SUMMARY REPORT
(2013 – 2017)

Executive Summary

Cooperation between the International Atomic Energy Agency and Fukushima Prefecture and Activities undertaken by Fukushima Prefecture

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

30 May 2018

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1. Objectives and scope of the cooperation

A memorandum titled, Practical Arrangements between Fukushima Prefecture and the International Atomic Energy Agency on Cooperation in the Area of Radiation Monitoring and Remediation (herein referred to as 'Practical Arrangements') and Modification No. 1 to the Practical Arrangements were signed by representatives of Fukushima Prefecture (herein referred to as 'the Prefecture') and the IAEA in December 2012 and April/May 2016, respectively. The objective of the Practical Arrangements is to set forth the framework for cooperation between the Prefecture and the IAEA, and to provide broad and extensive assistance in the Prefecture in areas related to radiation monitoring and remediation in order to ensure on-going protection of people and the environment from ionizing radiation resulting from the Fukushima Daiichi accident. This Executive Summary of the 5 Year Summary Report summarizes the current status and progress made in the cooperation conducted under the Practical Arrangements and activities undertaken by the Prefecture from 2013 through 2017.

2. Long Term Monitoring of Radioactive Material in Forests and Associated Countermeasures

When the Practical Arrangements were signed in 2012, the Prefecture determined that the most significant radiological hazard to people was that from external radiation emitted by ^{137}Cs and ^{134}Cs (collectively referred to herein as radiocaesium), which was present in both the terrestrial and aquatic ecosystems. The Prefecture concluded that radiocaesium levels in the environment, and associated doses to people would decline without intervention as a result of the radioactive decay of radiocaesium, and the removal of radiocaesium by weathering from surfaces and vertical migration down soil and sediment profiles. Once deposited within forests, radiocaesium is retained and recycled within the forest ecosystem.

In this area of cooperation, the Practical Arrangements focused on research and study on radiation monitoring, including: application of environmental mapping technology by using unmanned aerial vehicles; long term monitoring of radioactive materials in the forest areas, and associated countermeasures and the IAEA's assistance in the use of radiation monitoring data to develop maps to be made available to the public. As part of the cooperation, the IAEA also provided advice to the Prefecture on the long term monitoring of radiocaesium in forests and associated countermeasures performed by the Prefecture in relation to characterizing the distribution of radiocaesium, establishing radiation monitoring programmes, reviewing the effectiveness of countermeasures, developing the *Satoyama* Rehabilitation Model Project, addressing countermeasures for reducing radiation exposures of forest workers, assessing the radiological effects of forest fires, and assessing the implications of radiocaesium transfer to forest mushrooms and bamboo shoots.

Outcomes of Activities Undertaken by the Prefecture

An extensive work programme has been undertaken by the Prefecture to better understand the behaviour of radiocaesium in forests. The key conclusions which the Prefecture derived from this programme to date are:

— Radionuclides deposited in the forests of the Prefecture are effectively retained within the ecosystem and the likelihood of transfers of radiocaesium to agricultural land appears to be low.
— A long term monitoring programme in forests has been established by the Prefecture to track the rate of reduction of the air dose rate. Compared with August 2011, the air dose rate overall has decreased by about 70%. When only the original 362 monitoring locations that were established in 2011 are considered, between August 2011 and March 2017, the number of survey points with measured air dose rates of less than 0.23 μSv/h increased from 42 to 309; also, the number of survey points with measured air dose rates of greater than 1 μSv/h decreased from 127 to 61. These results are broadly in line with the reduction of air dose rate due to radioactive decay of radiocaesium. See Fig. 2.1, which shows measured air dose rates, estimated air dose rates based on the radioactive decay of radiocaesium, and estimated air dose rates in the future at 362 monitoring points in forests within the Prefecture.

