Radiation Monitoring and Remediation Following the Fukushima Daiichi Nuclear Power Plant Accident

Cooperation between Fukushima Prefecture and the IAEA

INTERIM REPORT (2013 to 2020)

【Fukushima Prefecture Initiative Projects】

【Executive Summary】

(Temporary translation)

March 2021

Fukushima Prefecture

Introduction

The Great East Japan Earthquake occurred on 11 March 2011. It was followed by the accident of Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant[1], and radioactive materials have been released into the environment which contaminated the land. Due to the contamination of the land and other relevant reasons, more than 160,000 prefectural residents were forced to evacuate. About 38,000 residents have not been able to return home, as of 2020 July, about 9 years after the disaster (Fukushima Prefecture's website "Fukushima Revitalization Station"; https://www.pref.fukushima.lg.jp/uploaded/attachment/403521.pdf).

In order for Fukushima Prefecture to recover from the severe and unprecedented nuclear disaster and create an environment where the residents can live with peace of mind in the future, it was necessary to respond at the aftermath by collecting knowledge and world-wide experience, so the prefecture decided to cooperate with the International Atomic Energy Agency (hereinafter referred to as the "IAEA"), which owns high-level nuclear-related knowledge. In December 2012, a memorandum for cooperation was signed between the prefecture and the IAEA.

Based on the memorandum, an agreement relating to the fields of "radiation monitoring" and "decontamination" was signed between the parties on the same day (projects based on this agreement is referred to as "FCPs; Fukushima Cooperative Project").

Subsequently in April and October 2013, agreements were signed for five projects (hereinafter referred to as "FIPs; Fukushima Initiative Project") as described below in a new framework in which these projects would be supported by the IAEA for three years, and the FIPs started (hereinafter referred to as "previous Project"). In April and May 2016, they signed agreements for extending the FIP cooperation period (originally set at "until December 2017") expanding the range of their cooperation[2].

The achievements of the FIPs conducted between April 2013 and December 2017 were compiled in the report on "Cooperation between Fukushima Prefecture and the IAEA – SUMMARY REPORT (2013 to 2017) [Fukushima Prefecture Initiative Projects]" in March 2018 (hereinafter referred to as "previous report"). The previous report is available in a book form and also in the following website:

https://www.pref.fukushima.lg.jp/sec/298/iaeasummary2017.html

However, because remediation of the environment in the Prefecture was halfway through and the accomplishment of the proposed projects required further support from the IAEA, the prefecture obtained in December 2017 the IAEA's agreement and signature for a continued support until December 2022 (hereinafter referred to as "this Project"). This report is an interim report on activities from Fiscal Year (hereinafter referred to as "FY") 2013, focusing on activities from FY2018 to FY2019, excluding FIP4. FIP4 was completed in FY2015 and has not been extended, so the previous report is reprinted with some wording revised and updated since FY2015.

1 The owner of the Fukushima Daiichi Nuclear Power Plant was renamed from Tokyo Electric Power Company to Tokyo Electric Power Company Holdings, Incorporated in April 1, 2016.

2 In accordance with the change of the cooperation range, the names of some FIPs were changed.

List of themes for the Fukushima Initiative Projects (FIPs) (themes in parentheses are titles used until 2017.)

FIP 1 Survey, and evaluation of the effect, of radiocesium dynamics in the aquatic systems based on the continuous monitoring
(Survey of radionuclide movement in river systems)

FIP 2 Survey of radionuclide movement with wildlife

FIP 3 Sustainable countermeasures to radioactive materials in freshwater system
(Countermeasures for radioactive materials in rivers and lakes)

FIP 4 Development of environmental mapping technology using GPS walking surveys

FIP 5 Study of proper treatment of waste containing radioactive material
(Study of the proper treatment of waste containing radioactive materials at municipal solid waste incinerators)

1. FIP1 Survey, and evaluation of the effect, of the effect of radiocesium dynamics in aquatic systems based on the continuous monitoring

1.1. Purpose

As a result of the Fukushima Daiichi Nuclear Power Plant accident in March 2011, large amounts of radioactive materials were released as fallout into the environment and deposited on prefectural land. Nine years after the accident, the concentration of radiocesium in the rivers of Fukushima Prefecture has decreased sufficiently. However, continuous monitoring of the effects of changes in the surrounding environment on the transport of in rivers is considered necessary. In the project, we have continued to study the dynamics of radiocesium in rivers, using direct monitoring and TODAM model simulations. In addition, we have examined the current status of radiocesium microparticles in river water and sources of suspended radiocesium in rivers in Fukushima Prefecture.

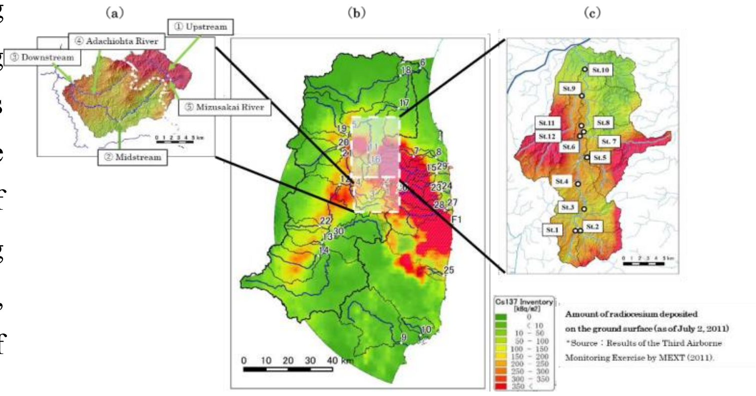

Figure 1. Monitoring points used in this study: (a)Kuchibuto River Basin (b)Wide-area multipoint survey and (c) Hirose River Basin
Amount of radiocesium deposition on ground surfaces (as of July 2, 2011) *Source: Results of the 3rd aircraft monitoring by the Ministry of Education, Culture, Sports, Science and Technology (2011)

1.2. Content of implementation

Using monitoring networks established in the previous project (Figure 1(a), (b) and (c)) , we obtained continuous data for turbidity and water levels, collected suspended solids (SS) using SS sampler, and collected river water samples for measurements of suspended and dissolved cesium-137.

