.

Future research challenges

As of late June 2016, national shipment restrictions remained for 26 commercially important marine species that occur in the coastal areas of Fukushima Prefecture (Table 1). Because many of these are important target species of coastal fisheries, shipping restrictions must be lifted to allow resumption of full-scale operations. Enhancement of the monitoring system and confirmation of the safety of these species can accelerate the lifting of these restrictions. Furthermore, in order for fishermen, distributors, and consumers to resume their respective activities with confidence, monitoring and scientific data will be needed to confirm the safety of target species, describe the phenomenon, and explain the cause. In the future, more detailed analyses should be added to current routine monitoring to assure the safety of commercial marine fish. The ecological and physiological characteristics of fish in which radioactive cesium is still detected should be quantified, and the rates of accumulation and excretion of radioactive cesium by each of these fish species should be determined.

Fig.9 Flow of decision making for the fishing trial.

Current state of fisheries

Fishing trials

Although the coastal fisheries of Fukushima Prefecture suspended their operations, a fishing trial and commercial distribution were initiated in June of 2012 for fish species that were confirmed to be safe by the prefecture's monitoring program. The main objective of the fishing trial was to determine how seafood from Fukushima Prefecture was evaluated in the distribution process. However, another objective was to assure the safety of fish from Fukushima Prefecture to consumers and brokers through distribution and sale.

Initially, the fishing trial involved an offshore trawl fishery boat that belonged to the Soma Futaba Fisheries Cooperative Association and was used to monitor North-Pacific giant octopus *Octopus* (*Enteroctopus*) *dofleini*, Chestnut octopus *Octopus* (*Paroctopus*) *conispadiceus*, and the whelk *Buccinum isaotakii*. The target area was limited to the coastal area of Soma, and to conserve resources, the bycatch of non-target species was limited by fishing at a depth >150 m. To conduct the fishing trial, which was based on the Shipment Policy of the Fishing Trial Target Species determined by the FPFFCA, the fishery cooperative of each district developed a plan for each area and fishing method. Then, after being approved by a fishing trial committee in each area (Soma, Futaba, and Iwaki), the plans were discussed by the Fukushima Prefecture Regional Fishery Recovery Council, which consists of experts from universities, distributors, and the federal and prefecture governments. Ultimately, the Prefectural Federation of Fisheries Co-operative Associations Chair Meeting approved the plans (Fig. 9).

In addition, marine commercial species that were captured during the fishing trial were gathered at (1) the Soma Haragama Regional Wholesale Market for the Soma Futaba Region and (2) the Iwaki City Regional Wholesale Market and Onahama Fish Market for the Iwaki area. At each market, each fish species was voluntarily tested on a daily basis for radioactivity