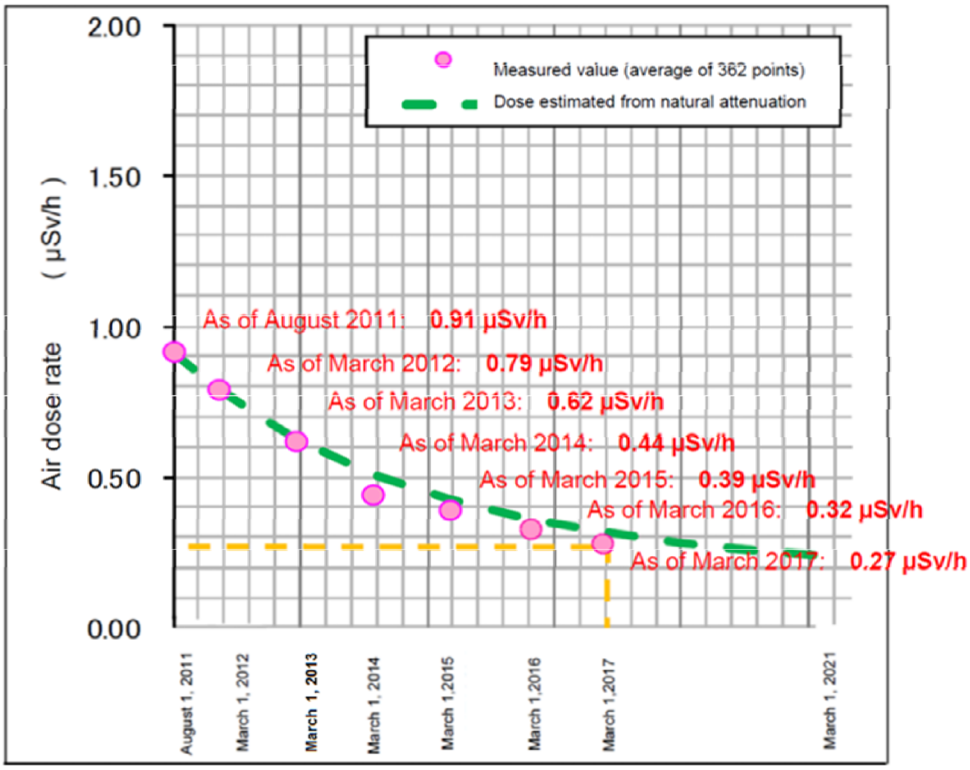

FIG 2.1: Measured air dose rates, estimated air dose rates based on radioactive decay of radiocaesium, and estimated air dose rates in the future at 362 monitoring points in forests within the Prefecture (Fukushima Prefecture)

— Forest maintenance procedures have helped to prevent erosion and soil-loss and are also very effective at retaining radiocaesium within forests.
— The presence of clay minerals in the underlying forest soils will chemically bind the radiocaesium and limit its transfer to vegetation. The result is that, for the same deposition, based on measurements undertaken by the Prefecture, the activity concentrations of radiocaesium in plants and animals in the Prefecture's forests are considerably lower than those observed in European forests after the Chernobyl accident.
— Based on experience with radiation monitoring in areas affected by the Chernobyl accident, radiation monitoring in forests may be necessary for many more years and monitoring procedures for measuring air dose rates and the radioactive content of trees may need to be adjusted to account for changing conditions such as the movement of radiocaesium in the

environment and the deposition of radiocaesium in waterlogged areas where the uptake by vegetation would be higher.

— Since 2012, most of the radiocaesium initially deposited in forests has been transferred from the trees to the soil and litter layers. The feasibility of removing large amounts of soil in order to reduce the air dose rate is not practical; it is expensive, produces additional waste material that must be managed, and has the potential to reduce the productivity of the forest.

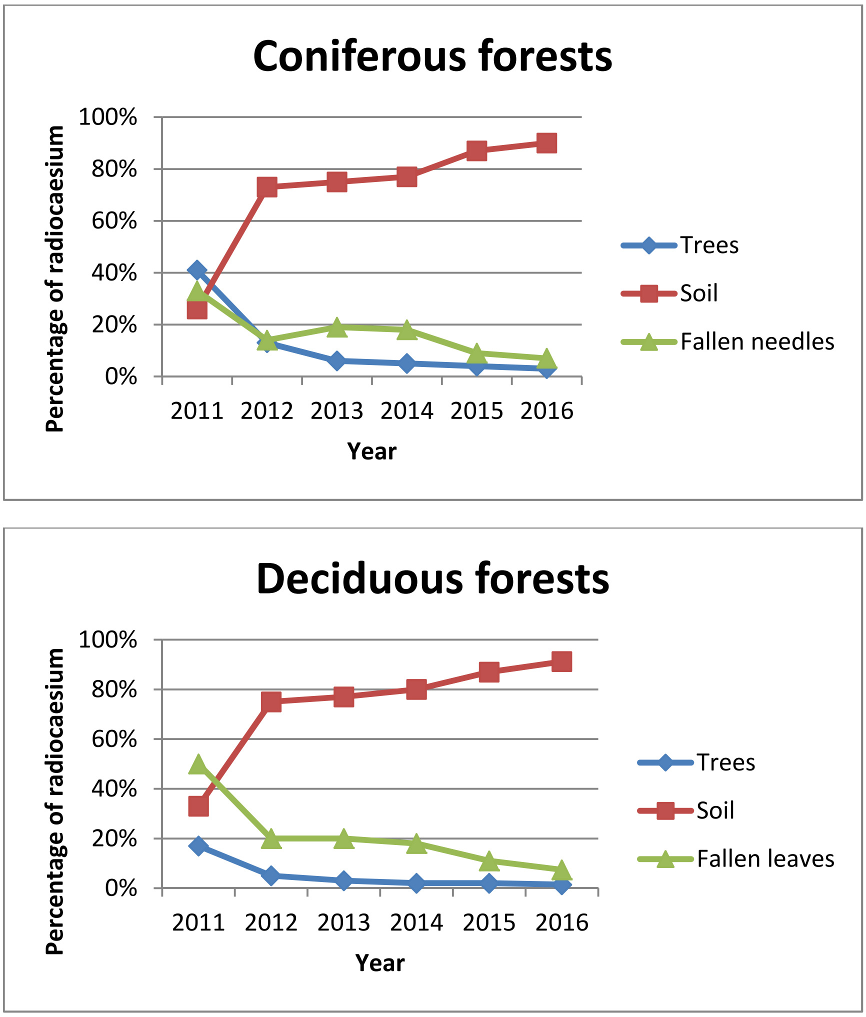

FIG 2.2: Change in distribution of radiocaesium in the Prefecture's coniferous forests and deciduous forests from 2011 to 2016 (Ministry of Agriculture, Forestry and Fisheries, and the Fukushima Prefectural Forestry Research Centre)

— Covering the forest floor with soil or wood chips that has no radiocaesium is an effective means of reducing air dose rates. However, such procedures are expensive and their long term effectiveness should continue to be evaluated. Regardless, it may be justified to apply them over limited areas with high air dose rates, especially if such areas are close to inhabited areas.