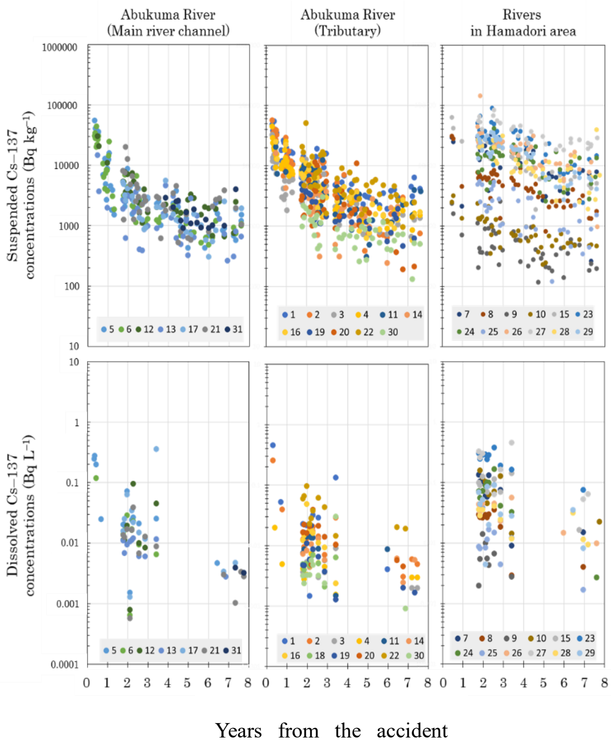

Figure 2. Cesium-137 concentrations in river water
(a) Suspended cesium-137, (b) Dissolved cesium-137

1.3. Results

Changes in the suspended and dissolved cesium-137 concentrations in river water over time are shown in Figure 2. The concentration of radiocesium in rivers has continued to decrease over time, although the changes are not as marked as immediately after the accident. Based on these data, the effective environmental half-lives of suspended and dissolved cesium-137 were estimated to be about 2.8 years and 3.6 years (excluding the data in 2011), respectively. It is estimated that the effective environmental half-life of suspended cesium-137 immediately after the accident was 0.24 years in the Abukuma River compared to 0.31 years in the Pripyat River after the Chernobyl Nuclear Power Plant accident. In the second year and beyond, the decreasing rate of the concentration of suspended cesium-137 has lowered to about 1/10 of the initial rate in Fukushima. However, like just after the accident, the values of effective environmental half-lives are similar still (values of Fukushima are within the same range of the values of European rivers; 1 to 4 years).

To assess the detailed changes in suspended radiocesium concentrations in rivers in response to decontamination activities in basins, the data for the Kuchibuto River Basin (Figure 1(a)) designated as a special decontamination area after the nuclear accident were analyzed. During the period of intensive decontamination activities in the basin, suspended cesium-137 concentrations decreased significantly at upstream monitoring point in the basin (Figure 3). It is considered that this decrease occurred in response to the increased sediment runoff resulting from decontamination practices. The amount of runoff decreased after the completion of decontamination, but was still higher than before decontamination started.

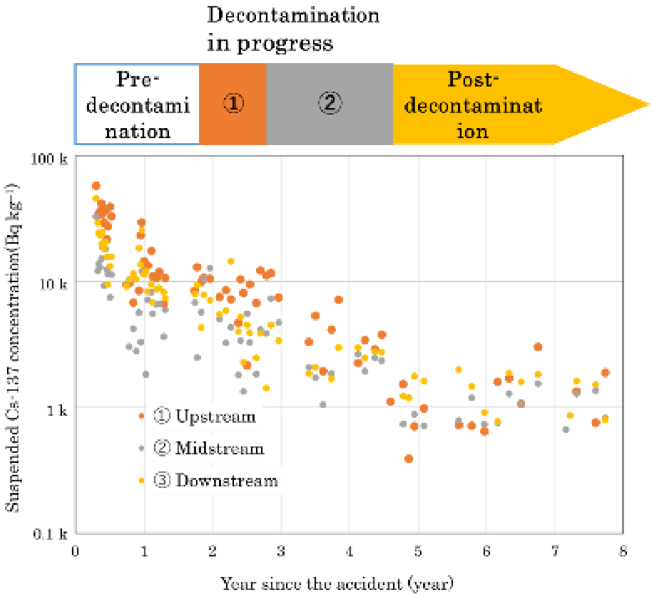

Figure 3. Change in suspended cesium-137 concentration over the course of decontamination

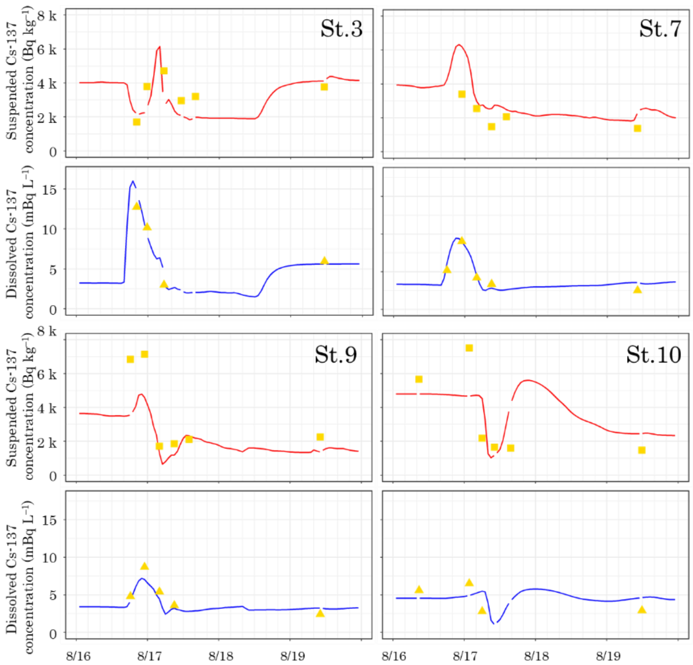

Figure 4. Simulation results of changes in cesium-137 concentrations during flood events using TODAM model [Upper rows: Suspended cesium concentration, lower rows: Dissolved cesium-137 concentration] (high-water flow events from 16 August to 19 August 2016)

For the model simulations, the Kuchibuto River Basin (Figure 1 (a)) has been added as an additional river basin in this period of the project (i.e. in addition to the Hirose River Basin (Figure 1 (c)). Figure 4 shows the simulation results for the changes in suspended and dissolved cesium-137 concentrations in river water under high-flow conditions in the Hirose River Basin. Although deviations were observed at some points, the general pattern observed in measured cesium-137 concentrations was reproduced.

1.4. Conclusions

In this project, continuous monitoring of the radiocesium concentrations in river water as well as future predictions by the model has been undertaken. The findings indicate that the decreasing trend observed in radiocesium concentrations that was reported previously has been maintained. In addition, the decontamination activities undertaken in the prefecture have had a marked effect on the concentration of suspended cesium-137 in river waters. The simulation results were refined under base-flow condition. In addition, the simulation was carried out under high-flow condition. Finally, preparation for new surveys and monitoring have been started in another basin.

2. FIP2 Survey of radionuclide movements with wildlife

2.1. Purpose

The accident at the Fukushima Daiichi Nuclear Power Plant caused a widespread environmental contamination by radioactive materials. Radionuclides have been detected in many wild animals and we have conducted studies to understand the movements of radionuclides in the ecosystem to clarify radiocesium migration to wild animals.

2.2. Content of implementation

(1) Measurement of radionuclide concentrations in the muscles of wild animals

Cesium-137 concentrations were investigated based on the results of monitoring survey of radionuclide concentrations in the muscles of wild animals such as wild boars and others in Fukushima Prefecture.

