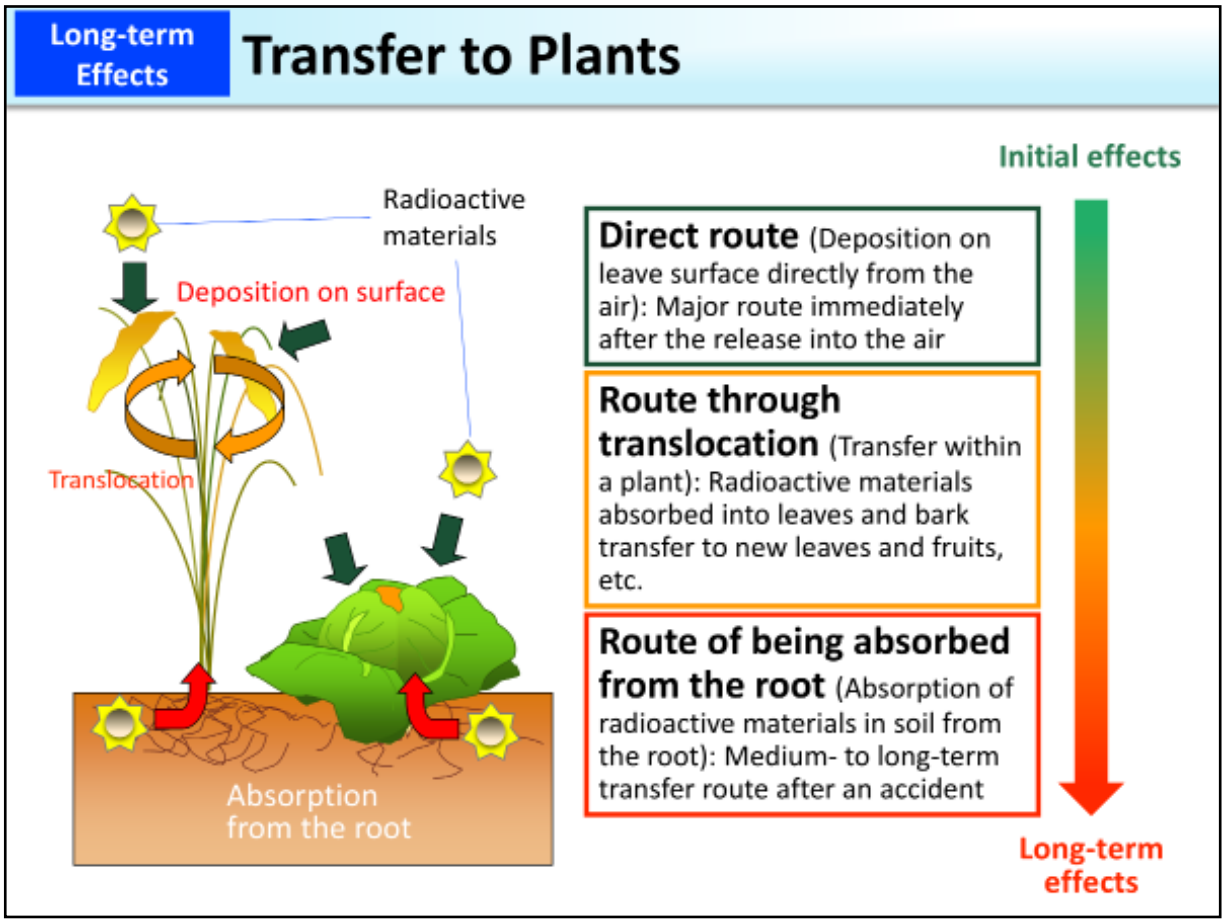


As Cs-137 has a long half-life of 30 years, once released into the environment due to an accident at a nuclear power station or other reasons, its effects may be prolonged. There are roughly three routes through which radioactive materials in the environment transfer to the edible parts of crops.

The first is the route wherein radioactive materials adhere to the surface of edible parts of crops directly from the air. Radioactive materials measured immediately after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS were those that were released into the air due to the accident and directly adhered to leaf surfaces.

The second is the route through translocation. Translocation refers to the phenomenon wherein absorbed nutrients or metabolites produced by photosynthesis are transported from some tissue to another tissue in a plant. Radioactive materials that adhere to leaves or bark are sometimes absorbed and transfer to new leaves and fruits within a plant. Relatively high levels of radioactive materials detected in tea leaves, bamboo shoots, loquats, plums, etc. are considered to have followed this route.

The third is the route wherein radioactive materials in soil are absorbed from the root. After the release of radioactive materials into the air stops, radioactive materials that fell onto farmland will mainly follow this route and will be absorbed into crops from the root.