— Various issues should be addressed in the early stages of the *Satoyama* Rehabilitation Model Project such as the possible generation of radioactive waste, the effectiveness of countermeasures, and defining how the success of the project will be evaluated.

— To date there appears to be no need to restrict the production and use of the timber harvested from forests. However, monitoring of timber should continue, especially as work commences in areas with higher concentrations of radiocaesium.

- Measures have been implemented to restrict the radiation exposure of forest workers; these include the use of harvesting machines and limitations on working hours. Overall, a conservative approach has been taken in order to reduce the radiation doses of these individuals.
- Studies of forest fires conducted by the Prefecture have not identified a significant radiological impact that resulted from these events. However, forest fires may have had a greater radiological impact if they had occurred soon after the Fukushima Daiichi accident when more of the radiocaesium inventory was in the litter layer and available to be redistributed as a result of forest fires.
- It is important that monitoring programs are maintained by the Prefecture so that any unforeseen changes in the behaviour of radiocaesium in forests are quickly identified and addressed. If survey data indicates that air dose rates over time are relatively stable, it may be justified to reduce the number of samples collected and monitoring points maintained.

3. Use of Radiation Monitoring Data to Develop Maps to be Made Available to the Public

In this area of cooperation, the Practical Arrangements focused on the IAEA's assistance in the use of radiation monitoring data to develop maps to be made available to the public.

As of the commencement of activities under the Practical Arrangements in 2013, the Prefecture maintained a website that made radiation monitoring data available to the public. The website provided detailed information on air dose rate measurements and measurements of radioactivity concentrations in material from several different sources.

As of 2014, the number of site visitors was approximately 20 to 50 thousand per month. The Prefecture gathered a number of recommendations from these users about how the website could be upgraded to better meet their information needs. The Prefecture also consulted with the public through a survey about ways in which the website could be improved. There was a clear wish for simple, easy to understand information, compatibility with mobile technology, and an explanation of the health risks.

The IAEA team presented information about web maps that have been developed in a number of countries and provided technical advice concerning the mapping of radiation monitoring data and presenting such information to the public.

Outcomes of Activities Undertaken by the Prefecture

The Prefecture recognized the availability of accurate and up-to-date information on the radiation situation in the Prefecture is important both for the local population and for visitors. Specifically, the Prefecture identified that while overview maps give a general view of how air dose rates are reducing with time, people also want more localized information regarding the location where they live, work or are visiting. The Prefecture's revised website that was finalized in 2016 made this information available in a form that is easy to understand and prioritized the most recent data while also ensuring that historic data is available for those who wish to review it. Clickable maps allow users to access data from specific points on a map (See Fig. 3.1). Air dose rates and the results of environmental samples are displayed on the same map. The variation of air dose rates with time can be accessed intuitively through the use of a "time ruler" (See Fig. 3.2).