(2) Long-term fluctuations of cesium-137 concentrations in the muscles of wild boars and Asian black bears

The long-term fluctuations of cesium-137 concentrations in the muscle of wild boars and Asian black bears after the accident were analyzed with a linear model.

(3) Genetic population structure of wild boars

The MIG-seq analysis was performed using wild boar DNA to investigate the wild boar genetic population structure in Fukushima prefecture.

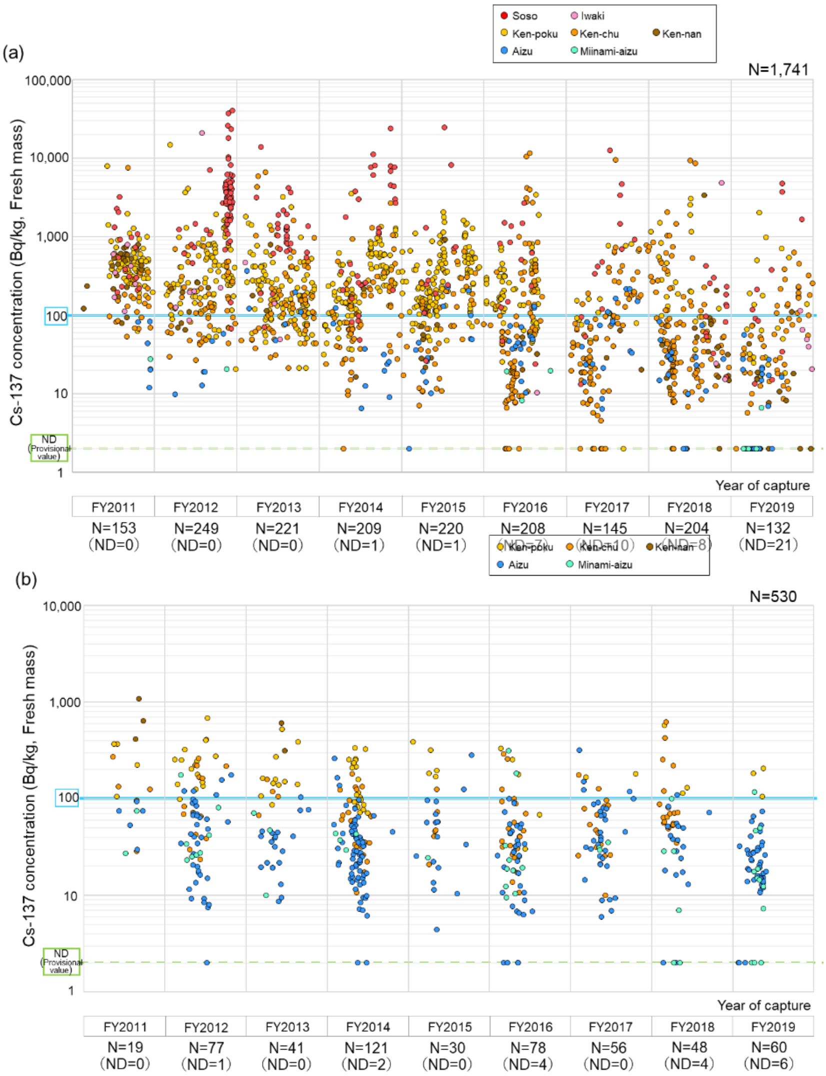

Figure 1. Cs-137 concentrations in the muscles of (a) wild boars and (b) Asian black bears (in regions where they were captured)
* Each dot indicates the measured value for each wild animal.

2.3. Results

(1) Measurement of radionuclide concentrations in the muscles of wild animals

In Soso District, Ken-poku District and Ken-chu District where the cesium-137 deposition density on soils was relatively high, many wild boars and Asian black bears captured in May 2011 to March 2020 were detected with high cesium-137 concentrations,. This trend suggested that there was a correlation between cesium-137 concentrations in muscle of these species and the amount of cesium-137 deposition on soil. On the other hand in Ken-chu District, some wild boars showed cesium-137 concentrations lower than the detection limit although, those showing cesium-137 concentrations close to 10,000 Bq/kg were also observed even in recent years (Figure 1).

(2) Long-term fluctuations of cesium-137 concentrations in the muscles of wild boars and Asian black bears

With regard to cesium-137 concentrations in the muscles of wild boars, a decreasing trend was observed during the entire period, in both the low-concentration period (April to August) and high-concentration period (December to March). However, the rate of decrease was small, and the cesium-137 concentrations estimated from a regression line showed a wide range in the high-concentration period. As for A decreasing trend of cesium-137 concentrations in the muscles of Asian black bears was also observed during the entire period and in the low-concentration period (July to September), but the range of estimated values widened over time during the high-concentration period (November to January) (Figure. 2).