Included in this reference material on March 31, 2013
Updated on March 31, 2019

Distribution of Radioactive Cesium in Soil

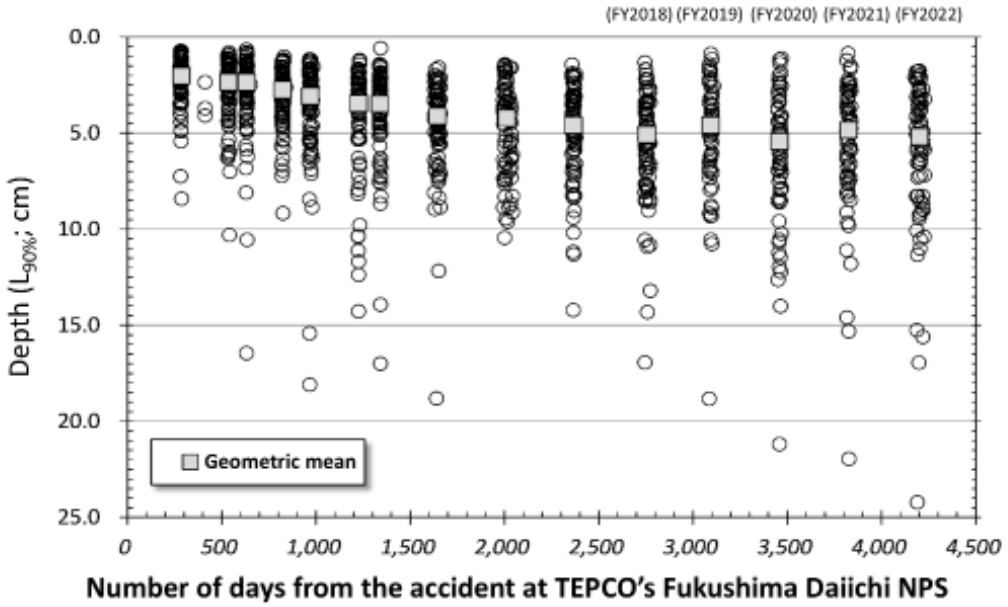


Figure: Data on changes over time in depth ($L_{90\%}$)* since December 2011 (85 locations at uncultivated land in Fukushima Prefecture, the southern part of Miyagi Prefecture and the northern part of Ibaraki Prefecture)

(Reference) Depth ($L_{90\%}$): The depth from the ground surface where 90% of all deposited radioactive cesium is contained

Source: Prepared based on the outcome report, "Survey of Depth Distribution of Radioactive Cesium in Soil," of the FY2022 project, "Compilation of Data on Distribution of Radioactive Materials Released due to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS" commissioned by the Secretariat of the Nuclear Regulation Authority

Surveys concerning the depth distribution in soil of radioactive cesium released due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS have been conducted since FY2011 in Fukushima Prefecture, the southern part of Miyagi Prefecture and the northern part of Ibaraki Prefecture.

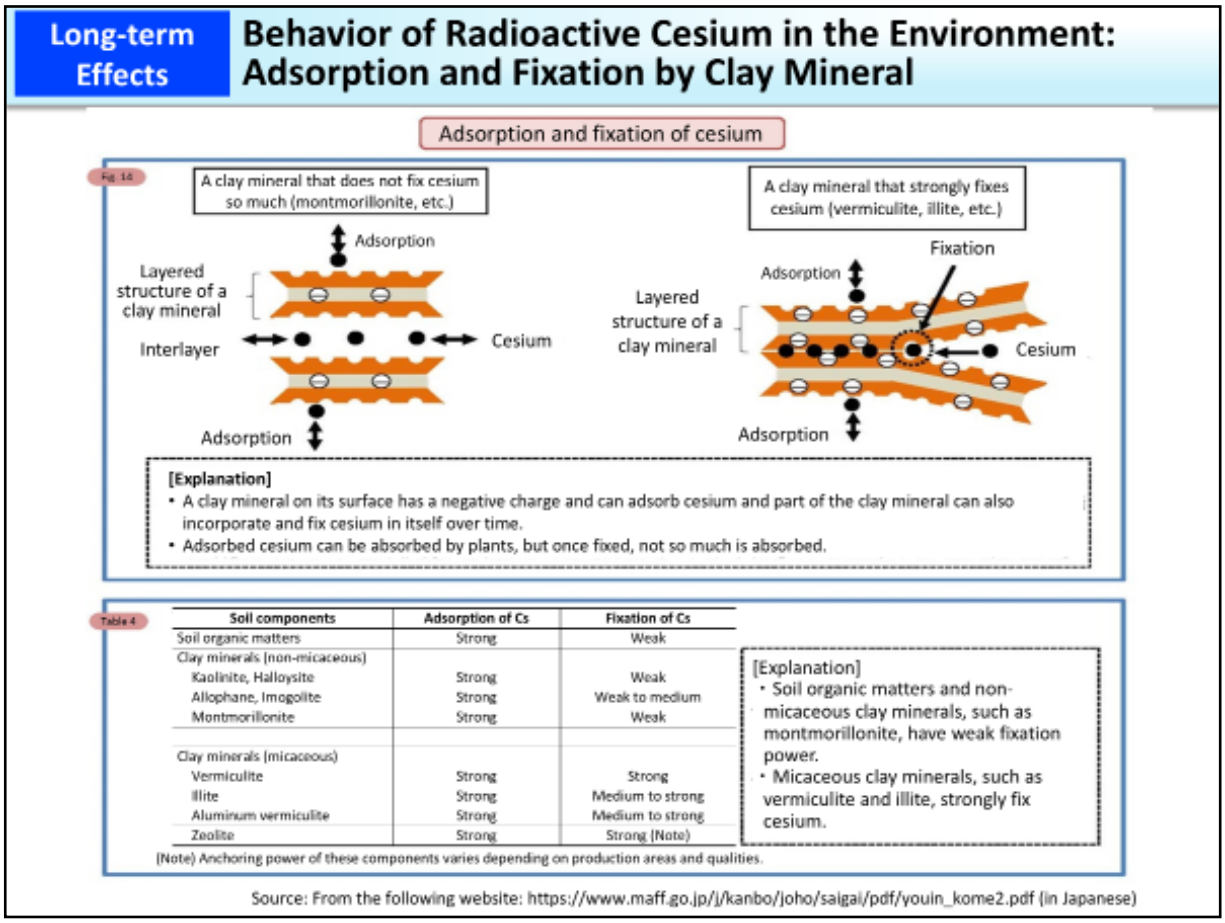
The depth from the ground surface containing 90% of all deposited radioactive cesium has been changing gradually over time, and the geometric mean as of September 2022 was 5.18 cm.