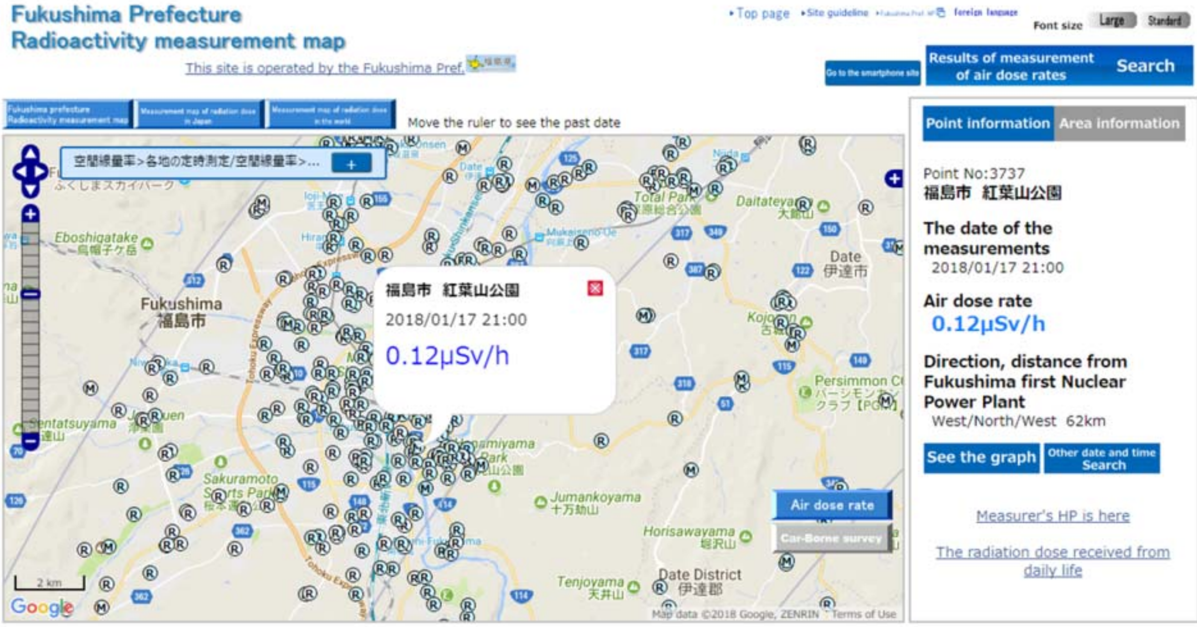

FIG. 3.1. Clickable Radiation Measurement Map (Fukushima Prefecture website)

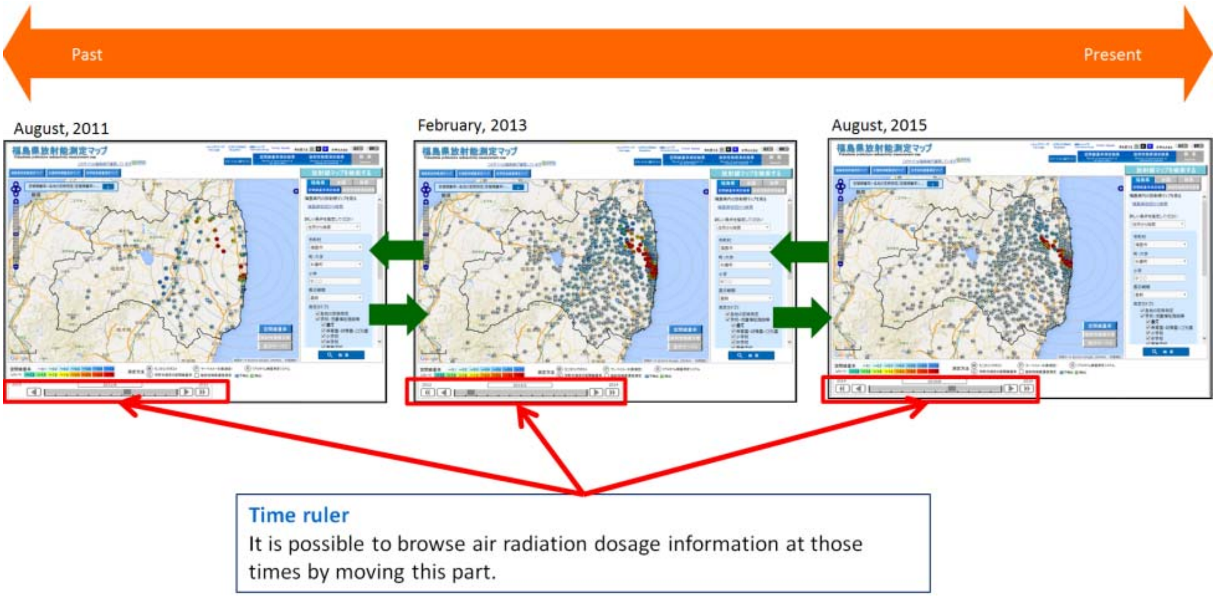

FIG. 3.2. Time ruler from Radiation Measurement Map (Fukushima Prefecture website)

In designing its website, the Prefecture recognized the challenge of making radiation data available to the public that had been collected in a number of different ways, each of which using different measurement methodologies. Over 3,000 monitoring stations provide continuous data from fixed locations across the Prefecture, and these are augmented by data collected by car-borne surveys (where radiation monitors are affixed to vehicles that are driven around the streets of the Prefecture).

The Prefecture recognized the challenges of presenting different datasets that were collected under varying conditions that could affect the results. For example, the air dose rate on a road is unlikely to be identical to that on a nearby footpath and snow cover in winter will reduce the air dose rate, which will increase when the snow melts.

The IAEA team noted that the provision of information through a website is only one component of a communications strategy.

The Prefecture identified the growing demand for the Prefecture to provide information and advice to potential returning evacuees on the expected reduction in air dose rate with time and the associated health risk. The presentation of such information must take account of reductions due to the physical half-life of radiocaesium and also the effectiveness of any applied countermeasures. Such calculations are site-specific and the uncertainties in the estimates of the future situation must also be provided. The Prefecture recognized that such information cannot easily be provided through a website and that further consideration will be necessary on how the Prefecture can best meet these needs.