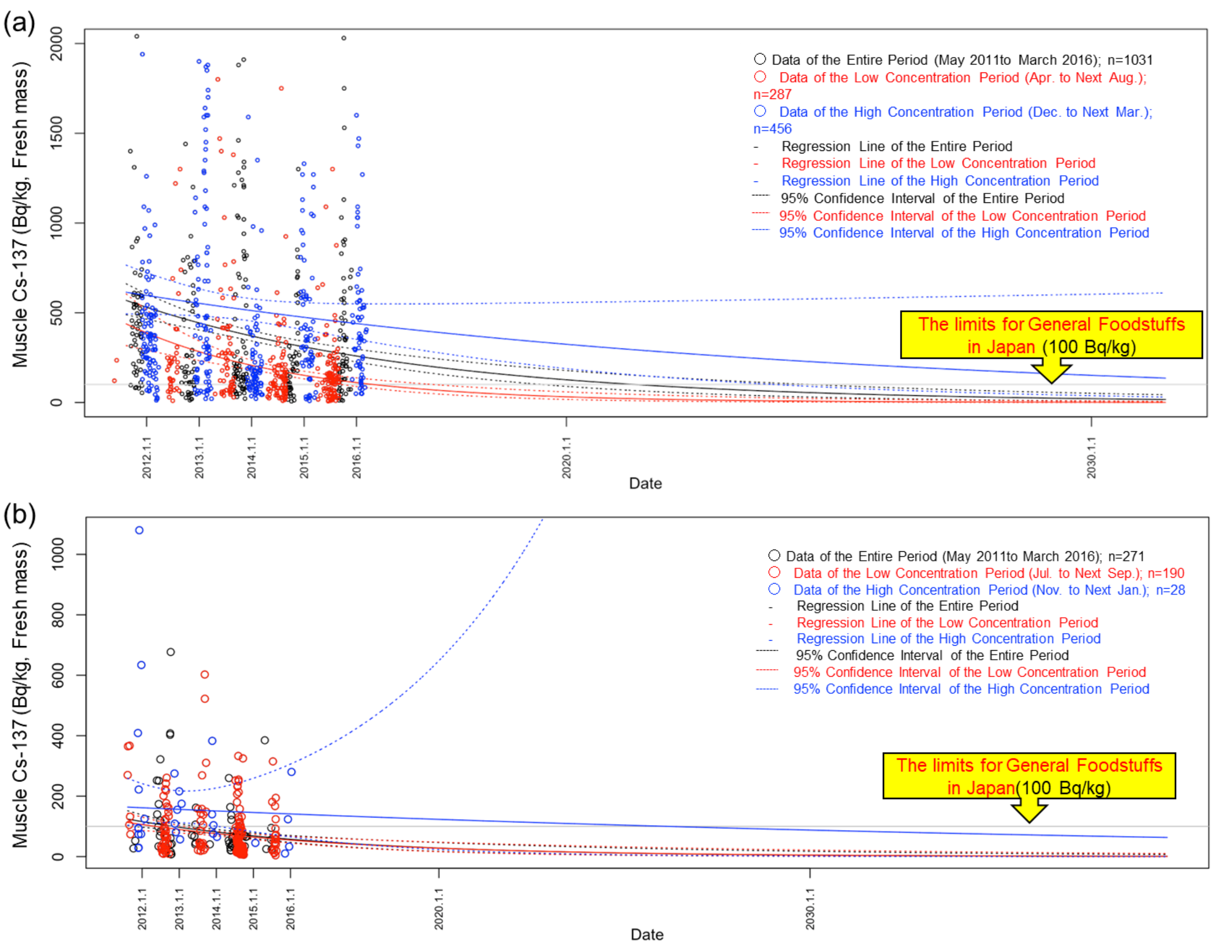

Figure 2. Long-term fluctuations of Cs-137 concentrations in the muscles of (a) wild boars and (b) Asian black bears

(3) Genetic population structure of wild boars

DNA was extracted from the muscle tissue of wild boars captured in Fukushima and Kumamoto Prefectures. Single-nucleotide polymorphisms (SNPs) were obtained from genome-wide regions by MIG-seq method. The results of the STRUCTURE analysis data for wild boars suggested that they were divided into two genetic lineages (Figures 3 and 4). The results of cluster analysis revealed two clusters that can be divided into an eastern group inhabiting northern Soso District, southern Soso District, Iwaki District and Ken-nan District of Fukushima Prefecture, and a western group inhabiting Ken-poku District, Ken-chu District and Aizu District of Fukushima Prefecture and Kumamoto Prefecture (Figures 3 and 5). Moreover, the results of the detection rates of two genetic lineages in each city, town and village in Fukushima Prefecture suggested that these lineages are divided by the east and west area along with Abukuma River as the boundary that restricted the movement to east and west (Figure 6).

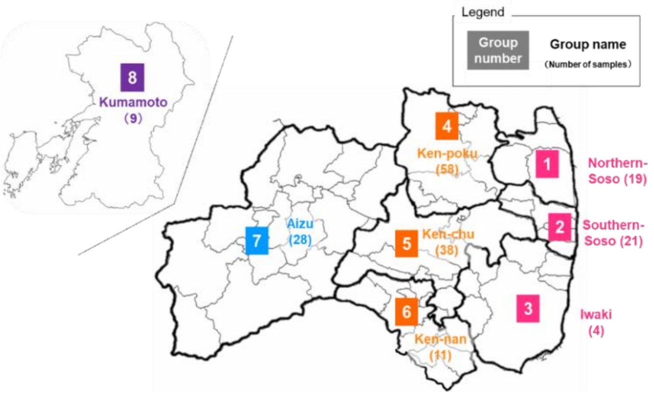

Figure 3. Grouping of specimens after their MIG-seq analyses and the number of analyses

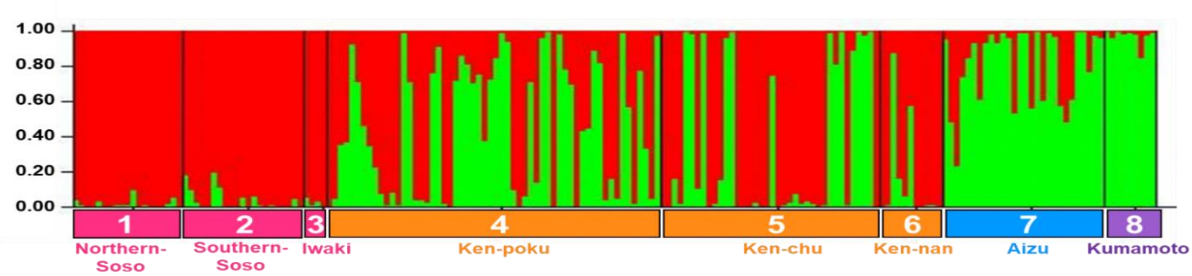

Figure 4. Results of STRUCTURE analysis based on wild boars' DNA data

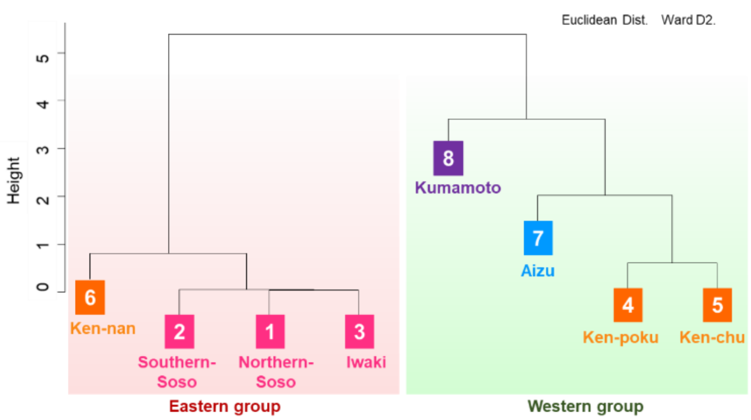

Figure 5. Results of cluster analysis based on wild boars' DNA data

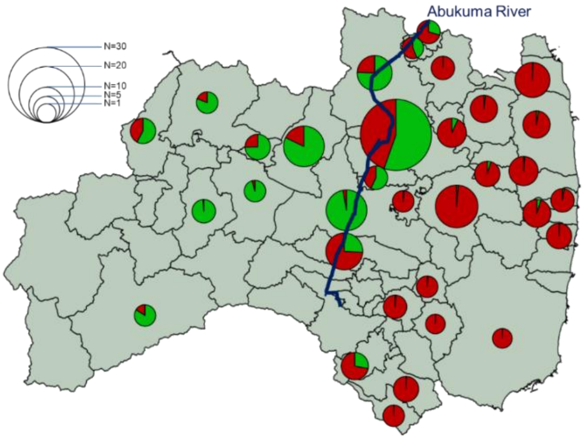

Figure 6. Geographical distribution of wild boars of two genetic lineages

2.4. Conclusions

High cesium-137 concentrations of muscle were observed in wild boars and Asian black bears captured in areas where the cesium-137 deposition density was high, but the concentrations significantly varied among individuals in the areas. Even in recent years, high cesium-137 concentrations of muscle were observed.