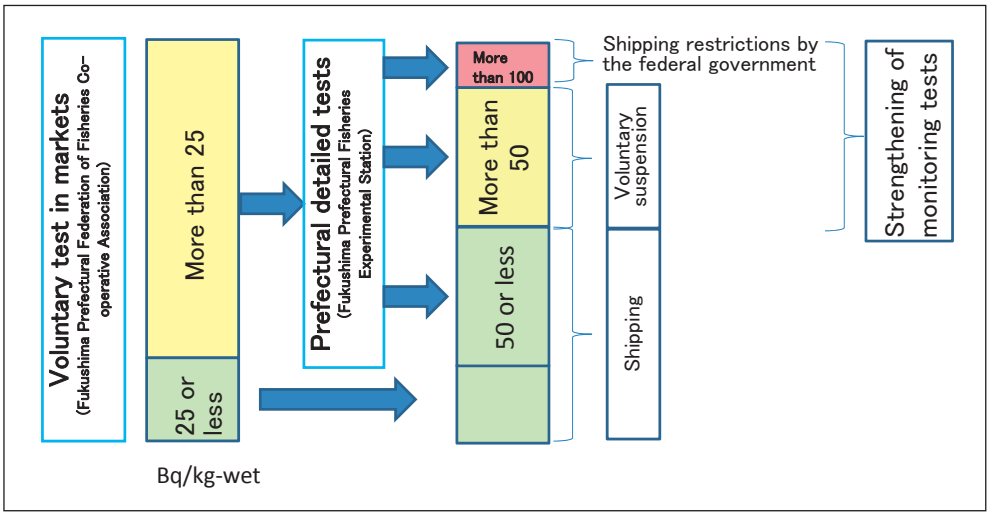

Fig.10 Voluntary test system of the Fishery Cooperative in the fishing trial.

Table 2 Sample number of voluntary test (as of March 2016)

		2012	2013	2014	2015	2016	Total
Iwaki	ND	0	71	489	812	364	1,736
	25Bq/kg-wet or less	0	2	25	23	2	52
	more than 25Bq/kg-wet	0	0	0	2	0	2
	more than 50Bq/kg-wet	0	0	1	0	0	1
	total	0	73	515	837	366	1,791
SomaFutaba	ND	149	543	1,150	1,931	548	4,321
	25Bq/kg-wet or less	1	3	6	10	1	21
	more than 25Bq/kg-wet	0	1	0	0	0	1
	more than 50Bq/kg-wet	0	0	1	0	0	1
	total	150	547	1,157	1,941	549	4,344
Total	ND	149	614	1,639	2,743	912	6,057
	25Bq/kg-wet or less	1	5	31	33	3	73
	more than 25Bq/kg-wet	0	1	0	2	0	3
	more than 50Bq/kg-wet	0	0	2	0	0	2
	total	150	620	1,672	2,778	915	6,135

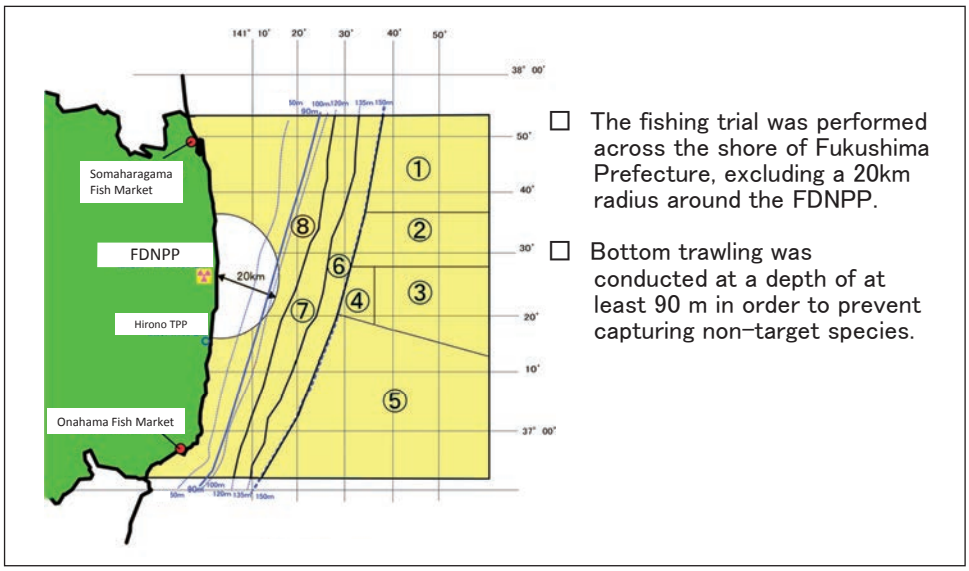

Fig.11 Trial fishing areas (as of June 2016). Numbers indicate the order of target area expansion for the bottom trawl fishery.