4. Off-Site Decontamination and Environmental Monitoring

According to data collected and an assessment conducted by the Prefecture, significant amounts of radioactive fallout were deposited in the Prefecture as a consequence of TEPCO’s Fukushima Daiichi accident, especially in the area northwest of the Fukushima Daiichi Nuclear Power Plant. During the time period in which the Practical Arrangements were active, the Prefecture identified that the most significant radiological hazard to people was from external radiation emitted by radiocaesium. Based on data collected, the Prefecture determined that radiocaesium levels in the aquatic and terrestrial ecosystems, and associated doses to people have declined because of decontamination activities, radioactive decay, and the removal of radiocaesium by weathering from surfaces and vertical migration down soil and sediment profiles. Figure 4.1 shows air dose rates in the Prefecture at a height of 1 meter on August 28, 2011 (5 months post-accident) and November 18, 2016 (5 years and 8 months post-accident). These dose rates were calculated by using data obtained from aircraft monitoring. The Prefecture concluded that the significant decrease in dose rates was due to decontamination activities, radioactive decay, and the removal and movement of radiocaesium caused by natural processes.

The Prefecture recognizes the need for remediation and decontamination depends to a large extent on the evolution of doses to members of the public over time. Decisions relating to remediation activities are based on an assessment of future doses that would be reduced by remedial actions and those that would occur without intervention. It is therefore helpful to make predictions regarding changes over time in air dose rates and doses to people.

Item 2 of the Practical Arrangements focuses on research and study of off-site decontamination including the IAEA’s assistance in analyses of results of environmental monitoring and exploration of exposure pathways in order to reduce or avoid exposure. The cooperation addressed the following topics for which the IAEA provided technical advice:

- Behaviour of radiocaesium in the terrestrial and aquatic ecosystems in the areas of the Prefecture affected by the Fukushima Daiichi accident;
- Effectiveness of remediation and decontamination measures for aquatic systems;
- Analysis of monitoring results in order to identify time trends of radiocaesium concentrations in environmental media (soil, water, sediments) and of the air dose rate;
- Review of experience gained from remediation activities in order to elaborate input for the selection of appropriate and technically feasible remedial actions;
- Application of models to simulate radiocaesium flux in aquatic systems;
- Effectiveness of decontamination measures implemented in residential areas.

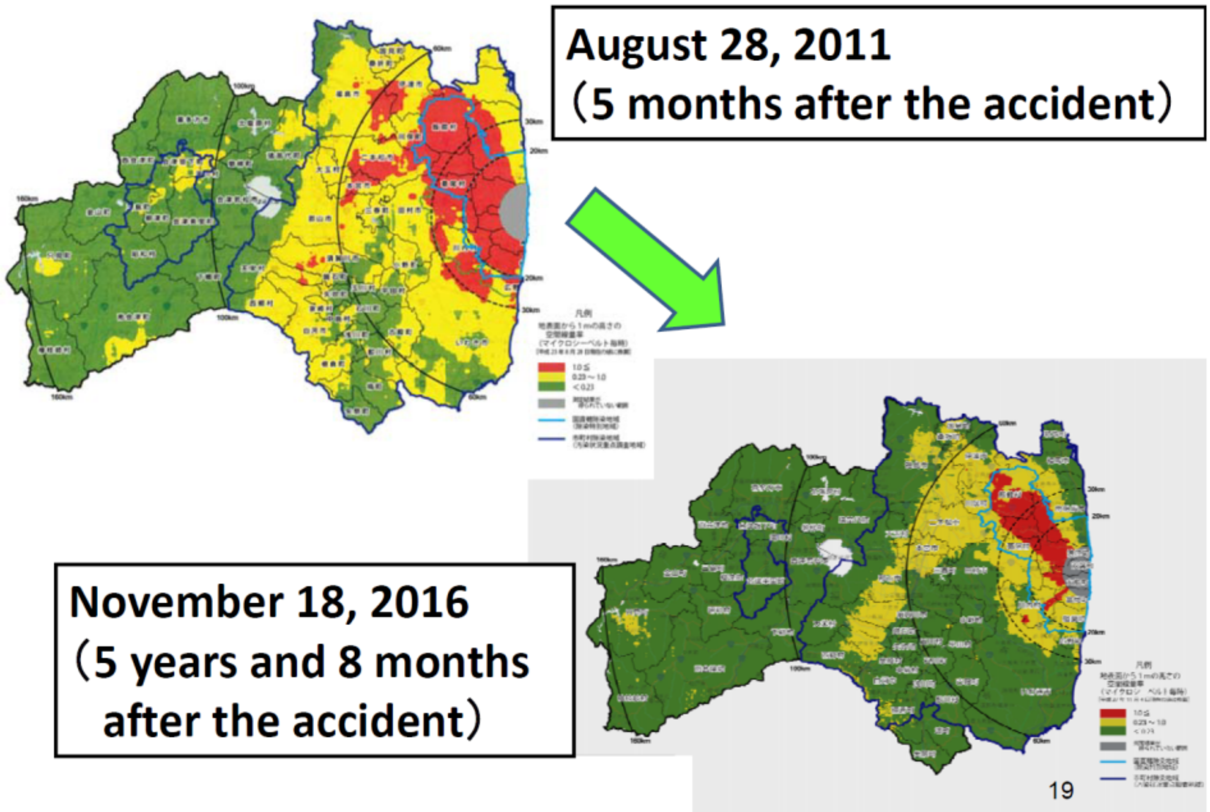

FIG. 4.1. Air dose rates in the Prefecture at a height of 1 m on August 28, 2011 and November 18, 2016 (Image credit: Fukushima Prefecture)

Outcomes of Activities Undertaken by the Prefecture

In general, in the terrestrial environment, caesium is strongly bound by mineral soil components, which results in its slow movement in soil and a low uptake by plants from soil. In freshwater ecosystems, caesium binds strongly to suspended sediments, which causes a rapid decline in dissolved radiocaesium, and the ultimate deposition of caesium that is bonded to sediment on the bottom of bodies of water.