Distribution of radioactive cesium varies depending on the status of soil such as cracks and as a result of decontamination work or deep plowing. Clayey soil contains clay minerals such as vermiculite, which strongly adsorb cesium. Cesium adsorbed in such clayey soil becomes hardly soluble in water and is fixed and retained near the surface layer of the soil for a long term (p.182 of Vol. 1, "Behavior of Radioactive Cesium in the Environment: Adsorption and Fixation by Clay Mineral").

Accordingly, radioactive cesium thus retained near the surface layer is physically isolated from the root of the types of plants that take root deeper in the soil.

The survey on effects of the Chornobyl NPS Accident that occurred in 1986 revealed that approx. 80% of Cs-137 deposited on soil due to the accident had been staying within 10 cm from the ground surface even after 14 years from the accident (Report of the Chornobyl Forum Expert Group (2006), International Atomic Energy Agency).

Included in this reference material on March 31, 2017
Updated on March 31, 2024



Cesium has a similar chemical property as potassium, etc. (having a positive charge) and can be easily adsorbed by clay minerals that have a negative charge superficially. Furthermore, some clay minerals have the ability to fix cesium that they have adsorbed, as time proceeds. It is known that cesium, once fixed, becomes hardly soluble in water.

Radioactive cesium released into the environment due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS has been adsorbed and fixed by clay minerals in soil as time passes and not much has been absorbed into crops (the above figure).

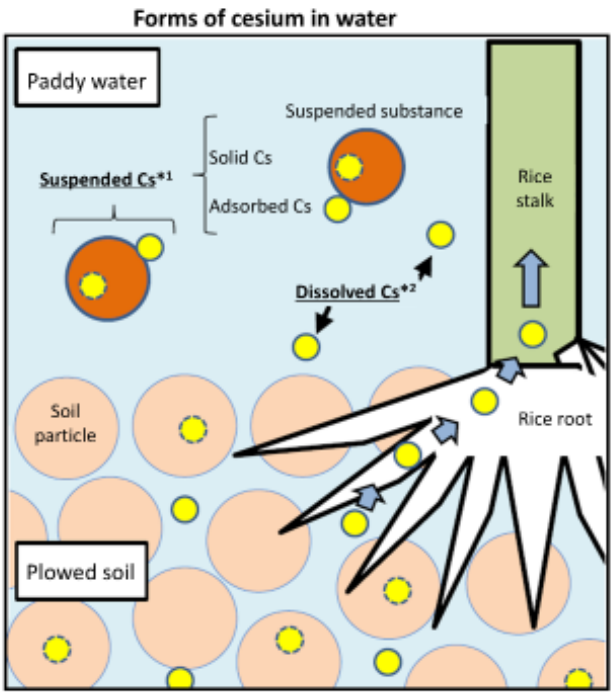
In particular, micaceous clay minerals, such as vermiculite and illite, are known to have the property to strongly fix cesium (lower table).

Research and studies conducted so far have confirmed a declining trend over time in the concentration of radioactive cesium in river water samples collected in Fukushima Prefecture, as well as a declining trend over time in the concentration of radioactive cesium that flows into rivers from forests, etc.[1]

1. Outcome report of the FY2014 project, "Compilation of Data on Distribution of Radioactive Materials Released due to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS and Development of Transfer Model" commissioned by the Secretariat of the Nuclear Regulation Authority

Included in this reference material on March 31, 2017

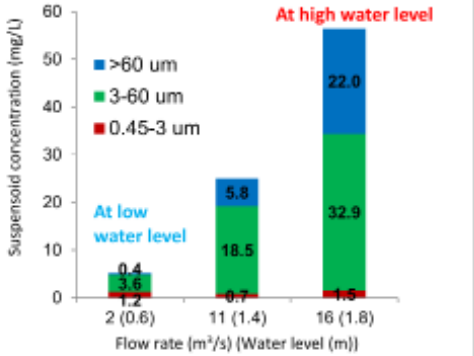
Long-term Effects — Behavior of Radioactive Cesium in the Environment: Transfer from Water to Plants



*1: Suspended form: Radioactive materials adsorbed and fixed in soil particles or organic matters; Suspended Cs is seldom absorbed directly from the root or stalk of rice.

