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

Cooperation between Fukushima Prefecture and the IAEA

SUMMARY REPORT (2013 to 2017)

[Fukushima Prefecture Initiative Projects]

Outline

(temporary translation)

March 2018

Fukushima Prefecture

1. FIP1: Survey of radionuclide movement in river systems

1.1. Purpose

The accident at Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Plant in 2011 resulted in wide contamination of the prefectural area with radioactive materials. Since river water is commonly used for drinking water and farming, it is important to clarify the dynamics of radioactive materials in rivers, and provide necessary information for the safe use of river water. If radiocaesium adsorbed by suspended particulate matters and flows downstream in a suspended form, re-deposition after events, such as floods, may affect the ambient air dose rates. Accordingly, the migration of dissolved radiocaesium through the ecosystem should be considered (Figure 1). Thus, we evaluated the dynamics of radiocaesium depending on its form. The purpose of this survey is to investigate the dynamics of radiocaesium transport with river flow down in Fukushima prefecture and to verify it by model simulation based on the monitoring data.

1.2. Content of implementation

The monitoring network was established in Hirose River basin. The survery was started from fiscal year 2013 at each monitoring point established in the mainstream of Hirose River and its tributaries (Figure 1 (a)). The wide-area survey was conducted at many points of the Abukuma River basin and eight water rivers in Hamadori area (Figure 1 (b)). At each monitoring point, we have monitored the turbidity and water level continuously and collected suspended sediments by suspended sediment samplers.

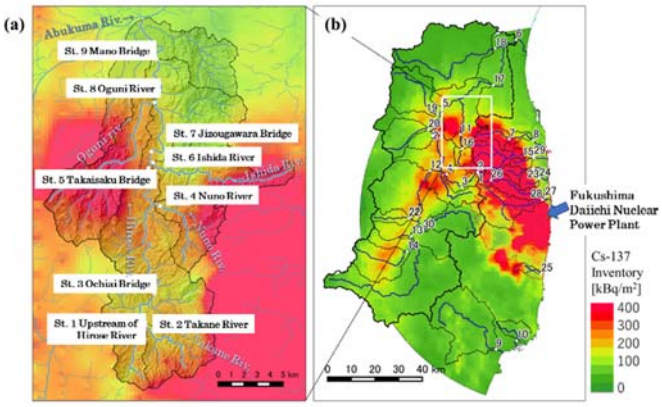

Figure 1: Monitoring points in this survey and the initial amounts of Cs-137 in these area (as of 2 July, 2011).
(a) The Hirose River basin. The numbers in the figure were corresponded to those in Table 3.
(b) The subjected area in the wide area river survey. MEXT (2011). Regarding the Results of the Third Airborne Monitoring.

1.3. Results

As water flows down the Hirose River, both dissolved and suspended radiocaesium concentrations changed. We verified these changes by the TODAM model. Figure 2 shows an example of the results. For this simulation, the ordinary water level and flow rate were set as base conditions, and the actual radiocaesium concentrations at the upstream end of Hirose River main stream and major tributaries were used as the boundary conditions The TODAM model could roughly reproduce the radioactive caesium

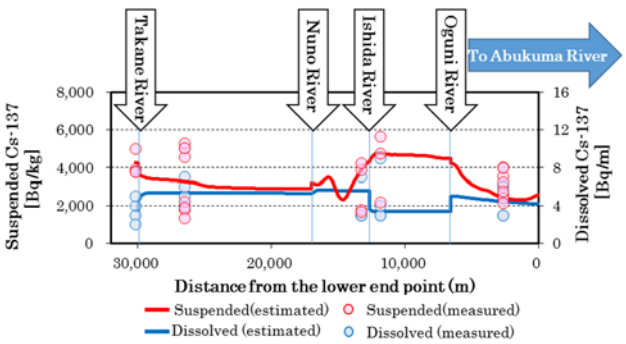

Figure 2: A result of simulation by TODAM model.

concentrations at each monitoring point in the Hirose River.

In the wide-area survey, the suspended caesium-137 concentrations collected at Abukuma River and rivers in Hamadori area until May 2017 are shown in Figure 3. The values were varied because of the difference in the initial amounts of caesium-137 deposition among the basins. However, it was commonly observed that caesium-137 concentrations decreased in all points during about one year from the accident significantly. This rate of decrease was slightly slowed down, but such trend has still continued until now. This continuous decline was seemed to result from the surface decontamination practices in the terrestrial area, which was widely conducted in the object basins. However, the similar trend was observed in European rivers after the Chernobyl nuclear plant accident (without the surface decontamination). Thus, it can conclude that the natural attenuation caused the decreasing trend observed in this survey.