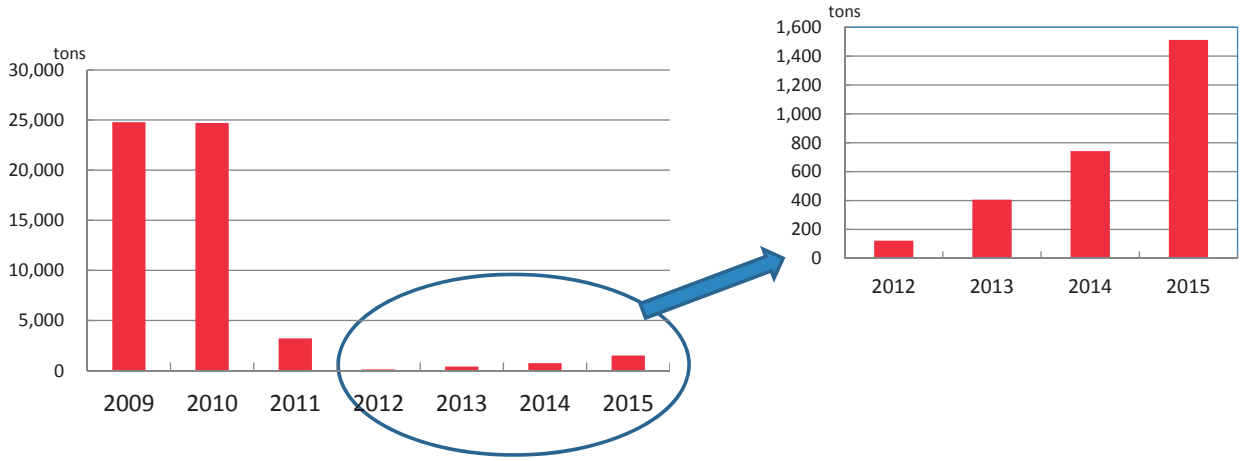

Fig.12 Catch by coastal fisheries in Fukushima Prefecture and in the fishing trial including offshore bottom trawl.

before shipping. The FPFFCA used 50 Bq/kg-wet as the self-imposed limit for shipping so that there was no chance of shipping any fish that exceeded the national standard limit of 100 Bq/kg-wet. Meanwhile, at each market, if a sample exceeded half of the self-imposed limit (i.e., 25 Bq/kg), it was shipped to the FPFES for a detailed analysis using a germanium semiconductor detector (Fig. 10). As of March 2016, 6135 samples had been voluntarily tested in the two markets. The majority of samples were below the detection limit of 12.5 Bq/kg-wet (Table 2); only five samples exceeded 25 Bq/kg-wet.

Over time, the number of fish species confirmed to be safe has increased, and as a result, the numbers of target species, target fishing methods, and target areas have gradually increased. As of June 2016, the number of target species was 73, and fishing trials were being conducted using many of the fishing methods that were used prior to the accident (e.g., trawl fishing, boat seine fishing, and gill-net fishing), but excluding angling and coastal longline fishing, which target restricted fish species. According to interviews with various fishermen's cooperatives, about 50% of the operating boats were participating in the fishing trial by the end of 2015, and 70% were participating as of June 2016. Meanwhile, the areas of the operation have been expanded to cover the whole nearshore area of Fukushima Prefecture, and although the operation has been voluntarily suspended within a 20-km radius of FDNPP (Fig. 11), discussion has begun about reducing the radius of that zone. The total catch of the fishing trial was 122 metric tons in 2012 and 1512 tons in 2015. However, this is a mere 5.8% of the 10-year average catch of 26,050 metric tons before the accident (Fig. 12).

At the beginning of 2012, harvested marine fish were shipped only to consumer markets and local retailers in urban areas of Fukushima Prefecture. Subsequently, they were shipped widely to the Tohoku, Kanto, Hokuriku, Chubu, and Kansai regions. According to a survey of local wholesalers by the Fishery Cooperative, the prices of marine fish from Fukushima Prefecture at the shipping destinations were similar to those of marine fish from other prefectures. However, the number of suppliers had decreased, and the sales of some fish species declined whenever there was a report of leakage of polluted water from FDNPP.