*2: Dissolved form: Radioactive materials dissolved in water

Results of the survey conducted downstream of the Ukedo River (Ukedogawa Bridge) (2014)



Concentration and shape of suspensoid in river water at high water level

Concentration of dissolved and suspended Cs in river water

At low water level / At high water level

River flow rate	2 m³/s	16 m³/s
Concentration of dissolved Cs-137	0.3 Bq/L	0.3 Bq/L
Concentration of suspended Cs-137	0.1 Bq/L	2.2 Bq/L
Percentage of dissolved Cs	75%	12%
Total concentration of Cs-134 and Cs-137	0.6 Bq/L	3.3 Bq/L

Source: From the following websites (in Japanese):
http://www.maff.go.jp/j/kanbo/joho/saigai/pdf/youin_kome2.pdf
https://fukushima.jaea.go.jp/report/document/pdf/pdf1702/hokokukai11.pdf

When paddy fields are plowed and watered, the water contains dissolved cesium and suspended cesium adhering to soil particles, etc. However, cesium adsorbed or fixed in soil is seldom dissolved in water and suspended Cs is not absorbed directly from the root or stalk of rice (figure on the left).

Cesium in reservoirs and water channels is adsorbed or fixed in soil as time passes. Therefore, in surveys in Fukushima Prefecture, radioactive cesium was mostly detected as being dissolved in water under circumstances where the river flow rate and turbidity were low and detected concentrations were lower than the detection limit for ordinary measurements of radioactivity concentrations (approx. 1 Bq/L).

As shown in the upper right figure, when the river flow rate is high such as upon a heavy rain (high water level), the concentration of suspensoid that has strongly adsorbed radioactive cesium becomes high (suspended Cs). Accordingly, when the water level is high, the concentration of dissolved Cs stays almost the same and only the concentration of suspended Cs becomes higher, but the latter also decreases over time. As the river flow rate increases, particles of suspended substances become larger and the turbidity increases. However, such turbidity can be solved through filtration. As shown in the lower right table, the survey conducted at the Ukedo River in Fukushima Prefecture confirmed that radioactive Cs concentrations in normal times were below the standard limit for drinking water (10 Bq/kg) and that radioactive Cs concentrations after filtration were below the detection limit (approx. 1 Bq/L) even for river water with high turbidity collected when the water level is high.

Included in this reference material on March 31, 2017
Updated on March 31, 2019

Long-term Effects: Behavior of Radioactive Cesium in the Environment: Outflow from Forest Soil

Surveys conducted so far revealed that the annual outflow rate of Cs-137 from forest soil is around 0.02% to 0.3% of the total amount of Cs-137 deposited on nearby watershed soil.

[Table 1] Outflow of radioactive Cs from watershed areas to rivers (Outflow rates)

Watershed area	Kawamata Town			Mt. Tsukuba	Marumori Town
	Around Mt. Iboishi*1	Around Mt. Ishihira*1	Around Mt. Kodaishi*1	Around Kasumigaura*2	Upstream of the Udagawa River*2
Survey period		44 to 45 days*3		21 months	15 months
Amount of Cs-137 deposited on soil (kBq/m³)	544	298	916	13	170-230
Amount of outflow of Cs-137*4 (kBq/m³)	0.087	0.026	0.021	0.06	0.22-0.34
Percentage of the amount of Cs-137 outflow against the total amount of Cs-137 deposited on soil	0.016%	0.009%	0.002%	0.5%	0.12-0.15%
Percentage of the annual amount of outflow of Cs-137*5	**0.13%**	**0.07%**	**0.02%**	**0.26%**	**0.10-0.12%**

*1: [Source] Outcome report of the FY2012 commissioned radiation measurement project, "Establishment of Methods to Ascertain Long-term Effects of Radioactive Materials Released due to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS," JAEA

*2: [Source] National Institute for Environmental Studies, 2012 and 2013

*3: Extracted and totaled comparable data for these three watershed areas obtained from October 1 to 9 or 10, from October 22 to November 3, and from November 29 or 30 to December 18 or 19, 2012 (44 to 45 days)

*4: ○ Watershed areas around Mt. Iboishi, Mt. Ishihira and Mt. Kodaishi: Total amount of Cs-137 in river water (dissolved Cs-137, suspended substances (SS) and large organic matters (leaves and branches flowing in the river))
- Dissolved Cs-137: The concentration of dissolved Cs in normal times (August and October 2012) multiplied by the river flow rate
- SS: The radioactive Cs concentration in SS samplers multiplied by the SS flow rate, which was obtained based on contiguous data from a turbidity meter and the river flow rate
- Large organic matters: The radioactive Cs concentration in organic matters multiplied by the total amount trapped

○ Watershed areas around Kasumigaura and the upstream of the Udagawa River: Cs-137 derived from SS

*5: The data indicated in the above table is converted into the annual outflow rate based on the outflow rate against the amount of Cs-137 deposited on soil and the survey period (calculated by the Ministry of the Environment).
Natural decay of radioactive cesium and precipitation during the survey period are not taken into consideration in the calculation.

Radioactive materials that adhered to tree leaves and branches immediately after the accident have transferred to the mulch layer and soil on the forest floor over time. At present, approx. 80% is retained in the soil surface layer and is strongly fixed in mineral soil (p.182 of Vol. 1, “Behavior of Radioactive Cesium in the Environment: Adsorption and Fixation by Clay Mineral”).

Surveys conducted so far revealed that the annual outflow rate of Cs-137 from forest soil is around 0.02% to 0.3% of the total amount of Cs-137 deposited on nearby watershed soil.