The long-term fluctuations of cesium-137 concentrations in the muscles of wild boars and Asian black bears, decrease over time during the entire period and in low-concentration periods. but during the high-concentration periods, the range of estimated values increased over time.

Genetic analysis of wild boars in Fukushima Prefecture suggested that they were divided into two genetic lineages and these genetic populations divided by east and west area along with Abukuma River and around as the boundary that restricted the movement to east and west.

Cesium-137 concentrations in muscles of wild boars and Asian black bears were on a decreasing trend, but they varied among individuals and fluctuated seasonally. Therefore, in order to precisely estimate their long-term fluctuations, further data expansion is necessary. Moreover, the movement and dispersion of the wild animals seem to be a factor contributing to the variation of cesium-137 concentrations observed even among those captured in the same region.

In the future, the monitoring of radiocesium concentrations in the bodies of wild boars and others will be continued, and the factors contributing to the high radiocesium concentrations in some wild animals will be investigated.

3. FIP3 Sustainable countermeasures to radioactive materials in freshwater system

3.1. Purpose

Radioactive materials (mainly radiocesium) spreading in the environment due to the accident at the Fukushima Daiichi Nuclear Power Plant had contaminated the water environment. As a response, monitoring surveys on water, deposited materials and aquatic products were conducted to clarify the behavior of radioactive materials, and decontamination and some other measures were taken by administrative agencies and research institutions. In this project that lasted until December 2017, applicable radioactive material countermeasures were organized based on the existing knowledge accumulated domestically and abroad. A decontamination test was also performed at a river where limited decontamination measures were taken, thereby clarifying the effectiveness of sustainability of decontamination. In addition, contamination situations were surveyed targeting public riverside areas in Fukushima Prefecture. The results of these surveys were shown in a previous report. However, flood can cause the erosion and deposition of sediments containing radioactive materials and change the contamination situation at the river. This could raise the concern of re-contamination of these public areas. For this reason, in 2018 and onward, the sustainability of decontamination effect on riverside areas where the decontamination test has been performed and was continuously checked, and the contamination situations and changes in air dose rate at riverside parks due to large flooding caused by typhoon No. 19 (Hagibis) in 2019 were investigated.

3.2. Content of implementation

(1) Verification of the sustainability of decontamination effect on riverside areas under the vegetation

At the riverbank where the decontamination test was conducted in 2014, air dose rates and radioactive concentrations in sediments were measured under the vegetated condition to check the re-contamination.

(2) Changes in contamination situation in riverside area due to large flooding

At riverside areas and riverside parks (three points in total) where surveys had been conducted in the past, changes in the air dose rate and the situations of the parks after the passage of typhoon No. 19 (Hagibis) in 2019 were investigated.

3.3. Results

(1) Verification of the sustainability of decontamination effect on riverside areas under the vegetation

At the test site, air dose rates at both the decontaminated and non-decontaminated zones continued to decrease (Figure 1). In the decontaminated zone, a decontamination test revealed that the air dose rate halved, and even after a weeding operation was stopped in 2017, the air dose rates continued decreasing. The rate of decrease in dose rate in the non-decontaminated zone was faster than that in the decontaminated zone. The measuring of air dose rates after the decontamination test confirmed no re-contamination.

From the end of 2016 until August 2017, the radiocesium concentrations in newly-deposited materials that accumulated on the flood channel with vegetation were higher than those without vegetation, but lower than those before the decontamination test. On the other hand, after typhoon No. 21 (Lan) in 2017, a 20 cm thick sediment deposited in the riverside area; however, its radiocesium concentration and mud ratio were low. After one-year of vegetation recovery, a normal rainfall can cause the deposition of fine-grained sediment which is trapped by the vegetation; however, the trapping effect of the fine-grained sediments is deemed to have been small in large-scale flooding.

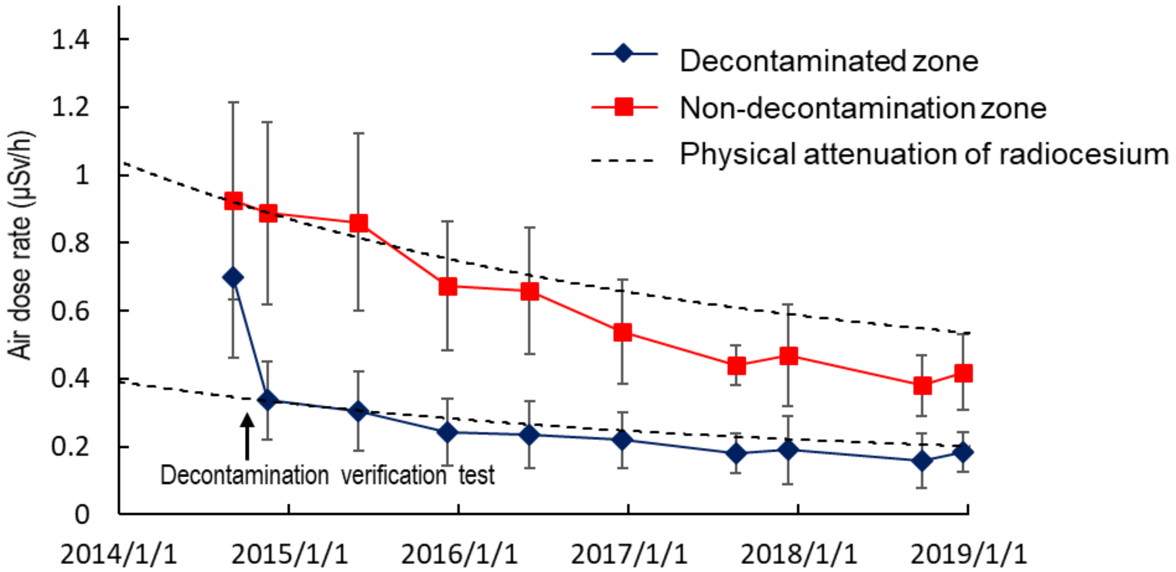

Figure 1. Changes in air dose rate at the Kami-Oguni River
Note: The physical dacay of radiocesium 134 and 137 was calculated with the initial deposition ratio being 1:1. Initial values were fitted to the values measured on November 16, 2014 after the completion of the decontamination test.

(2) Changes in contamination situation in riverside area due to large flooding

The air dose rates measured in all surveyed sites generally decreased after typhoon Hagibis (Figure 2). The reduction rate was larger than that due to the physical decay of radiocesium and was greatly larger than that following the typhoon No. 15 (Etau) in 2015. The survey results at riverside parks indicated that sediments with high radiocesium concentrations were partly flushed away along the river and that a large volume of sand, pebble and gravel were deposited along the river channel. The loss of radiation sources due to sediment outflow and a shielding effect due to covering by sand and gravels whose radiocesium concentrations were low seems to have contributed to the reduction in the air dose rates.

This survey revealed that typhoon No. 19 (Hagibis) in 2019 did not cause re-contamination in general; rather, it was confirmed that natural attenuation has caused the decreased air dose rates.

