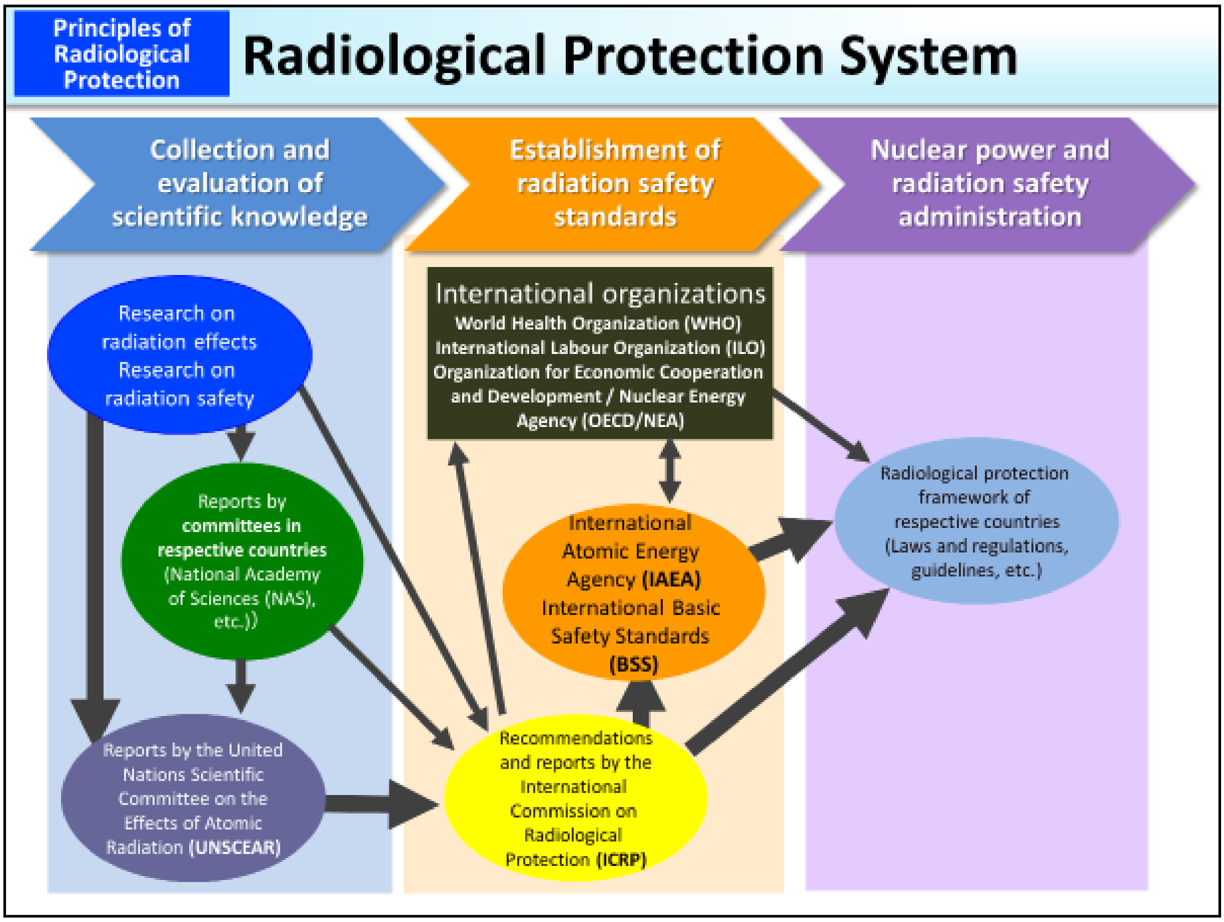

Every year, a large number of reports on research concerning radiation sources and effects are publicized by researchers worldwide.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) comprehensively evaluates wide-ranging research outcomes, compiles scientific consensus obtained internationally from a politically neutral standpoint, and periodically releases its positions in the form of a report.