Challenges of resuming full-scale operation

To resume full-scale fishery operations, the safety of the 26 restricted species (as of June 2016) needs to be confirmed as soon as possible, and fishing restrictions must be lifted. In addition, the fisheries-related facilities that were damaged by the earthquake and nuclear power plant accident need to be rebuilt in a timely manner. Fisheries operations have been suspended for a long period. During that time, some of the older fishermen have retired, and some of the younger fishermen have found other jobs. The recovery of local suppliers has therefore been delayed. Thus, there are serious issues for the fishing industry from the standpoint of both human resources and the infrastructure needed for production, shipping, and distribution. In the future, it will be necessary to rebuild

the fishery by setting targets and schedules, including clear specification of the time when normal fishing operations will be resumed.

Summary

In the present study, we monitored the radioactivity of a large number of commercial fish to determine the impact of the Fukushima nuclear power plant accident and to identify commercial fish safe for human consumption based on fishing trials. Monitoring is important for guaranteeing the safety of fisheries products, determining when to lift shipping restrictions, and providing a scientific basis for a return to full-scale operations. It has been over five years since the Fukushima nuclear power plant accident, and the level of radioactivity in commercial fish is extremely low. However, to assure the public that consumption of commercial fish from Fukushima Prefecture is safe in the future, monitoring must be continued, and the results must be made public.

On 9 June 2016, shipping restrictions were lifted on Japanese flounder, a fish very much associated with commercial fishing off Fukushima. This action created high hopes of major progress towards full-scale resumption of commercial fishing operations. Scientific information, such as the results of monitoring levels of radioactivity in fish, should be provided to fishermen and consumers to accelerate progress towards full-scale resumption of fishery operations.

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Special Report: “Radioactivity in the Marine Environment and in Fishery Products during the Five Years after the Fukushima Dai-ichi Nuclear Power Plant Accident”

Panel Discussion Concerning the Program of Further Monitoring of Radioactive Substances in the Ocean

Chairperson: Takashi Ishimaru*1§
Panelists: Yoshiharu Nemoto*2, Masashi Kusakabe*3,
Hyoe Takata*3 and Mizurou Yokota*3

Mr. S. Fujii (MC):

Let us begin the panel discussion session. Dr. Takashi Ishimaru, an honorary professor of the Tokyo University of Marine Science and Technology, is the chairperson. After the accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP), he began surveys of radioactivity in the coastal area off Fukushima using training ships from the University. Presently, he is actively working on the front line of marine surveys as a specially appointed professor at the University. Now, I will give the floor to Dr. T. Ishimaru.

Panel discussion

Dr. Ishimaru:

Thank you for the introduction.

We had four presenters today. First, Dr. M. Kusakabe from the Marine Ecology Research Institute (MERI) introduced us to the subject of naturally occurring radioactive substances in the ocean and the behavior of radioactive substances that enter the ocean due to nuclear power plant accidents and nuclear tests. He also provided us with basic information and the history of research related to radioactivity in the ocean. Second, Dr. H. Takata from MERI presented the changes in the activities of radionuclides in seawater and marine sediments that MERI has been monitoring for the last five years. He compared those changes to changes of activities reported since 1983 along shorelines near nuclear facilities, and he discussed those long-term changes. He was followed by Mr. M. Yokota, also from MERI, who presented the changes in activities of radioisotopes in commercial marine fish harvested outside of Fukushima Prefecture. Finally, Mr. Y. Nemoto of the Fukushima Fisheries Experimental Station presented an outline for monitoring of radioactivity in commercial fish captured in Fukushima Prefecture from the accident until the present time. He

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also described the efforts being made to resume fishery operations.

All lecturers discussed monitoring of radioactivity. Therefore, in this panel discussion, we would like to discuss "the program of further monitoring of radioactive substances in the ocean". First, let us hear from our speakers.