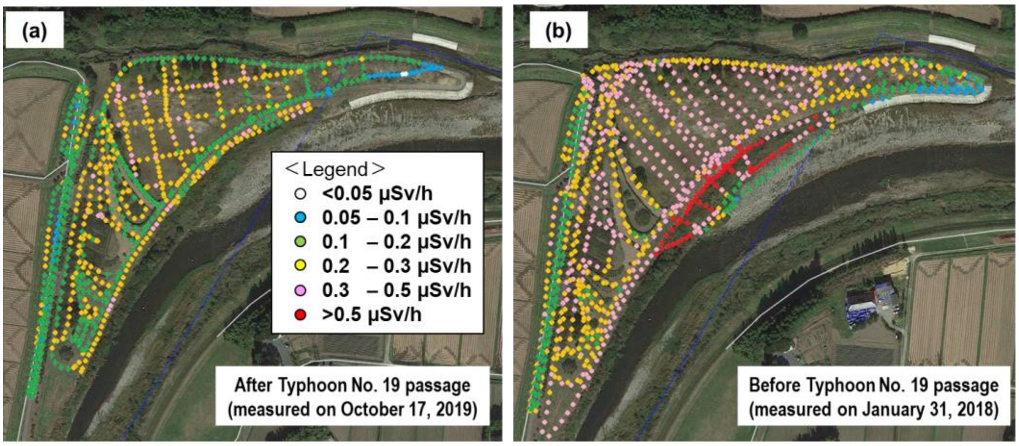

Figure 2. Air dose rate distribution in a riverside park [(a) after the passage of Typhoon No. 19, (b) before its passage]
Note: Background photograph (a) is a satellite image taken by the Cabinet Intelligence and Research Office on October 17, 2019. Background photograph (b) was obtained from Google Earth Pro (date of the photo: October 21, 2018).

3.4. Conclusions

At the riverside site where the decontamination test was performed in 2014, the persistence of the decontamination test was confirmed. Air dose rate decreased with time even on the vegetated flood channel. An increase in radiocesium accumulation on the flood channel was not observed. These results show the persistence of the decontamination test.

In order to investigate the re-contamination in the riversides due to the passage of typhoon No. 19 (Hagibis) in 2019, air dose rate and the situation of the sites were investigated at riverside parks etc. Air dose rate did not increase in general; rather, a large decrease in the air dose rate along the riversides and the effect of natural attenuation due to flooding were observed.

4. FIP4 Development of environmental mapping technology using GPS walking surveys

4.1. Purpose

To understand the air dose rate in Fukushima Prefecture after the accident at the Fukushima Daiichi Nuclear Power Plant, we have conducted air dose rate measurements employing a variety of methods, and have provided information on our homepage.

However, it is difficult to conduct fixed-point measurements or car-borne surveys in some places, including parks, forests, and alleys near residential areas. We therefore developed environmental mapping technology using GPS walking surveys (hereinafter, simply referred to as walking surveys) to interpolate other forms of monitoring.

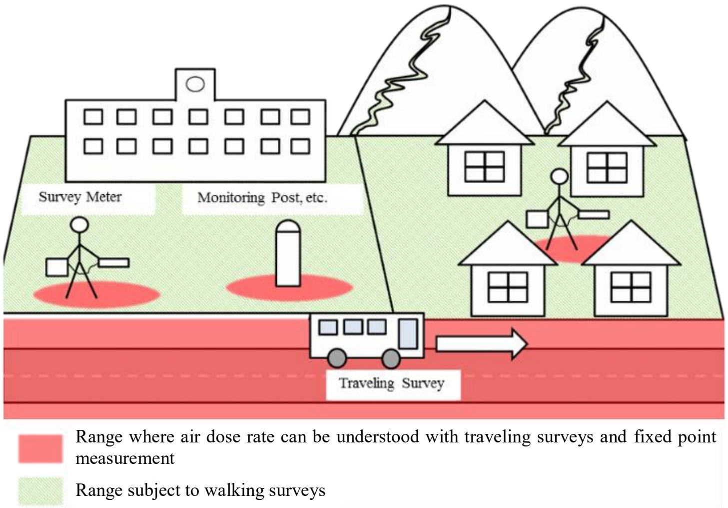

Figure 1. Measurement range of walking surveys

4.2. Content of implementation

(1) Development of equipment

We used the KURAMA (Kyoto University RAdiation MApping System)-II, which was developed by Kyoto University, for walking surveys. KURAMA-II is a system that can combine data obtained from a radiation detector and GPS device to map air dose rates.

We used a high-precision GPS device and stored the equipment in a backpack in a way suited to walking surveys. A manual was prepared so that even inexperienced people can use the system.

We also developed a GIS data processing system for mapping the measured results.

Figure 2. View of a walking survey

(2) Gathering parameters necessary for walking surveys

Because shielding from the measurers themselves affects the contribution from the radiation source depending on the walking direction in walking surveys, we checked the direction characteristics.

We assumed measurements made with a NaI (Tl) survey meter at a height of 1m to be the most reliable, and the survey meter was calibrated with traceability. To determine correction factors of walking surveys in a comparison test with survey meters, we compared measurement data made using a survey meter with those obtained in a walking survey.

(Note: Reprint of the executive summary of the previous report with some wordings revised and update added since the theme ended in FY2015).

4.3. Results

Results for the direction characteristics indicate that the impact of direction characteristics on a measured value of a walk survey was considered small. Additionally, in our comparison with NaI (Tl) survey meters, we found that it is necessary to use different CsI detectors for low and high air dose rates with 1 μSv/h as the dividing line.

In light of this, we set the correction factors to 1.3 when using a low-air-dose-rate detector and 1.1 when using a high-air-dose-rate detector.

4.4. Conclusions

Results were obtained in developing walking surveys by 2015, making it possible to measure the air dose rate in a walking survey.

In FY2016, we conducted walking surveys or lent the necessary equipment at the request of municipalities. In recent years, walking surveys have been utilized in the public projects for monitoring of the air dose rates (e.g., Satoyama Restoration Model Project).

5. FIP5 Study of proper treatment of waste containing radioactive material

5.1. Purpose

The incineration of municipal waste containing radiocesium scattered from the accident at TEPCO's Fukushima Daiichi Nuclear Power Plant resulted in the migration of radiocesium to bottom ash and fly ash. Because radiocesium in fly ash in particular is likely to elute upon contact with water, there is a concern that after it is put in landfill, it will contaminate the surrounding environment by radiocesium. Therefore, it is an urgent task to properly treat and disposal of the bottom ash and fly ash contained in it.

Based on understanding of the characteristics of radiocesium elution from bottom ash and fly ash, the technology to suppress radiocesium elution by utilizing clay minerals has been studied. Moreover, at the Fukushima Prefecture's landfill disposal sites that have started the landfill of incineration ash containing radiocesium, a correlation between a disposal site structure and radiocesium concentrations in leachate (seeping water) is being investigated.