The International Commission on Radiological Protection (ICRP), which is an independent private international academic organization, makes recommendations concerning radiological protection frameworks from a professional perspective, while referring to reports, etc. by the UNSCEAR. In consideration of ICRP Recommendations and the International Basic Safety Standards established by the International Atomic Energy Agency (IAEA) based on an international consensus, the government of Japan has also formulated laws, regulations and guidelines, etc. concerning radiological protection.

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

Principles of Radiological Protection

International Commission on Radiological Protection (ICRP)

International Commission on Radiological Protection (ICRP)

The Commission aims to make recommendations concerning basic frameworks for radiological protection and protection standards. The Commission consists of the Main Commission and four standing Committees (radiation effects, doses from radiation exposures, protection in medicine, and application of the Commission's recommendations).

(Reference) Dose limits excerpted from ICRP Recommendations

	1977 Recommendations	1990 Recommendations	2007 Recommendations
Dose limits (occupational exposure)	50 mSv/year	100 mSv/5 years and 50 mSv/year	100 mSv/5 years and 50 mSv/year
Dose limits (public exposure)	5 mSv/year	1 mSv/year	1 mSv/year

mSv: millisieverts

The International X-ray and Radium Protection Committee was established in 1928 for the purpose of protecting healthcare workers from radiation hazards. In 1950, the Committee was reorganized into the International Commission on Radiological Protection (ICRP), which was assigned a significant role as an international organization that makes recommendations concerning basic frameworks for radiological protection and protection standards. In recent years, the Commission made recommendations in 1977, 1990 and 2007 (p.161 of Vol. 1, “Aims of the Recommendations”). When the ICRP releases its recommendations, many countries review their laws and regulations on radiological protection accordingly (p.171 of Vol. 1, “ICRP Recommendations and Responses of the Japanese Government”).

ICRP Recommendations are based on wide-ranging scientific knowledge, such as that obtained through epidemiological studies on atomic bomb survivors, and its radiological protection system has been maintained since 1990 on the basis of its position that comprehensive estimation of deterministic effects (tissue reactions) and stochastic risks is basically unchanged.

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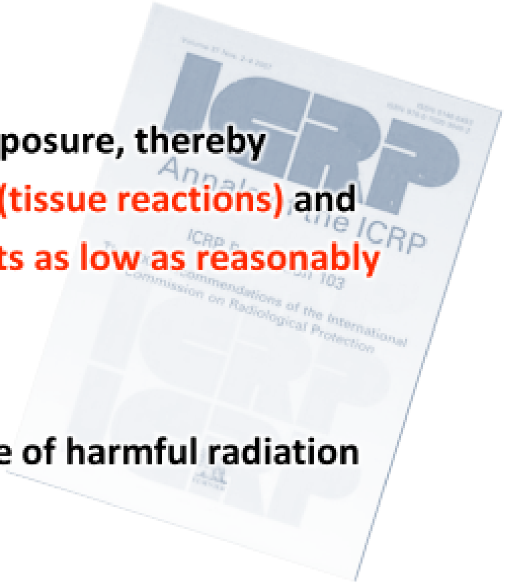
Principles of Radiological Protection

Aims of the Recommendations

Aims of the Recommendations(2007 Recommendations of the International Commission on Radiological Protection (ICRP))



1) To protect human health

- Manage and control radiation exposure, thereby preventing deterministic effects (tissue reactions) and reducing risks of stochastic effects as low as reasonably achievable

2) To protect the environment

- Prevent or reduce the occurrence of harmful radiation effects

Source: Prepared based on the ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

The ICRP makes recommendations with the aim of contributing to an appropriate level of protection of human beings and the environment against the detrimental effects of ionizing radiation exposure without unduly limiting preferable human beings' efforts and behavior associated with the use of radiation.

The 2007 Recommendations state that in order to achieve this, scientific knowledge on radiation exposure and its health effects is an indispensable prerequisite, but due consideration needs to be given to social and economic aspects of radiological protection in the same manner as in other risk management-related sectors.

The major aim of the ICRP Recommendations has been the protection of human health, but the aim to protect the environment was newly added in the 2007 Recommendations.