Reference

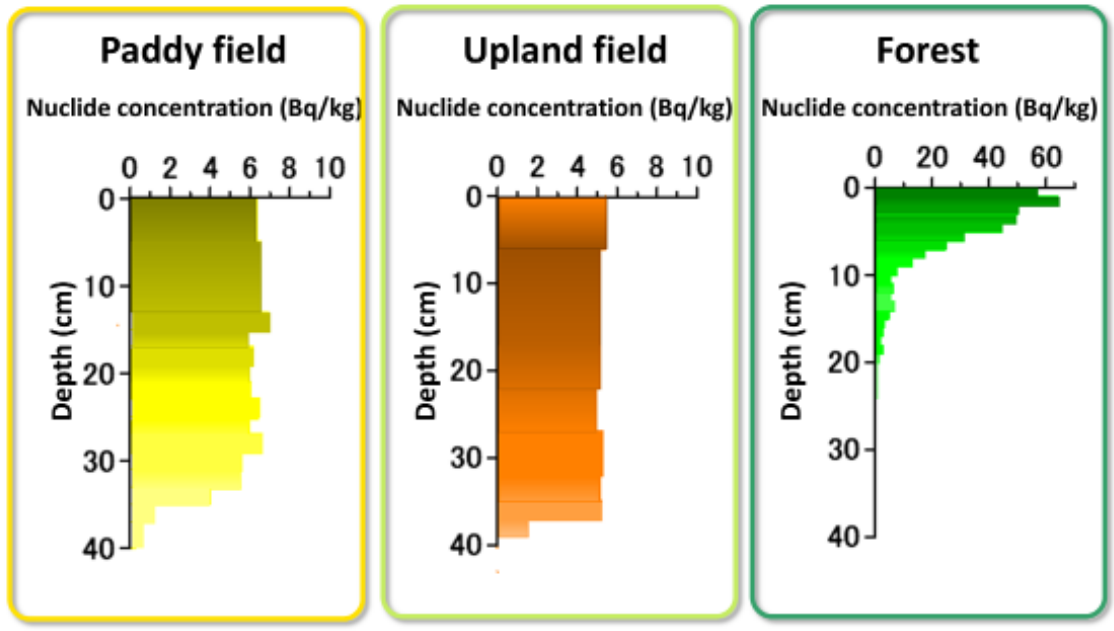
- The material for the 16th meeting of the Environment Recovery Committee

Included in this reference material on March 31, 2017

Long-term Effects

Effects of Nuclear Test Fallout (Japan)

Depth distribution of Cs-137 concentrations in soil samples collected in Hokkaido in October 2009



Bq/kg: becquerels per kilogram

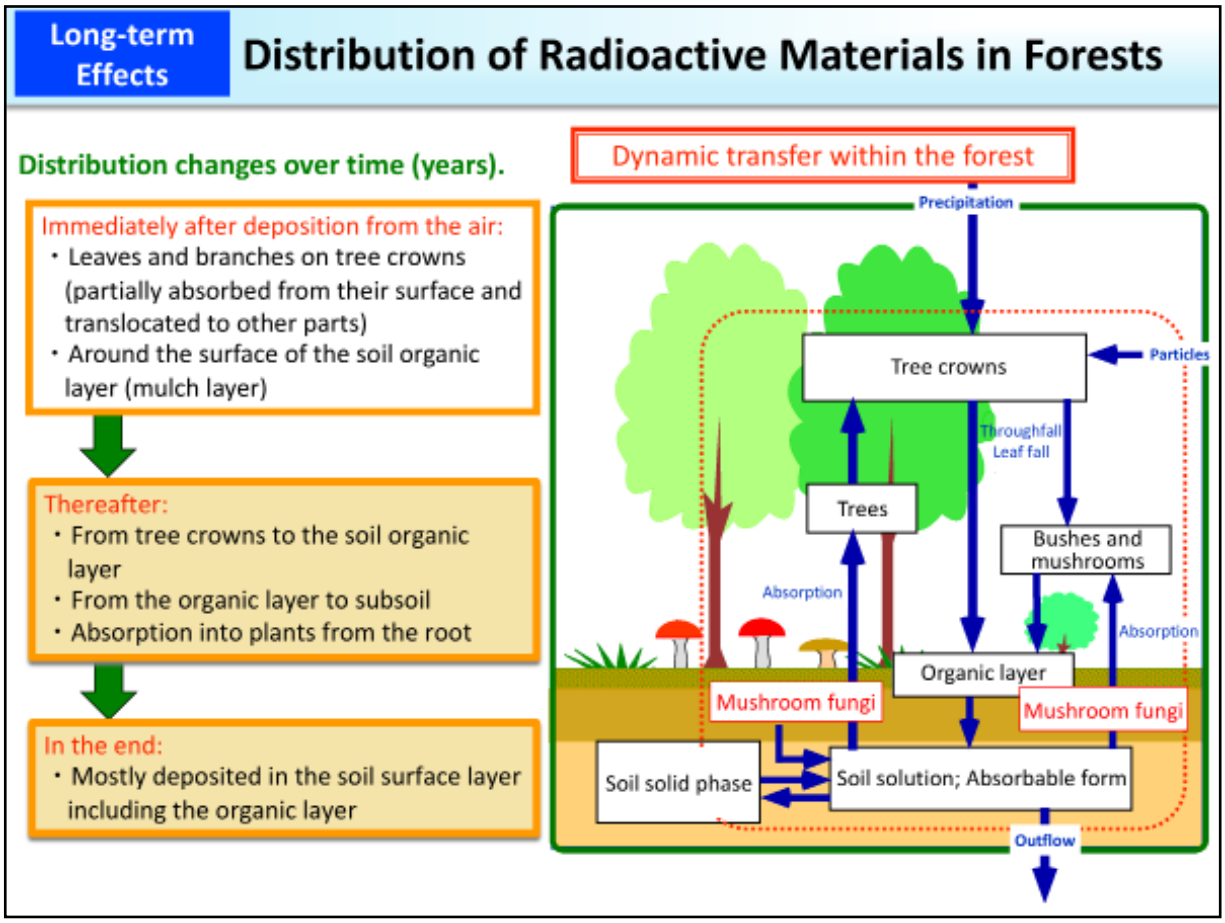
Source: Prepared based on the Compilation of the Outcomes of the 52nd Environmental Radioactivity Survey (2010), Kikata, et al.