5.2. Content of implementation

(1) Tests on radiocesium elution suppression

Radiocesium concentrations and Cs elution rates in pure water were measured for bottom ash, humidified bottom ash (treated bottom ash), fly ash, and fly ash subjected to heavy metal elution prevention treatment (treated fly ash); each of these were sampled from municipal waste incineration facilities in Fukushima Prefecture. In addition, acid clay, which is expected to be effective as a radiocesium elution suppressor, was added to the incineration ash, and the measurement of radiocesium concentration in eluate (effluent) from the ash and the analysis of element concentration were carried out.

(2) Tests on radiocesium elution suppression in incineration ash at municipal waste incineration facility

The feasibility of radiocesium elution suppression by zeolite, which was found effective in suppressing radiocesium elution from the incineration ash in previous studies, was verified by conducting zeolite addition tests at municipal waste incineration facilities.

(a) A test during normal operation

Using incineration ash obtained during the normal operation of municipal waste incineration facilities, radiocesium concentration measurements, radiocesium elution tests, and radiocesium elution tests with the addition of zeolite were carried out.

(b) Tests on zeolite addition to an exhaust gas treatment agent at actual facilities

At the waste incineration facilities mentioned in (a), an exhaust gas treatment agent was mixed with zeolite before the operations of the facilities, and the post-operation exhaust gas was analyzed and the treated fly ash was sampled. Using the sampled treated fly ash, the radiocesium concentration measurements and radiocesium elution tests were carried out.

(c) Tests on zeolite addition to the mixture of fly ash and chelate agent by kneading at actual facilities

At the municipal waste incineration facilities mentioned in (a), during a treatment for suppressing heavy metal elution from fly ash by using a chelate agent, zeolite was added and then the facilities were operated. Subsequently, the treated fly ash was sampled. Using the sampled treated fly ash, a radiocesium concentration measurement and a radiocesium elution test were carried out.

(3) Situations of landfill and radiocesium elution

Investigations were conducted at landfill disposal sites in Fukushima Prefecture to investigate correlations between radiocesium concentrations in leachate and the situations of the incineration ash landfill.

(4) Correlation between the annual elution situation of radiocesium and other elements

Leachate was sampled once a month from the landfill disposal sites where radiocesium had been detected in leachate, and the concentrations of radiocesium and other elements were analyzed.

5.3. Results

(1) Tests on radiocesium elution suppression

Regarding radiocesium concentrations in incineration ash, those in fly ash and treated fly ash were higher than those in bottom ash and treated bottom ash. Radiocesium elution rates were also higher for fly ash and treated fly ash than bottom ash and treated bottom ash. Long-term elution tests in which fly ash was mixed with a heavy metal elution suppression agent (chelate agent) and acid clay indicated that the acid clay has a radiocesium elution suppression effect (Figure 1) and does not block the heavy metal elution suppression effect of the chelate agent.

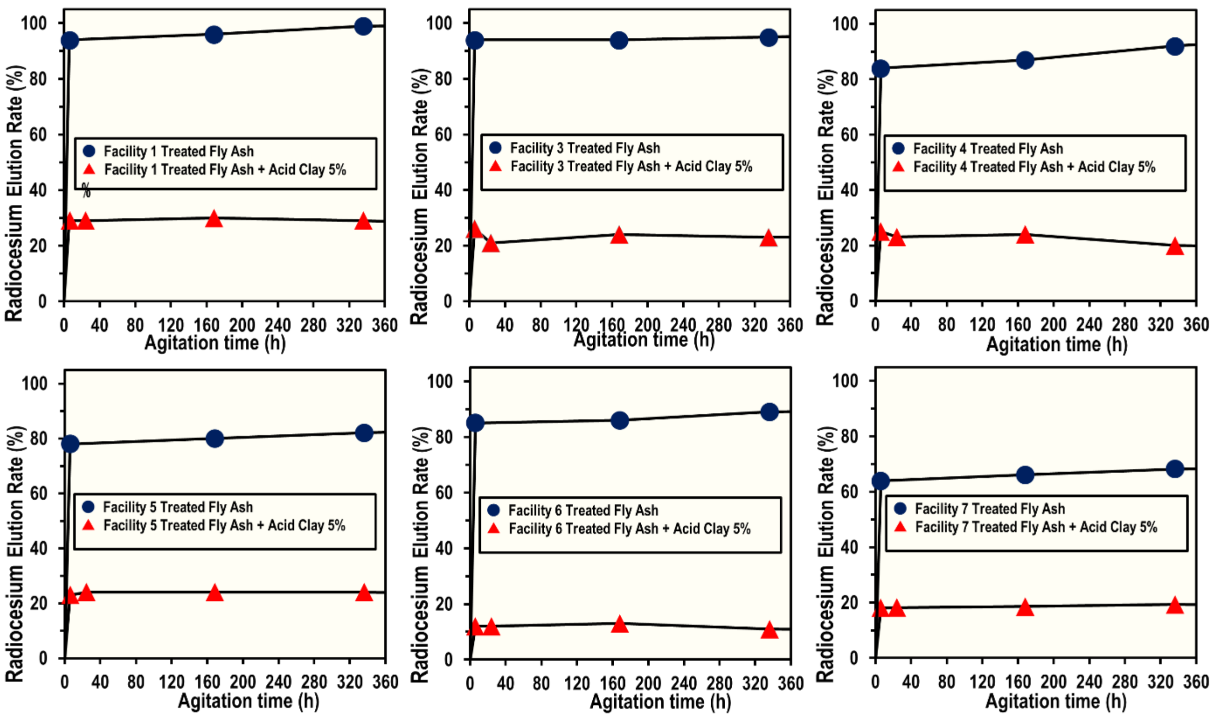

Figure 1. Results of radiocesium elution suppression tests (radiocesium elution rates)

(2) Tests on radiocesium elution suppression in incineration ash at municipal waste incineration facilities

(a) A Test during a normal operation

An elution test using incineration ash sampled during the normal operation indicated that the radiocesium concentration and radiocesium elution rate were higher for fly ash than they are in the bottom ash. Repetitive elution tests conducted on the same samples indicated that the radiocesium elution rate at the first test was the highest (Table 1 and 2). Furthermore, based on comparison with the elution test in which zeolite was added to fly ash and to the treated fly ash, it was concluded that zeolite suppresses radiocesium elution and that zeolite addition do not block the heavy metal elution suppression effect of chelate agent.

Table 1. Results of repetitive elution tests using bottom ash (during normal operation)

Item		Unit	Bottom Ash (1st day afternoon)			
			1st	2nd	3rd	4th
JISK0058-1	Radiocesium Concentration (elution)[*1]	Bq/L	0.5	0.3	0	0
	pH	-	11.7	11.3	10.8	10.9
	EC	mS/m	420	109	55.0	42.9
	Radiocesium Elution Rate[*2]	%	2.0	1.2	0	0
	Hg	mg/L	<0.0005	<0.0005	<0.0005	<0.0005
	Cd		<0.009	<0.009	<0.009	<0.009
	Pb		<0.03	<0.03	<0.03	<0.03
	As		<0.01	<0.01	<0.01	<0.01
	Se		<0.01	<0.01	<0.01	<0.01
	Cr		<0.02	<0.02	<0.02	<0.02
	Cl-		1,010	136	46.0	14.7

* Each value is calculated with its radiocesium concentration (content) as of 250 Bq/kg.