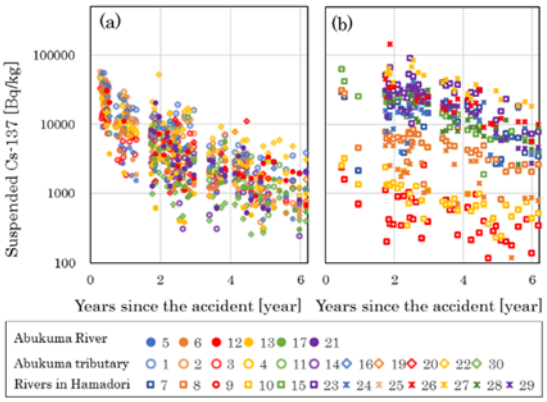

Figure 3: The changes of the suspended Cs-137 concentrations in river waters.
(a)Abukuma River basin,
(b) Rivers in Hamadori area

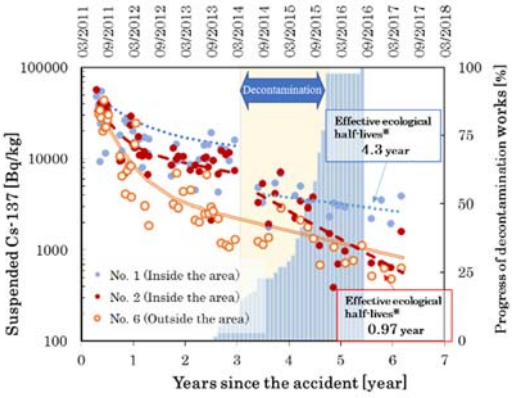

Figure 4: Suspended Cs-137 concentrations at upstream points of the Mizusakai (No.1) and Kuchibuto River (No.2).
Blue bar: Progress of surface decontamination (agricultural land) in the area.

In addition, the effects of the surface decontamination on the suspended caesium-137 concentrations were investigated at the two monitoring points (No.1 (Mizusakai River) and No.2 (upper stream of Kuchibuto River) in Fig. 1(b)). The effects would be pronounced at the points because the basin including those points was totally assigned as the special decontamination area. Figure 4 showed the relationship between the suspended caesium-137 concentrations and the progression rate of the surface decontamination of the agricultural lands within the basin. It was shown that the intensive efforts were conducted from April 2014 to December 2015 in the object area. During the period, the drastic decrease in the suspended caesium-137 concentrations coincided with the advance in the surface decontamination.

1.4. Conclusions

We established the monitoring network in the Hirose River basin and investigated the dynamics of radiocaesium with river flow. The simulation by the TODAM model using the monitoring data could roughly reproduce the change in radiocaesium with the river flow in the Hirose River. Further works are needed to improve the prediction accuracy by the continuous monitoring and the reevaluation of the effects by Oguni River basin due to its high initial radiocaesium level. On the other hand, the suspended radiocaesium

concentrations showed the decreasing trend with time at the Abukuma River basin and major rivers in Hamadori area as the wide-area multipoint survey. In addition, the effects of the surface decontamination were detected at some monitoring points. It can conclude that the continuous monitoring and the subsequent assessment was important because of the possible changes in radiocaesium concentrations in river waters by such as the recovery of vegetation and resumption of agricultural practices.

2. FIP2: Survey of radionuclide movement with wild life

2.1. Purpose

After the accident at Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Plant, radiocaesium and other radionuclides have been detected in many wild animals inhabiting the natural environment. Therefore, we carried out survey and research on the dynamics of radiocaesium in the ecosystem to understand the implications for the lifting of restrictions, and make prefectural residents feel safe.

2.2. Content of implementation

(1) Investigating dynamics of radionuclide in wild animals

We measured and analyzed caesium-137 concentrations in the muscles of wild boars, Asian black bears, and other wild animals, and also in the stomach contents of wild boars.

(2) Investigating the home ranges of wild animals

We investigated behavior of wild boar by using GPS collars.