Nuclear tests in the atmosphere were frequently conducted from late 1950s to early 1960s, causing a large amount of radioactive fallout across the globe. Radioactive cesium and radioactive strontium, etc. detected before March 11, 2011, are considered to be part of such fallout (p.78 of Vol. 1, “Effects of Radioactive Fallout due to Atmospheric Nuclear Testing”).

As a result of a soil survey conducted in Hokkaido in 2009, Cs-137 was detected as deep as 40 cm from the ground surface in plowed soil, such as paddy fields and upland fields, but it was found that in forests where soil is not plowed, Cs-137 was mostly located within 20 cm from the ground surface.

How deep radioactive cesium is adsorbed in soil depends on the property of soil, but it is known that Cs-137 tends to remain in the surface layer also in Japan.
(Related to p.181 of Vol. 1, “Distribution of Radioactive Cesium in Soil”)

Included in this reference material on March 31, 2013
Updated on March 31, 2015



Distribution of radioactive materials in forests is considered to change significantly over years.

Radioactive cesium in the air adheres to leaves and branches, which eventually wither and turn into soil containing organic matter like muck soil. Some radioactive materials are absorbed from leaves or bark and transfer to new leaves or fruits within the plant, but they also turn into soil in the end.

Organic-rich soil lacks clay minerals that adsorb cesium and cesium tends to be absorbed into plants in such soil.

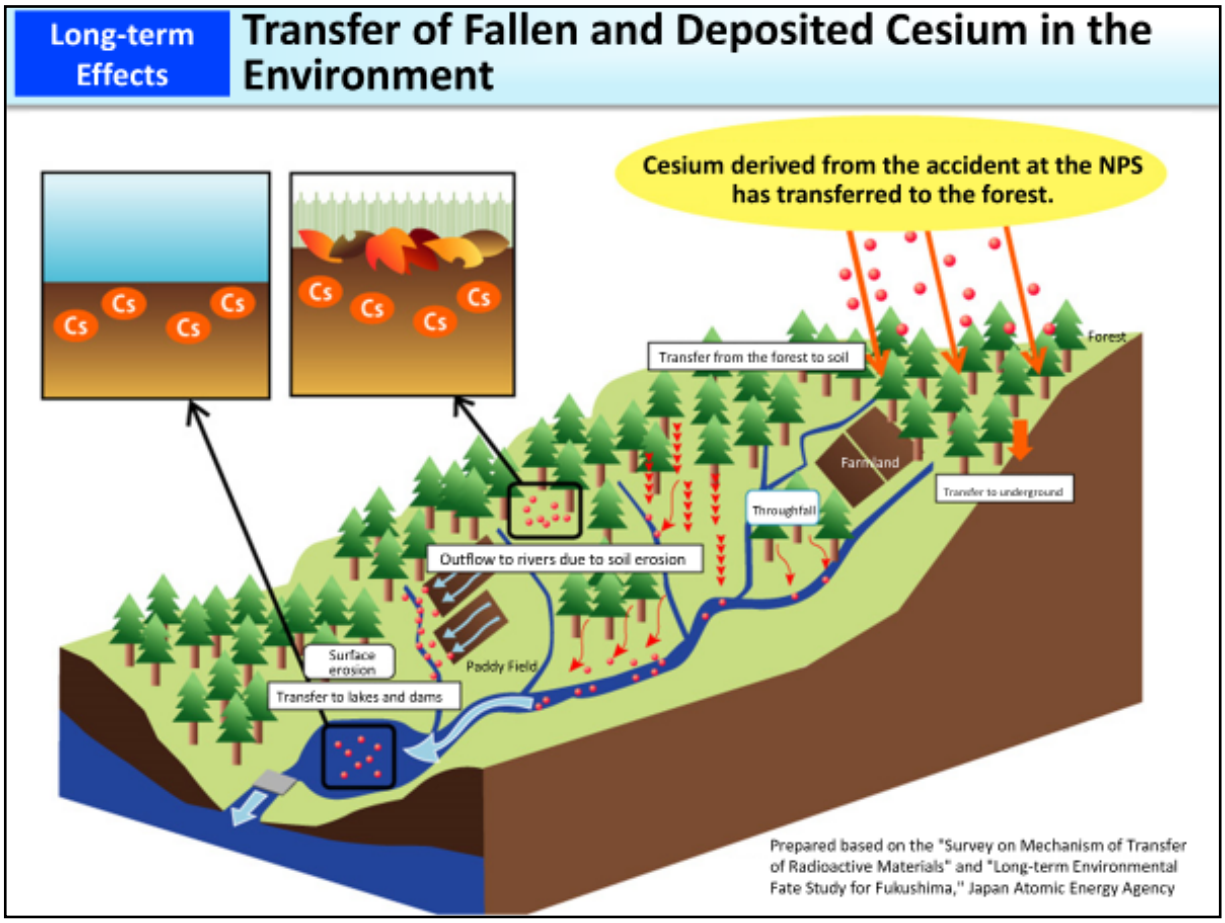
Radioactive cesium in the organic layer gradually transfers into subsoil, and plants that take root deeper than the surface layer will come to absorb such cesium.