Dr. T. Ishimaru

Dr. Kusakabe:

In my presentation, I focused on marine radioactivity prior to the accident. However, since the accident, I have wondered if the data collected for more than 30 years by MERI were still useful for analyzing the activities of radioactive substances in the ocean following the accident. They constitute essential data for analyzing temporal changes and current conditions accurately and predicting future changes.

Dr. M. Kusakabe

Dr. Takata:

I presented mostly the changes in activities of radioactive substances before and after the accident. Monitoring data before and after the accident were used to predict future changes and the time required for the activities to return to pre-accident levels. I intended to explain possible future changes in the activities of radioactive substances in the ocean based on scientific evidence, especially in a way easily understood by laypersons.

Dr. H. Takata

Mr. Yokota:

The program of radioactivity monitoring of commercial fish that I presented has gained attention from the fishing industry and general public, and it has become popular worldwide in the context of food safety and security. Many people came from around the world to visit our laboratory. Seeing the analytical procedures and directly exchanging information with researchers provided a good opportunity for visitors to gain peace of mind. However, some countries are still restricting the importation of fish and other seafood harvested in eastern Japan because not all negative rumors have been dispelled. Therefore, we will continue to analyze samples of commercial fish for radioactivity as part of the monitoring program. There will be no reduction in the number of samples analyzed, and the monitoring will not be interrupted.

Mr. M. Yokota

Mr. Nemoto:

Fukushima Prefecture was severely affected by the earthquake and the nuclear accident. As a result of the nuclear accident, commercial fishing had to begin at a time when there was much concern about the risk associated with eating fish from the part of the ocean impacted by the accident. To earn the trust of consumers, Fukushima Prefecture has been analyzing as many specimens as possible and has published all the data. Five years have now passed since the accident, and the activities of radioactive substances have decreased significantly; in fact, they have almost returned to the levels prior to the accident. The Prefecture plans to continue monitoring the radioactivity of commercial fish in the future to assure consumers that the fish are safe to eat.

Mr. Y. Nemoto

Dr. Ishimaru:

Thank you so much. I have been told that continued long-term monitoring is important. It is also important to share our knowledge worldwide to gain the trust of consumers. If anyone in the audience has any questions, please go ahead.

General participant:

Mr. Yokota from the MERI told us in detail about the sample processing associated with the monitoring program, and so on. However, is this method the same as the one used as a part of the monitoring conducted in Fukushima Prefecture?

Mr. Nemoto:

It is essentially the same. In the case of Fukushima Prefecture, a fish that is used as a specimen is brought to the experiment station, and samples for analysis are taken from edible parts of the fish once the species is determined. Which parts of the fish are consumed depends on the species of fish. For example, Japanese flounder is usually eaten as sashimi, and therefore only the muscle tissue is analyzed. Round greeneyes and other fish that are deep-fried whole were analyzed in their entirety. We adjust the sample processing and analytical method to reflect the way the commercial fish are eaten.

General participant:

The activity of radioactive substances in commercial fish from Fukushima Prefecture is only that of ^{137}Cs. However, the data from MERI are the combined activities of ^{134}Cs and ^{137}Cs. Is Fukushima Prefecture measuring the activity of ^{134}Cs?

Mr. Nemoto:

The radioactivity of cesium monitored in commercial fish samples is the sum of the activities of ^{134}Cs and ^{137}Cs. Substances such as smaller prey fish and seawater, which are analyzed for other scientific programs, are assayed for only ^{137}Cs to document the decreasing trend in ^{137}Cs activity.

Dr. Ishimaru:

When measuring radioactivity with a germanium semiconductor detector, ^{134}Cs and ^{137}Cs are measured

simultaneously. Therefore, I believe that Fukushima Prefecture has all the data for both radioisotopes.