In the freshwater bodies of the Prefecture — more than 6 years after the accident — measurements by the Prefecture indicate that dissolved radiocaesium levels in water are close to or below the detection limit of 0.05 Bq/L. This can be explained by the strong sorption of caesium by sediments in riverbeds, in which much higher radiocaesium levels are observed. There is also a clear decline of the concentration of radiocaesium in suspended sediments. Measurements performed by the Prefecture covered more than 30 points; the results for the suspended ^{137}Cs concentrations since 2011 are shown in Figure 4.2.

Measurements by research institutes in Fukushima Prefecture of radiocaesium in the in- and outflow of reservoirs show that the amount of suspended radiocaesium in the outflow is much less than in the inflow. This shows that reservoirs act as a kind of sediment trap.

Sorption of caesium to suspended matter plays a key role for its behaviour in the environment. Measurements by the Prefecture of the sorption of radiocaesium in soils and sediments show that it is in general stronger under the conditions of the Prefecture in comparison to the observations made after the Chernobyl accident in Ukraine and the Russian Federation.

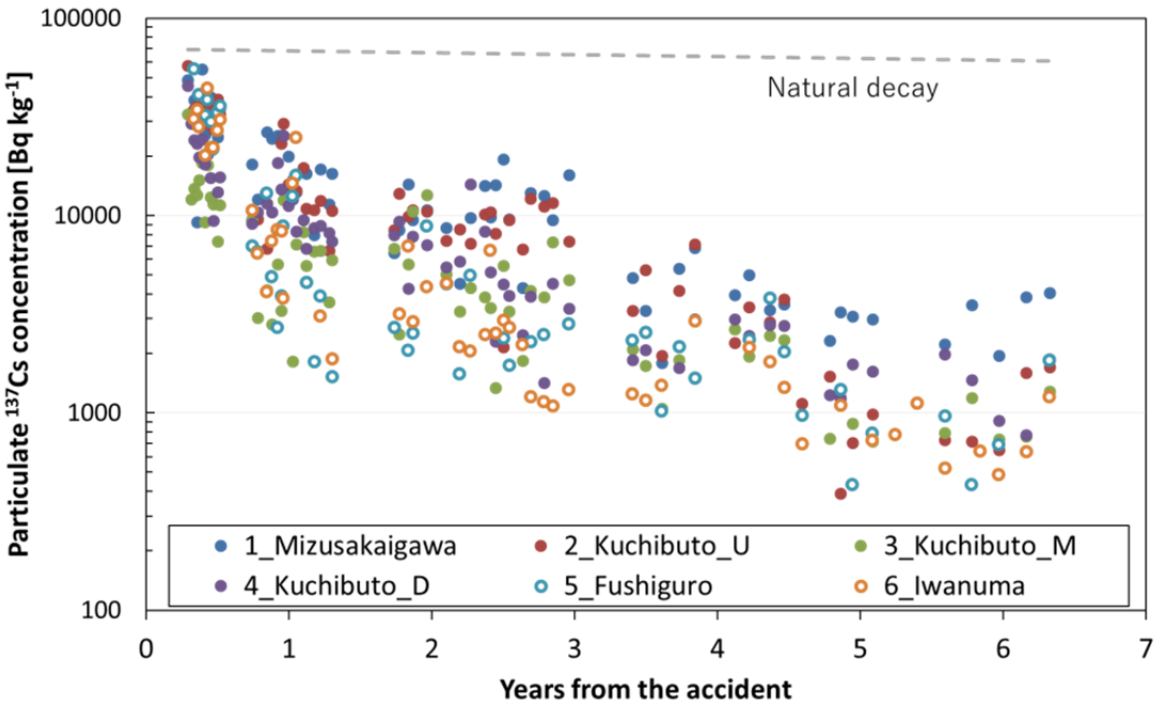

FIG 4.2. Decline of ^{137}Cs in suspended matter of rivers in the Prefecture from 2011 – 2017 (Fukushima Prefecture)

Measurements by research institutes in Fukushima Prefecture indicated that the amount of radiocaesium incorporated into zoo- and phytoplankton was very low. The radiocaesium activities for both phyto- and zooplankton range from tens to tens of thousands of Bq/kg (dry weight). This means that the total radiocaesium activity incorporated into phyto- and zooplankton did not exceed a small fraction of a percent of the radiocaesium present in the body of water.

To facilitate the interpretation of monitoring results, models were applied by the Prefecture to simulate the transport of radiocaesium from the catchment area through the river system to the Pacific Ocean. The Prefecture recognized that models were also very useful in assessing the effectiveness of remediation measures to be applied for rivers. In addition, simulation models allowed the assessment of the effect of re-contamination of rivers. The Prefecture recognized that if decontamination measures are necessary, the use of models may help to identify the most appropriate locations within the freshwater ecosystem to apply such measures.