In this manner, radioactive cesium is fixed in the clayey soil in the process of circulating between plants and soil and is finally deposited in the surface layer of soil, as in the case of stable cesium.

As a result of the measurement of cesium in river water conducted by the Forestry and Forest Products Research Institute, cesium was not detected in most of the river water samples. Cesium was detected only in samples of turbid water collected on days with precipitation but the detected values were very small (p.34 of Vol. 2, “Readings of the Monitoring of Radioactive Cesium in Mountain Streams (2012)”).

(Related to p.32 of Vol. 2, “Changes in Ambient Dose Rates in Forests,” and p.33 of Vol. 2, “Changes in Radioactive Cesium Distribution in Forests”)

Included in this reference material on March 31, 2013
Updated on March 31, 2019



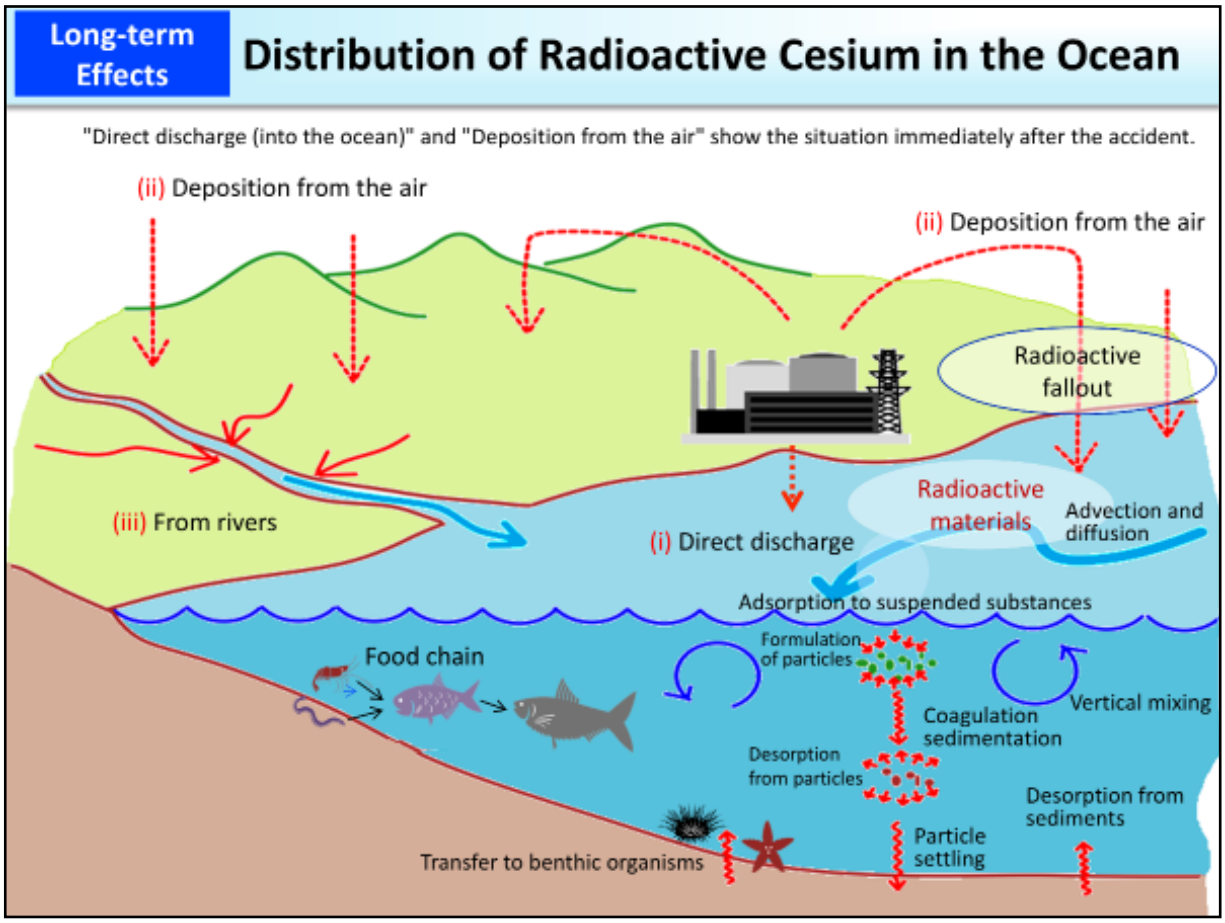
Distribution of radioactive cesium released into the environment due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS has changed significantly over time. Cesium that adhered to tree bark, branches and leaves immediately after the accident transferred onto the forest soil due to leaf fall and precipitation, etc. At present, over 90% is found to be located within a depth of 5 cm from the ground surface. In the meantime, as the decrease in cesium at the ground surface is larger than the decrease due to physical attenuation, it is estimated that some cesium has transferred to underground.