Table 2. Results of repetitive elution tests using treated fly ash (normal operation)

Item		Unit	Chelated Fly Ash (1st day afternoon)			
			1st	2nd	3rd	4th
JISK0058-1	Radiocesium Concentration (elution)[*1]	Bq/L	120	10	1	0
	pH	-	12.4	12.5	12.6	12.6
	EC	mS/m	3,380	1,150	911	871
	Radiocesium Elution Rate[*2]	%	75.0	6.3	0.6	0
	Hg	mg/L	0.0006	<0.0005	<0.0005	<0.0005
	Cd		<0.009	<0.009	<0.009	<0.009
	Pb		0.16	0.10	0.14	0.14
	As		<0.01	<0.01	<0.01	<0.01
	Se		<0.01	<0.01	<0.01	<0.01
	Cr		0.07	<0.02	<0.02	<0.02
	Cl-		10,400	1,200	256	88.6

* Each value is calculated with its radiocesium concentration (content) as of 1,600 Bq/kg.

(b) Tests on zeolite addition to an exhaust gas treatment agent at actual facilities

An exhaust gas treatment agent and zeolite were mixed and injected (by blow injection) into exhaust gas at waste incineration facilities. As a result, the mixture neither negatively affected the exhaust gas nor blocked the heavy metal elution suppression effect of chelate agent and was able to suppress the radiocesium elution caused by contact between treated fly ash and water.

(c) Tests on zeolite addition to the mixture of fly ash and chelate agent by kneading at actual facilities

When zeolite was added to chelated fly ash, the kneaded mixture did not block the heavy metal elution suppression effect of the chelate agent and it suppressed radiocesium elution to the same degree as the blow injection mentioned above.

(3) Situations of landfill and radiocesium elution

As a result of investigating the situations of incineration ash landfill and radiocesium concentrations in leachate at landfill disposal sites, no radiocesium was detected from the leachate of the sites where only bottom ash was landfilled, and radiocesium was detected from leachate of the sites where fly ash was landfilled in contact with water in the same way as before the accident and also at some landfill disposal sites where fly ash was landfilled without contact with water.

(4) Correlation between the annual elution situation of radiocesium and other elements

When radiocesium concentrations in leachate were measured at four landfill disposal sites where radiocesium had been detected from leachate for two consecutive years, no common seasonality trend in radiocesium concentration was observed (Figures 2 and 3). In addition, no seasonality in radiocesium concentration was observed in any disposal site.

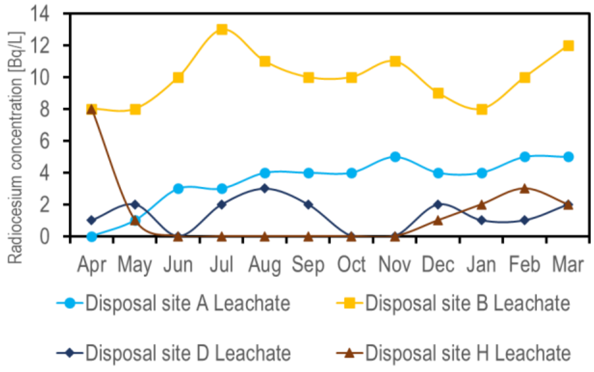

Figure 2. Measurement results in FY 2017

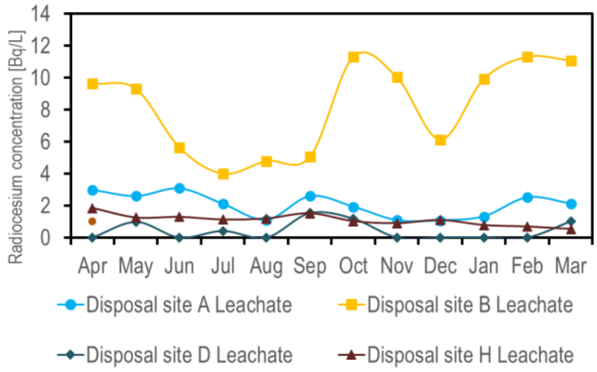

Figure 3. Measurement results in FY 2018

Regarding a relationship between the concentrations of radiocesium and other elements, a positive correlation was observed between radiocesium elution concentration and chloride ion elution concentration (Figure 4). This suggests the possibility that the chloride ion concentration in incineration ash and the level of chloride ion elution affect the radiocesium elution.

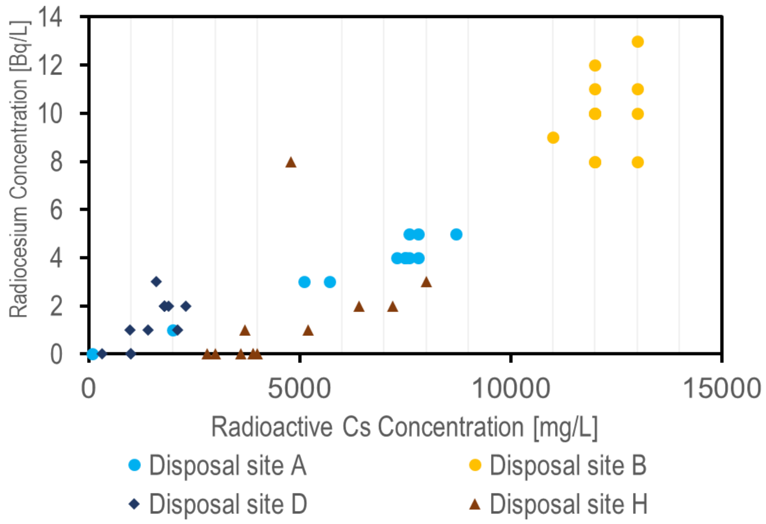

Figure 4. Correlation between radiocesium and chloride ion concentrations

5.4. Conclusions

In order to study methods for treating, disposing of, and managing radiocesium-containing fly ash generated in the prefecture, we conducted investigations and tests at landfill disposal sites and waste incineration facilities. As a result of investigating leachate, we found that the landfilling of fly ash in contact with rainwater causes radiocesium elution from the fly ash, resulting in radiocesium being detected from leachate.

In order to suppress radiocesium elution from the fly ash, we conducted elution tests using incineration ash as well as tests for suppressing radiocesium elution from the incineration ash in laboratory and landfill disposal sites. As a result, we found that the addition of zeolite to incineration ash significantly suppresses radiocesium elution. However, the application of these methods to actual disposal facilities requires the consideration of the characteristics of each incineration facility and landfill disposal site, including consideration of an increase in the amount of landfill disposal due to zeolite addition as well as facility structure and capacity.