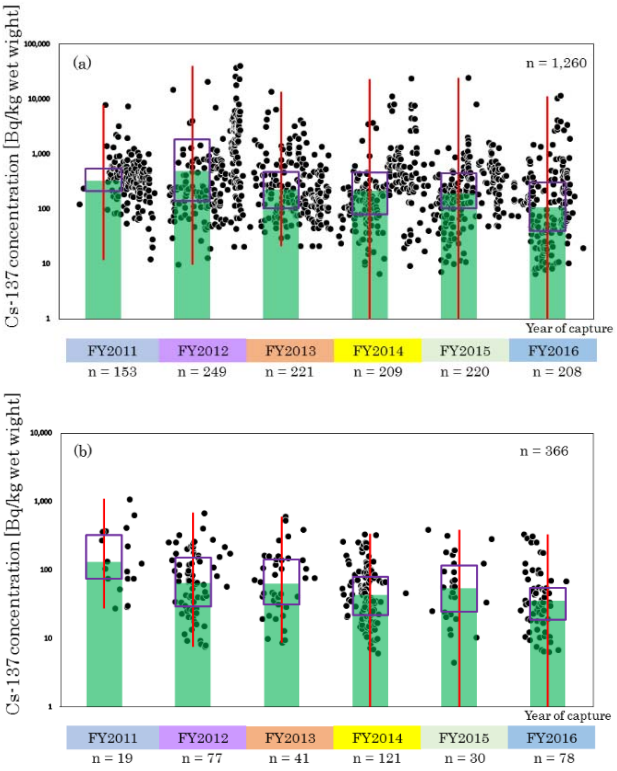

Figure 1: Annual changes of caesium-137 concentrations in (a)wild boar and (b)Asian black bear muscles (Period: May 2011 to March 2017).

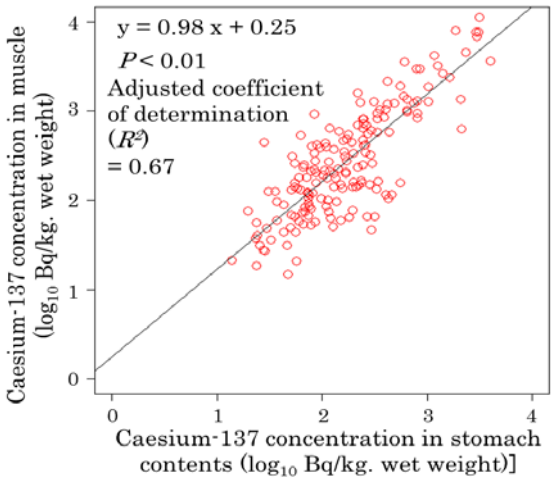

Figure 2: Relationship between caesium-137 concentration in muscle and in stomach contents of wild boar.

2.3. Results

(1) Dynamics of radionuclide in wild animals

A. Measurement of radionuclide concentrations in wild animals

Caesium-137 concentrations in the muscles of wild boars and Asian black bears were compared. Wild boars showed great dispersion between individuals and no clear tendency, but Asian black bears showed tendency of decrease. Tendency differed between species of wild animals (Figure 1). Birds also showed different tendencies depending on the species. When we compared wild boars and Asian black bears captured

where the caesium-137 soil ground deposition is the same, caesium-137 concentrations in muscles was higher in wild boars. In addition, caesium-137 concentration in muscle of Asian black bear and wild boar varied with the seasons.

B. Radionuclide migration from the environment into wild animals

We investigated relationships between caesium-137 concentrations in muscles and in the stomach contents in wild boar. Individuals having higher caesium-137 concentrations in stomach contents showed higher caesium-137 concentrations in muscles (Figure 2). This confirmed the strong effect of intake of caesium-137 such as food item and soil.

(2) Investigating the home ranges of wild animals

We investigated the behavior of wild boars by using GPS collars. The wild boars living outside the evacuation order zone showed larger home ranges than the individuals living inside the zone where the human pressure is weak (Figure 3).

For comparison, we sampled eight individuals whose data could be acquired for one month or longer in the periods from November to December (winter) and from January to February (breeding season). Although the number of samples was small, home ranges tended to be greater in the evacuation order zone than outside (Figure 4). We also investigated habitat type in the home ranges of individuals. In home ranges of individuals at the evacuation order zone, farmland occupied a high percentage. It suggested that the home ranges of individuals in the evacuation order zone tended to extend to farmland (Figure 5).