General participant:

When changes in the activities of radioactive substances in seafood and seawater before and after the accident are presented at gatherings and conferences concerned with risk management and communication, the results are explained to consumers in the context of changes in attenuation curves and mean values. It is argued that these are approaching values prior to the accident. However, whether or not the values of something are similar before and after the accident must be determined with a statistical test. For example, can you detect the difference before and after the accident if a nonparametric significance test is used? How do you feel about the need for scientific determination and prediction?

Dr. Ishimaru:

Are these projects using statistical analyses?

Dr. Kusakabe:

As you pointed out, statistical analysis of the activities of radioactive substances before and after the accident is necessary. There are some candidate specific methods to be used. We are examining this issue. However, statistical analysis is not easy. For example, there are large variations in the activities of radioactive substances in the marine sediments that I am working on. Even if I considered the activities in the sediment from a single location, the change is not constant. In any case, statistical analysis is indeed necessary.

General participant:

Saying, "The mean activity of radioactive substances before and after the accident is approximately the same, or it is generally decreasing" is not scientific or professional. I was also wondering what scientific analytical methods were available for these data.

Dr. Ishimaru:

For example, the activity of radioactive substances in the ocean around a nuclear power plant would be variable, because the leak from an accident would be intermittent. In addition, ocean currents do not flow from upstream to downstream similar to the flow in a river; instead, ocean currents are complex and variable, and they have vortex structures. An analysis that took these issues into consideration would require a very long-term monitoring program. In the case of radioactive substances in marine sediments, the grain size of the sediments (e.g., sand or clay) and the median grain size of the sand create variations in the radioactivities. Furthermore, there are differences in the depths of the sampling points. To perform a highly reliable data analysis, more data would be required. Are there any other questions?

Dr. Akira Wada(Honorary Professor, Nihon University):

MERI has been conducting various monitoring surveys in the ocean adjacent to nuclear power plants throughout Japan. MERI is a research institution rich in experience. In the case of the present nuclear power plant accident, MERI has been conducting surveys based on their expertise. For example, with much effort, MERI has been monitoring strongly nonlinear phenomena. An example is the exchange of radioactive substances between seawater and marine sediments, as presented by Dr. Kusakabe. There are consequently some convincing research results. Although it has been five years since the accident, monitoring should continue. The scale, however, may change. Recently, MERI presented the radioactivity monitoring results in a very skillful manner. In the future, it will be important to continue the survey, but it will also be important to improve the presentation of results. For example, visual aids such as publication-quality graphs should be used to help the general public understand the current status of radioactivity in the marine environment and in seafood. For example, the figure showing the distributions of ^{137}Cs and ^{134}C activities in the ocean on page 28 of the proceedings and the figure showing the activity of ^{137}Cs remaining in seawater on page 29 can lead to misunderstanding if presented individually. These figures need supportive explanations. In addition, the analysis of monitoring data needs to be scrutinized.

Dr. Ishimaru:

All speakers who presented today have published in international scientific journals, and they are highly respected for their achievements as scientists. However,

it is very difficult for them to explain the current results to laypersons; communicating to the public may not be their cup of tea. In the future, it may be necessary for someone who has experience presenting to the general public to prepare graphs and tables of research results to present to the general public. Are there any more questions?

General participant:

According to Mr. Nemoto, they evaluate safety with the goal of having the activities be lower than the national standard because they give high priority to the safety of consumers. I understood that well. The presentation by MERI excluded data for seafood from Fukushima Prefecture. What was the reason behind this? If possible, can you set up a system in which measured values can be crosschecked between MERI and Fukushima Prefecture?

Mr. Yokota:

The objective of our project was to monitor activities of radioactive substances in seafood sold in the market to ensure food safety and security. As you know, the fishery industry in Fukushima Prefecture was annihilated by the tsunami and nuclear power plant accident in the immediate aftermath of the disaster. Therefore, we examined seafood that was generally available in the market. Fukushima Prefecture measures the activities of radioactive substances in seafood in Fukushima Prefecture, whereas the MERI measures that of other fishery products. In that manner, we share our task load.