Since the Fukushima Daiichi accident, the focus of remediation and decontamination activities of the Prefecture were on public areas including routes traversed by children going to and from kindergarten and schools, and on recreational areas. In addition, the Prefecture has initiated a number of projects concerning freshwater bodies to demonstrate the effectiveness of such countermeasures. Such measures reduce air dose rates. Some of the most common decontamination techniques that have been employed in the Prefecture are shown in Fig. 4.3.

FIG. 4.3. Main decontamination techniques (Photo credit: Fukushima Prefecture)

The IAEA team described worldwide experience with freshwater remediation activities which indicates that technical measures have not, for the most part, been able to control the dispersion of radionuclides in freshwater bodies. The IAEA team indicated that for reducing exposure to the public from radionuclides deposited in freshwater bodies, recommendations and restrictions with regard to the use of these freshwater bodies are relatively easy to implement and more effective in reducing exposure than technical measures.

Since 2011, intensive decontamination work has been carried out by the Prefecture in private homes, public facilities, roads, agricultural land, and forests. For residences (houses), decontamination is the most advanced; as of the end of October 2017, 99.9 % of the planned activities were completed.

The Prefecture applied specific sets of remediation actions to residential areas, public facilities, roads, agricultural land, and forests. Depending on the type of area, the Prefecture observed that air dose rates were reduced by approximately 20% – 50%; such a reduction in dose rates are very similar to those achieved by remediation measures in areas affected by the Chernobyl accident.

5. Management of Waste from Remediation Activities

As stated in Technical Volume 5, Post-accident Recovery, of the IAEA's *The Fukushima Daiichi Accident*, "According to the decontamination plan formulated by the MOE (Ministry of the Environment), contaminated soil and waste generated from remediation in the Prefecture are to be collected and stored at, or near, the sites undergoing remediation in temporary storage sites. Afterwards, the material will be placed in the ISF (Interim Storage Facility). After interim storage for up to 30 years, final disposal will be take place outside Fukushima Prefecture." The ISF is to be developed and operated by the central government. Temporary Storage Sites (TSS) have been established in municipalities and the Prefecture based on laws and government guidelines. Since the Fukushima Daiichi accident, the Prefecture has performed a significant amount of work concerning remediation activities and the management of the resulting radioactive waste.

Representatives of the Prefecture stated that when activities under the Practical Arrangements commenced in 2013, the Prefecture was faced with an urgent shortage of TSSs in which to store waste from remediation activities. Furthermore, the Prefecture noted concerns that were raised by the public about the safety of existing TSSs, and prospective TSSs that were to be established to accommodate radioactive waste generated by ongoing remediation activities. Also, it became necessary to store waste in TSSs for greater time periods than was originally intended. TSSs were established with the intention that waste would be stored in these facilities for only three years before being transferred to the ISF. However, because of delays in the development of the ISF, waste is now being stored in TSSs for more than three years. Consequently, the safety of the storage of waste in TSSs for more than three years is an issue that should be evaluated to ensure the safety of these facilities and also to address public concerns.

Item 3 of the Practical Arrangements refers to research and study on the management of radioactive waste including IAEA’s assistance in the study on management methods of low level radioactive waste from the above-referenced decontamination activities.

The activities concerning the management of waste from remediation activities under the Practical Arrangements consequently focused on providing technical advice to the Prefecture related to:

- finalizing technical guidelines for the establishment of temporary storage sites;
- demonstrating the safety of temporary storage sites in different situations for the different phases of their development; and
- retrieval strategies for waste stored in TSSs.

Outcomes of Activities Undertaken by the Prefecture

The use of the IAEA’s SAFRAN (Safety Assessment Framework software tool) provided the Prefecture with the ability to use an iterative approach in performing a safety assessment of TSSs. The three main types of TSSs that have been established in the Prefecture — aboveground storage, semi-underground storage and underground storage — are depicted in FIG 5.1. SAFRAN also provided a means for the Prefecture to go through the key steps in developing a safety assessment several times to refine assumptions, add elements, and optimize the balance between conservatism and realism. Since the safety assessment is updated automatically during each of these steps, Fukushima experts noted, the risk that such iterations lead to confusion, contradictions and the lack of consideration of important aspects is substantially reduced.

During the implementation of the software, a part of the SAFRAN database was changed by the IAEA team to fit to the specific conditions of the TSSs in the Prefecture.

Fukushima experts noted that the development of a safety assessment for the TSSs in the Prefecture through the application of SAFRAN to: a model TSS, a TSS in Fukushima Prefecture, and nine selected TSSs, is an important step toward establishing a safe and reliable way to store the large amount of radioactive waste accumulated from remediation activities after the Fukushima Daiichi accident.