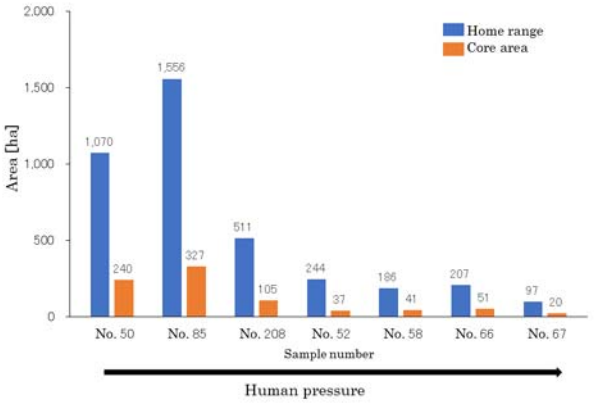

Figure 3: Comparison of home range and core area.

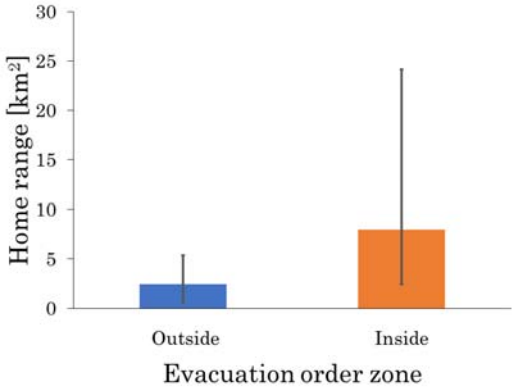

Figure 4: Average of home range size of wild boars inside and outside the evacuation zone. Error bar indicates minimum and maximum value.

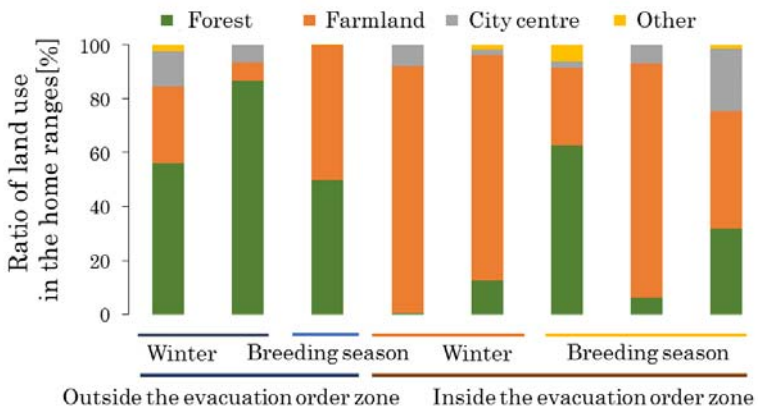

Figure 5: Ratio of land use in the home ranges of wild boars inside and outside the evacuation order zone (each bar indicates the value for an individual).

2.4. Conclusions

① When caesium-137 concentrations in muscles were compared between wild boars and Asian black bears, wild boars showed greater values. The tendency differed between species.

② Caesium-137 concentrations in the muscles of wild boars were found to have been strongly affected by food habits. Both wild boars and Asian black bear showed seasonal variation.

③ Compared with wild boars outside the evacuation order zone, individuals inhabiting the zone tend to have larger home ranges and shifted to farmland.

To find out the cause of high caesium-137 concentrations in wild boars, we are investigating food habits in detail by using cameras and performing DNA analysis on stomach contents while comparing with Asian black bears and other species. It is considered necessary to monitor the transition of radiocaesium concentrations in wild boars and predict future tendencies.

3. FIP3: Countermeasures for radioactive materials in rivers and lakes

3.1. Purpose

As a result of the Fukushima nuclear disaster, radioactive caesium was released into the environment. This disturbed the use and management of rivers and lakes and caused public concern. Therefore, we evaluated measures to counteract environmental caesium based on the findings of previous studies and our researches.