Cesium has a property to be strongly adsorbed by specific clay minerals and is seldom dissolved in water (p.182 of Vol. 1, "Behavior of Radioactive Cesium in the Environment: Adsorption and Fixation by Clay Mineral"). Furthermore, re-scattering into the air due to wind, etc. is hardly observed at present. Given these, outflow of cesium from forests to people's daily living areas is considered to be very minor.

The above figure illustrates the process that fallen and deposited cesium in the forest flows from the upstream to a downstream dam lake. The two enlarged pictures show the forest floor and the sediment at the bottom of the dam lake, both indicating that cesium is deposited in the surface layer of soil.

In a racing river, cesium is transported to the downstream while being adsorbed to soil particles, and in a gentle stream, cesium tends to be deposited onto river sediments. When there is a dam in the upstream, cesium is blocked at the dam lake and the amount that flows out to the downstream is smaller. Even when the water level of the dam lake becomes higher due to a typhoon or a heavy rain, the flow at the bottom sediments near the sluice is slow and deposited soil seldom raises up.

Included in this reference material on March 31, 2016



Distribution in the ocean of radioactive materials released due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS has changed significantly over time. There are three routes through which radioactive materials are transported to the ocean: (i) direct discharge of radioactive materials into the ocean from the NPS; (ii) fall onto the ocean of radioactive materials transported with wind; and (iii) transportation into the ocean of fallen radioactive materials via rivers or groundwater. However, in the case of cesium, which is strongly adsorbed in soil, it is hardly possible to imagine that it transfers together with groundwater and reaches the ocean.

Radioactive Cs concentrations in seawater increased significantly immediately after the accident but declined in one or two months as cesium was transported or diffused with the ocean current. Radioactive Cs concentrations in marine organisms, which have much to do with radioactive Cs concentrations in seawater, also declined in tandem with the decline in radioactive Cs concentrations in seawater. Additionally, transfer of radioactive Cs, part of which was deposited on the sea bottom, to bottom fish was a worry, but the survey results show declines in radioactive Cs concentrations in flatfish, Pacific cod, and other bottom fish including those caught off Fukushima Prefecture. As reasons therefor, it is pointed out that radioactive Cs is strongly absorbed in clayey soil in saline mud and that Cs rarely transfers from sea-bottom soil to benthic organisms, and Cs absorbed in clayey soil is unlikely to be drawn into the bodies of marine organisms (Source: "Report on Inspection of Radioactive Materials in Fishery Products" (2017), Fisheries Agency).

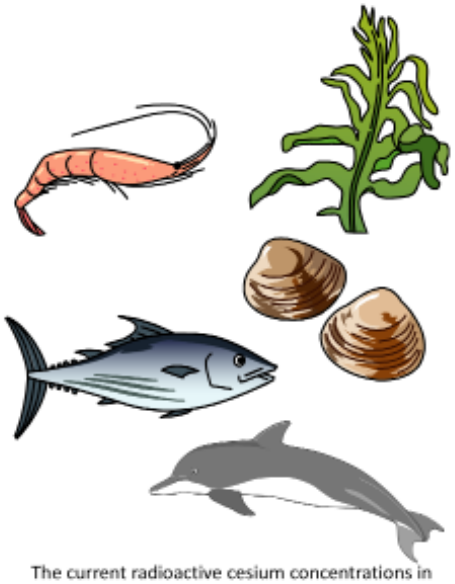
Included in this reference material on March 31, 2013
Updated on March 31, 2023

Long-term Effects

Concentration Factors for Marine Organisms

Concentration factor = (Radioactivity concentration in a marine organism) / (Radioactivity concentration in seawater)

Types of organisms	Concentration factor* (cesium)
Squids and octopuses	9
Phytoplankton	20
Zooplankton	40
Algae	50
Shrimps and crabs	50
Shellfish	60
Fish	100
Dolphin	300
Sea lion	400



The current radioactive cesium concentrations in seawater are at the same level as that before the accident (0.001 - 0.01 Bq/L).

* Concentration factors are recommended values in the following document by the IAEA.

Source: "Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment, 2004," International Atomic Energy Agency (IAEA)

The concentration factor is the ratio between the radioactivity concentration in a marine organism and the radioactivity concentration in seawater, assuming that the relevant marine organism is placed in seawater at a certain radioactivity concentration for a long period. This indicates the level of accumulation of radioactive materials in the relevant marine organism.

Comparing concentration factors of cesium, the concentration factor is higher for fish than plankton and is further higher for large mammals that eat fish.

Cesium also bioaccumulates, but is not continuously accumulated in organisms unlike mercury or cadmium. Instead, radioactive cesium concentrations in organisms are considered to decline in accordance with the decline in radioactive cesium concentrations in seawater.

Concentration factors indicated in the above figure are those recommended by the International Atomic Energy Agency (IAEA). At present, radioactive cesium concentrations in seawater have declined to almost the same level as that before the accident (0.001 - 0.01 Bq/L), except within the port near Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (p.48 of Vol. 2, "Changes in Radioactivity Concentrations in Seawater").

Included in this reference material on March 31, 2013
Updated on March 31, 2015