General participant:

Is there a plan to perform a crosscheck between the two organizations in the future?

Mr. Yokota:

MERI began measuring activities of radioactive substances in commercial marine fish captured off the coast of Fukushima Prefecture as of last year.

Dr. Ishimaru:

The monitoring survey conducted by MERI was commissioned by the Japanese government. Monitoring of seafood from Fukushima Prefecture has been performed by Fukushima Prefecture, whereas MERI monitors other seafood. The Fisheries Agency summarizes the results from both organizations and publishes the results on their website. The same measurement methods are used by both organizations. The methods are evaluated and verified by international organizations, and their reliability is assured.

Dr. Takata:

As far as crosschecking is concerned, there is a comprehensive skill test by the International Atomic Energy Agency (IAEA), in which seawater and marine sediments that have been analyzed by the IAEA are measured to evaluate the analytical skill of each facility. Only analytical facilities that have passed this test are analyzing the samples. Hence there is no difference between facilities, and reliability is assured.

The activity of radioactive substances in seawater varies near FDNPP. Based on the figure on page 28 of the proceedings, variation is great, and the activity of radioactive cesium is not clearly decreasing with time. Our monthly survey and daily data from Fukushima Prefecture and the Tokyo Electric Power Company (TEPCO) have been summarized to reveal trends, but in the future, more detailed scientific data should be combined to produce a simple model of changes that can be used to clearly explain the decreasing trend.

Dr. Ishimaru:

Are there any other comments?

Mr. Nemoto told us that various responses to negative rumors are being considered, because such rumors are expected to continue. I am wondering if someone from the Women's Forum could comment on that. How can you prevent negative rumors? Is there a policy for rumor prevention?

General participant:

I want to thank you for the opportunity to participate in an event like this as a consumer. Though consumers demand food safety and security, in fact most are unaware that various researchers are diligently conducting many different studies. Rumor is born out of ignorance. It would therefore be great if you could find a way to present your research results in a way that would be easier for the general public to understand.

Understanding would lead to peace of mind for consumers.

We, the Women's Forum for Fish, are a group of female fishery workers and consumers who consider the safety and security of food and food culture. We focus primarily on fish. We have been working for decades with female fishery workers from Hisanohama, Fukushima, who were severely affected by the earthquake disaster. We plan to contact homemakers in Hisanohama, hold study sessions on food safety while enjoying fish from Fukushima, and support the fishery industry of Fukushima. In these study sessions, I hope to share the results of the radioactivity research that I learned about today. I hope you will continue with these surveys and find a way to share your results that is easy for general consumers to understand. Thank you again for this opportunity.

Dr. Ishimaru:

Since we have an opportunity here, let us hear from the president.

President Kagawa:

We hope to continue with this radioactivity survey, because it is also necessary. As for the project, etc., we will continue the project as well as discussions with the government of Japan. In addition, we plan to publish the results of the project and related information in a way that is easy to understand.

Dr. Ishimaru:

I have been asked to give a lecture several times by groups associated with fish markets. I have also given lectures upon request by Fukushima Prefecture. I assume that other researchers who presented today have had similar experiences. We will not turn down any request for lectures. Not only would we be glad to accept requests, but we would also be grateful for the opportunity to present.

Mr. Nemoto:

Thank you for your support. Actually, I also have talked about radioactivity and the survey results in many different venues, and I am surprised that many people "heard" this information "for the first time". I have come to realize how inadequate our public relations have been. The most effective way to share information seems to be mass media: either we invite the media to come to Fukushima, or we head out to Tokyo for a press conference. In addition, the construction of a new fish market was completed in Onahama last year, and construction of another will be completed in Soma this year. We plan to hold fish festivals in these fish markets. In the future, we can communicate about issues like food safety and security to consumers through events like this. As for public relations, we would like to take your advice and welcome more comments.