3.2. Content of implementation

(1) Selection of suitable measures against radiocaesium in Fukushima Prefecture

(2) Riverside decontamination and the sustainability of its effect

(3) Investigation of contamination in riverside parks and the selection of countermeasures

(4) Interview survey on issues related to the water environment and investigation of temporal trends

3.3. Results

(1) Selection of suitable measures against radiocaesium in Fukushima Prefecture

Issue	Related media	Measures
Internal exposure by drinking	Rivers and lakes	Changing water sources
Transfer from irrigation water to agricultural products and external exposure during farming	Rivers and lakes	Reducing sediment inflow using silt fences Sediment deposition in dams
	Irrigation ponds	Reducing sediment outflow using silt fences Decontamination of bottom sediments
	Agricultural products	Potassium fertilisation to suppress uptake
Internal exposure by the consumption of fishery products	Rivers and lakes	Shipping restrictions Potassium input (effective only in closed lakes)
External exposure by the use of watersides (parks, roads, residences, etc.)	Rivers and lakes	Use restriction and soil decontamination Removing riverbed sediments to reduce sediment deposition onto riversides Embankment for inundation control
	Irrigation ponds (at drainage)	Use restriction, decontamination, and covering of exposed bottom sediments
Common to all issues		Source decontamination and sediment discharge prevention Risk communication to reduce anxiety about use

(2) Riverside decontamination and the sustainability of its effect

Radiocaesium is distributed in topsoil in farmland and residential areas, whereas it is frequently observed at greater depths in riverside sediments. Sediment removal that considers the spatial

distribution of radiocaesium is important for effective riverside decontamination. Although recontamination associated with floods has been negligible, it may be dependent on the condition of the riverside, including the recovery of plant communities. Accordingly, it is necessary to devise suitable countermeasures against recontamination.

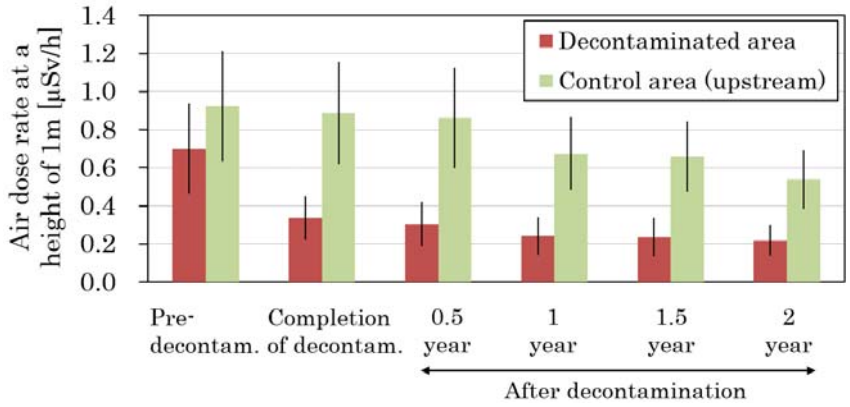

Figure 1: Temporal changes in the air dose rate at 1 meter above the ground. Values are presented as means and standard deviation.
(lower part of the Kami-Oguni River, a tributary of the Abukuma River in Fukushima).

(3) Investigation of contamination in riverside parks and the selection of countermeasures

We investigated the contamination state at riverside parks of the lower part of the Niida River, which is one of the main rivers in the coastal region of Fukushima Prefecture and is heavily contaminated in the upstream area. On the riverside, the radiocaesium inventory was increased by a factor of ten and the air dose rate was several times higher. However, an extreme flood caused soil erosion and the deposition of a low radiocaesium concentration in the sediment, resulting in a significant attenuation of the air dose rate. Additional external exposure dose during activities at the parks was estimated to be below 0.1 mSv per year, indicating that these activities are safe.

(4) Interview survey on issues related to the water environment and investigation of temporal trends

We investigated issues related to the water environment in Fukushima Prefecture after the Fukushima Daiichi nuclear power plant disaster and evaluated temporal tends. At 5 years after the disaster, the Fukushima prefectural government indicated the following issues: ‘difficulty in continuing activities that were conducted before the disaster’, ‘the impact of radioactive materials in the future’ and ‘continuing countermeasures against the disaster’. In Fukushima Prefecture, the perception of the recovery of safety with respect to the water and air environments differed among regions. The recovery was slower in the central (Nakadori) and coastal (Hamadori) regions than in the western (Aizu) region. The view of safety was related to the perception of the radiation risk.

3.4. Conclusions

We reviewed countermeasures against radiocaesium according to local activity and evaluated a

decontamination measure to reduce external exposure at riversides. Considering the contamination condition of riverside parks, the selection of countermeasures should comprehensively account for the spatial distribution of radiocaesium, exposure dose rate, and user anxiety.

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

4.1. Purpose

To grasp the air dose rate (hereinafter, simply referred to as the dose rate) in Fukushima Prefecture after the accident at the Fukushima Daiichi Nuclear Power Plant, we have measured the dose rate employing a variety of methods, and we provide this information on our homepage.