During the development of the safety assessment for TSSs, several technical issues were identified whose impact on safety has been evaluated by the Prefecture (e.g. water accumulation in different places of the temporary storage, flooding, retrieval of waste bags from TSSs, transport of waste bags, collapse of waste packages, and blockages of exhaust piping). On the basis of these dedicated evaluations of the impact on safety, the Prefecture could establish technical measures to remediate and prevent the problems and could assess their effectiveness.

Fukushima experts concluded that the systematic process carried out using SAFRAN provided arguments and confidence that no significant issues were disregarded. It also provided a framework for explaining why certain systems and processes are considered safe and why certain improvements of safety and countermeasures are necessary.

The results gained through the use of SAFRAN and the analysis conducted by the Prefecture in the development of a safety assessment for the TSSs in the Prefecture clearly indicated that all radiation doses (calculated using conservative values) are in most of the cases well below the prescribed dose limits.

Following discussions with the IAEA team concerning retrieval strategies for waste stored in TSSs that took account of the ageing of waste bags, Fukushima experts noted that the safety assessment for TSSs should be revised to account for new information that arises as a result of the ongoing work on the ageing of waste bags.

Fukushima experts also noted that decommissioning of TSSs after all waste material has been removed will be a significant undertaking that should be approached in a systematic way.

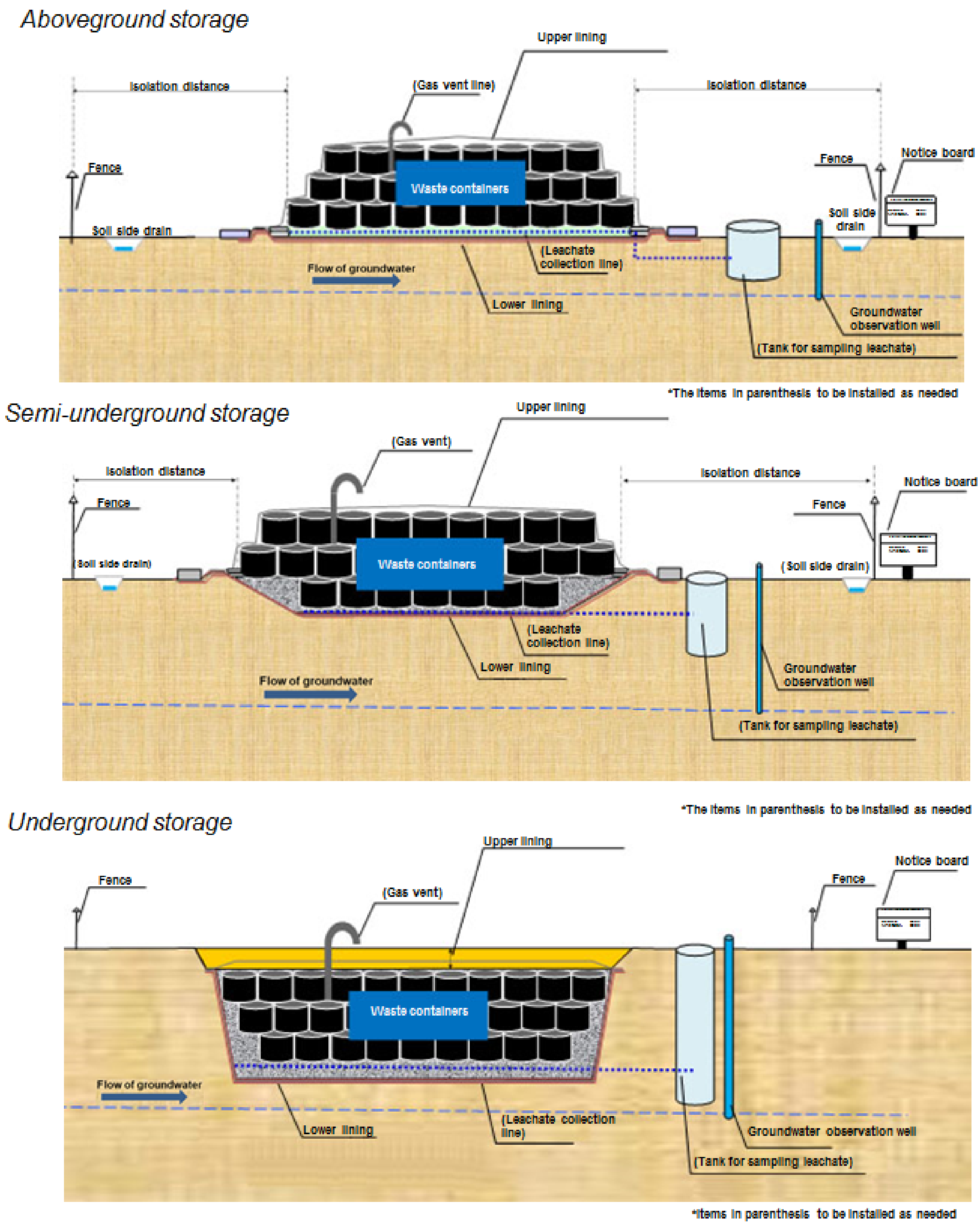

FIG. 5.1 Conceptual diagrams of three types of TSSs (Image adapted from Technical Guidelines for Temporary Storage Sites, Fukushima Prefecture)