Dr. Ishimaru:

Are there any other comments or questions?

General participant:

I presently belong to the Chuo-ku Kankyo-Hozen Network. It is my personal belief that fish in the market is safe. In the Consumers' Co-operative that we usually use, the food has stickers showing the results of radioactivity tests, and consumers can choose based on these stickers. If other retailers and markets employed this approach, consumers would feel safer with their purchases.

General participant:

The areas where fishing trials are being conducted are outside of the 20-km radius from FDNPP. Therefore, as long as this 20-km radius is set, we feel that the marine environment and fishery products within that area are unsafe. We would like you to have that 20-km radius removed and declare that the marine environment and ecosystem around the shores of Fukushima Prefecture are safe. If this 20-km radius continues to be used, consumers and the general public most likely will not feel safe.

Mr. Nemoto:

With respect to labeling food at the co-op with the radioactivity test results, Fukushima Prefecture itself adds test results when shipping fishery products from the market. We are actively encouraging supermarkets to add labels as well. As for the 20-km radius; in 2013, when TEPCO reported that contaminated water was leaking from the area around the nuclear plant, all trial

fishing operations were temporarily stopped, and when the trial fishing was resumed, the 20-km radius was voluntarily set up. Presently, a water barrier has been built, and the activities of radioactive substances around the nuclear plant have notably decreased. During the monitoring survey, seawater and seafood within the 20-km radius have been tested carefully, and safety is evaluated based on these results. Indeed, the 20-km radius may invite misunderstanding, and we are considering reducing this radius as well.

Dr. Ishimaru:

Is there anything else?

General participant:

I understood the importance of the monitoring project by MERI. Given that these monitoring results should be kept as a legacy, data must be shared widely with the general public. For example, I assume that there is a large amount of data other than the activity of radioactive substances, such as the coordinates of where a fish was collected and the size of the fish. MERI has been the first to analyze the data, but if there are limited human resources and time, sharing these other data with multiple institutions may allow modeling analysis to be performed smoothly. Furthermore, providing data to the IAEA will create an opportunity for foreign research institutions to participate in the analyses and thus accelerate data analysis.

Other than in cases where no part of a sample remained after the analysis, are you not able to negotiate with the government on a project so that monitoring samples are stored as assets to allow future generations to analyze the samples, as is the case with marine sediments?

Dr. Ishimaru:

On the one hand, because MERI is commissioned by the Japanese government, we must work with the government and other associated organizations. On the other hand, as long as we are commissioned by the government, the funding comes from taxes; therefore, the results must be passed on to future generations and must be scientifically evaluated. Furthermore, it is extremely important to properly explain the results to citizens and consumers.

Any comments from Mr. Kagawa, the president of MERI?

Mr. Kagawa:

If the general public strongly demands publication of data and sample storage, the government would likely consider it. We will keep the lines of communication open on this topic. However, radioactivity levels in commercial fish have already been published on the Fishery Agency homepage, along with an English summary of the data. Please go review those websites.

Dr. Ishimaru:

The website of each ministry publishes detailed results of the radioactivity surveys. If you are interested, please go to the websites of Fukushima Prefecture, Ministry of the Environment, Fisheries Agency, Ministry of Health, Labour and Welfare, and Nuclear Regulation Authority, among others. I think that there is a surprisingly large amount of information there. However, these data may not be easily comprehensible for those who are not specialists.

In addition, I get the impression that the efforts of various ministries and agencies are not directly connected, although, for example, the Ministry of the Environment and the Fisheries Agency have been conducting surveys to elucidate the cause of freshwater fish contamination with high levels of radioactivity. I look forward to cross-sectional efforts between ministries and agencies.

Well, our time is up, so let us conclude the panel discussion.

Mr. Fujii (MC):

I would like to thank the chairperson, Dr. Ishimaru, and all the panelists for their time.

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Report of Marine Ecology Research Institute

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