However, it is difficult to conduct fixed-point measurements or car-borne surveys in the alleys of residential areas, parks, or forests. We therefore developed environmental mapping technology that uses GPS walking surveys (hereinafter, simply referred to as walking surveys) to supplement other forms of monitoring.

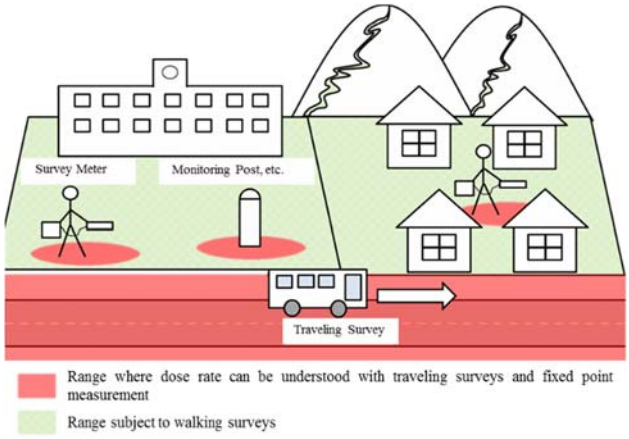

Figure 1: Measurement range of walking surveys.

4.2. Content of implementation

(1) Development of equipment

We used KURAMA-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 dose rates. We used a high-precision GPS device and stored the equipment in a backpack as a configuration that is appropriate for walking surveys.

Picture 1: Image of a walking survey.

(2) Gathering parameters necessary for walking surveys

Because the contribution of radiation sources varies depending on the direction in walking surveys, owing to obstruction by the measurer himself or herself, we confirmed the direction characteristics.

To decide the correction factor employing comparative tests with survey meters, we used the dose rate measured 1 m above ground by a NaI (Tl) survey meter, whose traceability has been established as the most certain, and compared that dose rate with the measurement obtained in walking surveys.

4.3. Results

Results for the direction characteristics indicate that the effect of direction characteristics on measurements of walking surveys is weak. Additionally, in our comparison with NaI (Tl) survey meters, we found that it is necessary to use different detectors for low and high dose rates with 1 μSv/h as the dividing line.

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

4.4. Conclusions

Certain results have been achieved in the development of walking surveys by 2015, making it possible to measure the dose rate in a walking survey.

In fiscal 2016, we are conducting walk surveys or lending necessary equipment at the request of municipalities.

5. FIP5: Study of the proper treatment of waste containing radioactive materials at municipal solid waste incinerators

5.1. Purpose

We thus conducted tests to confirm the effectiveness of methods to control the migration of radiocaesium to bottom ash and fly ash. After understanding general aspects of the radiocaesium leaching characteristics of incineration ash generated in Fukushima Prefecture, we examined technologies and methods to make radiocaesium in bottom ash and fly ash less soluble.

We evaluated the radiocaesium distribution in bottom ash and fly ash, damage to equipment at the municipal solid waste (MSW) incinerator and impact on the environment when bag filter cloths were co-incinerated together with MSW.

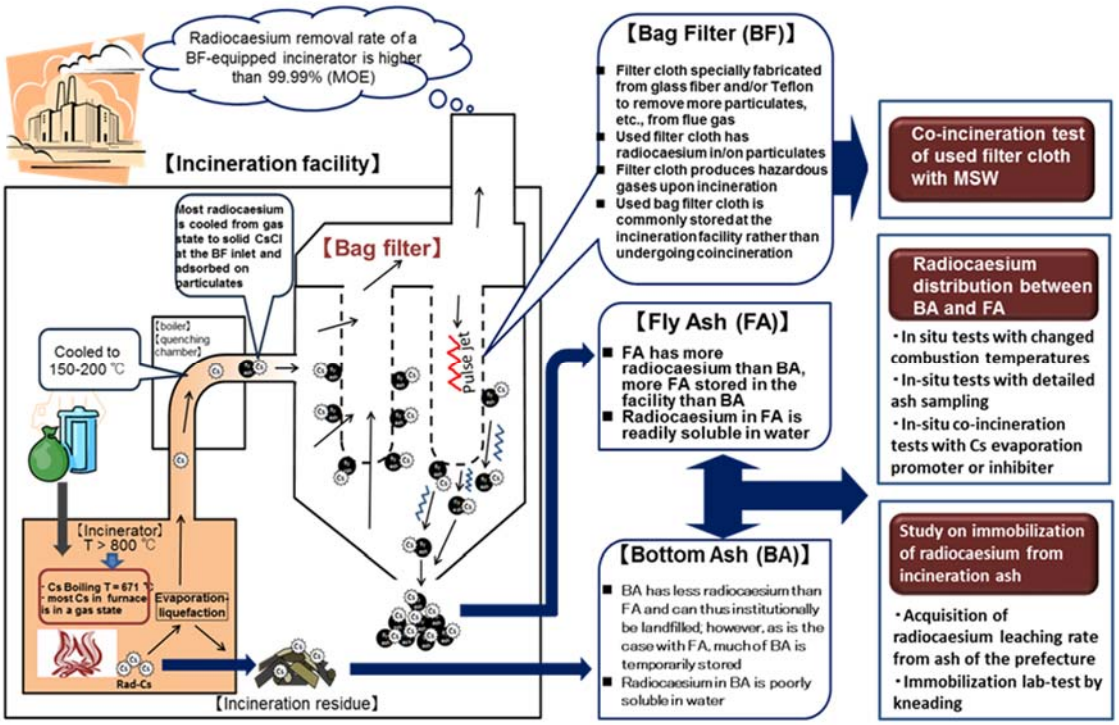

Figure 1: Waste incineration processes and research issues.

5.2. Content of implementation

(1) Radiocaesium distribution between bottom ash and fly ash

- Effects of combustion temperature

  We raised and lowered the combustion chamber exit temperature by about 50℃, and compared the radiocaesium distribution in bottom ash and fly ash with the usual distribution to investigate the impact of temperature changes on migration.

- Continuous sampling test

  We sampled bottom ash and fly ash continuously during ordinary operation and investigated the relationships between combustion temperature and radiocaesium migration to bottom ash and fly ash.

- Effects of a radiocaesium evaporation accelerator and inhibitor

  We added a caesium evaporation accelerator (hydrated lime) and inhibitor (bentonite) at the waste

hopper and investigated their effects.

(2) Proper treatment of used filter cloths of bag filters

At two MSW incineration facilities that use filter cloths of different materials were compared. We co-incinerated used filter cloths with MSW by changing input ratio and interval to check the impact on the combustion status.

(3) Study of the reduction of radiocaesium leaching from fly ash

- Data acquisition of radiocaesium leaching characteristics

  We carried out leaching tests for bottom ash and fly ash in the prefecture to investigate the leaching characteristics of radiocaesium.

- Laboratory radiocaesium immobilisation test

  We investigated the capability of zeolite and other materials to reduce radiocaesium leaching from fly ash.

5.3. Results

(1) Radiocaesium distribution between bottom ash and fly ash

The addition of an evaporation promoter caused radiocaesium to migrate to fly ash. However, reproducibility could not be confirmed. We did not detect clear relationships between combustion temperature and radiocaesium behaviour.

(2) Proper treatment of used filter cloths of bag filters

We co-incinerated used bag filter cloths with MSW at their original incineration facilities. There was no impact on the combustion status when the cloths mixing rate was appropriate.

(3) Study on the reduction of radiocaesium leaching from fly ash

- Date acquisition of radiocaesium leaching characteristics

  We conducted tests of radiocaesium leaching from bottom ash and fly ash generated at fifteen MSW incineration facilities in Fukushima Prefecture. Despite a very low leaching rate from bottom ash, as expected (less than 1% to 16%), we confirmed a very high rate of leaching from fly ash (35% to 94%).

- Laboratory radiocaesium immobilisation tests

  We investigated changes in the radiocaesium leaching rate in response to the addition of zeolite, bentonite, and sewage sludge in bottom ash and fly ash. Zeolite showed a remarkable reducing effect on radiocaesium leaching (from 79.1% to 4.3%).

5.4. Conclusions

Regarding relationships between radiocaesium distribution to fly ash and combustion temperature and chemicals, observations showed but poor reproducibility. We will conduct laboratory tests to understand what the differences in waste composition causes the cesium distribution to fly ash. We co-incinerated used bag filter cloths with MSW at their original incineration facilities. There was no impact on the combustion status when the cloths imput ratio was appropriate.

Adding and mixing of zeolite to incineration ash was proved effective for reduction of radiocaesium

leaching from fly ash. We will continue the study to pursue more effective additives and mixing methods and identify materials with greater immobilisation capability.

Contents of main support received from IAEA

1. FIP1 Survey of radionuclide movement in river systems

- Provision of the TODAM model, a numerical simulation of contaminant migration in a river network, for the quantitative estimation of radionuclides deposited in rivers.
- Technical guidance on the selection of monitoring points and monitoring items, with an emphasis on the importance of continuous monitoring at each monitoring point, based on previous studies of Chernobyl and Mayak.
- Advice about the operation of TODAM model using the monitoring data by the prefecture, that is, the importance of measuring the K_d value (solid-liquid distribution coefficient) and sediment particle size distribution at each observation point, as well as ion concentrations in rivers.
- Advice about the effectiveness of combining wide-area monitoring and simulation models, and the importance of including small lakes as research subjects for improving our understanding of the dynamics of radioactive materials in rivers.
- Advice about the need to assess the impact of decontamination and analyzing data excluding artificial effects.
- Support for on-site inspections concerning radionuclides monitoring in Ukraine, Germany, Slovakia, and so on.

2. FIP2: Survey of radionuclide movement with wild life

- Provision of foreign literature describing the relationship between wild animals and radionuclides, such as radionuclide migration to wild animals, including boars and deer, in various regions following the Chernobyl nuclear disaster and changes in radiocaesium levels in the bodies of birds, such as the American gallinule and American wood duck, at the Savannah River Ecology Laboratory.
- Provision of information about recent scientific results concerning the bioaccumulation of radiocaesium and in vivo radiocaesium concentration measurement technology.
- Discussions of study results and data analysis methods, such as the potential for mushrooms to explain a higher radiocaesium concentration in wild boars than those in other taxa in Fukushima Prefecture, based on observation that mushrooms (deer truffles) cause a high radiocaesium concentration in the muscle tissues of wild boars in Europe.
- Explanation of the impact of the Chernobyl disaster on wildlife animal groups in surrounding areas, the dynamics of wolves and other animals and survey methods to clarify these impacts.

3. FIP3: Countermeasures for radioactive materials in rivers and lakes

- Provision of information related to the environmental dynamics of radioactive materials in rivers and lakes.
- Provision of information related to global environmental remediation activities in rivers and lakes, including the removal of radioactive materials (countermeasures against the discharge of radioactive material from the heavily contaminated floodplain in the vicinity of the Chernobyl nuclear power

plant, and countermeasures against the inflow of radioactive materials into the Kiev Reservoir).

- Facilitation of a visit to the Chernobyl accident site.
- Recommendation regarding the evaluation of a radiocaesium decontamination test in a riverside (e.g., selection of the study site, simulation before decontamination, particle size of sediment, and density of the plant community).
- Advice on the study of countermeasures against radiocaesium in riverside parks (investigation of the history of floods, dikes and dredging to prevent recontamination).
- Recommendations about the study of Fukushima prefectural residents' anxiety and issues related to the water environment (including the age and sex of residents as factors).
- Support related to the preparation of published materials (papers).

4. FIP4: Developing of environmental mapping technology using GPS walking surveys

- Provision of information about efforts made by various institutions, such as the United States Environmental Protection Agency and Lawrence Berkeley National Laboratory, to perform local radiation dose mapping.
- Suggestion that inverse-distance weighting (IDW) is more appropriate than Kriging as a means of interpolation for walking surveys using GIS and that the shielding effect of buildings and the like must be considered.
- Advice to judge measurement conditions of walking surveys according to the conditions at each measurement point, as uniform measuring conditions are not always necessary.

5. FIP5: Study of proper treatment of waste containing radioactive materials at municipal solid waste incinerators

- Provision of information related to treatment methods employed in other countries for fly ash, treatment methods employed in other countries for low-level radioactive waste (i.e., incineration, melting treatment of metal, and plasma melting) and instruments for measuring the concentrations of radioactive substances in waste.
- Technical advice about the incineration of general waste, such as the need for studies conducted from the perspective of the radiocaesium balance of payments, the importance of comparative analyses of actual test data and model analysis results, and the need to optimize test conditions and assess waste quality.
- Advice about the importance of countermeasures against the generation of hydrogen fluoride in the mixed incineration of bag filters (made from Teflon).
- Advice regarding the safety (e.g. exposure protection and management) of facility workers.
- Suggestion that reducing radiocaesium elution from fly ash is important for the margin of safety when landfilling fly ash.