Included in this reference material on March 31, 2013
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Principles of Radiological Protection

Exposure Situations and Protection Measures

People's exposure to radiation

Planned exposure situations	Existing exposure situations	Emergency exposure situations
Situations where protection measures can be planned in advance and the level and range of exposure can be reasonably forecast	Situations where exposure has already occurred as of the time when a decision on control is made	Contingency situations where urgent and long-term protection measures may be required
Dose limits (Public exposure) 1 mSv/year (Occupational exposure) 100 mSv/5 years and 50mSv/year	**Reference level** A lower dose range within 1 to 20 mSv/year, with a long-term goal of 1 mSv/year	**Reference level** Within 20 to 100 mSv/year
Measures Manage disposal of radioactive waste and long-lived radioactive waste	**Measures** Ensure voluntary efforts for radiological protection and cultivate a culture for radiological protection	**Measures** Evacuate, shelter indoors, analyze and ascertain radiological situations, prepare monitoring, conduct health examinations, manage foods, etc.

mSv: millisieverts

Source: Prepared based on the ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

The International Commission on Radiological Protection (ICRP) categorizes exposure situations into normal times that allow planned control (planned exposure situations), emergencies such as an accident or nuclear terrorism (emergency exposure situations), and the recovery and reconstruction period after an accident (existing exposure situations) and sets up protection standards for each of them.

In normal times, protection measures should aim to prevent any exposure that may cause physical disorders and to reduce risks of developing cancer in the future as low as possible. Therefore, the dose limit for public exposure is set at 1 mSv per year, requiring proper management of places where radiation or radioactive materials are handled to ensure that annual public exposure doses do not exceed this level. For workers who handle radiation, the dose limit is set at 100 mSv per five years.

On the other hand, in an emergency such as a nuclear accident (emergency exposure situations), as physical disorders that would never be seen in normal times may develop, priority should be placed on measures to prevent serious physical disorders rather than on measures to be taken in normal times (to reduce risks of developing cancer in the future). Therefore, a reference level of 20 to 100 mSv/year is set for the public instead of applying dose limits and efforts to reduce exposure doses are required. For people who are engaged in emergency measures or rescue activities, a level of 1,000 or 500 mSv may sometimes be adopted as a rough indication depending on the circumstances.

Then, in the recovery and reconstruction period (existing exposure situations), a reference level is to be set within the range of 1 to 20 mSv/year, which is lower than the reference level in an emergency but higher than the dose limits applicable in normal times.

(Related to p.171 of Vol. 1, “ICRP Recommendations and Responses of the Japanese Government”)

Included in this reference material on March 31, 2013
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Principles of Radiological Protection

Biological Aspect

Health effects of radiation have deterministic effects (tissue reactions) and stochastic effects.

- **Absorbed doses up to approx. 100 mGy are not judged to cause any clinically significant dysfunction in any tissues.**
- **In the range below approx. 100 mSv, the occurrence of stochastic effects is assumed to increase in proportion to increases in equivalent doses in organs and tissues. (Adoption of the linear non-threshold (LNT) model)**
- **The dose and dose-rate effectiveness factor for solid cancer is 2.**
- **Assuming a linear reaction at low doses, the fatality risks due to cancer and heritable effects increase by approx. 5% per sievert.**

Source: Prepared based on the ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

One of the aims of the ICRP Recommendations is to provide considerations and assumptions for building a radiological protection system, thereby preventing the occurrence of deterministic effects (tissue reactions). The ICRP recommends the introduction of protection measures in cases where annual doses have increased close to 100 mGy (≒100 mSv), which is the minimum threshold.

The probability of stochastic effects is very low in the case of annual doses below approx. 100 mSv, and the linear non-threshold (LNT) model, which is based on the assumption that the occurrence of stochastic effects increases in proportion to increases in radiation doses exceeding background doses, is considered to be practical for the management of radiological protection at low doses and low dose rates, and also preferable from the viewpoint of the precautionary principle.

While the ICRP uses, as the grounds for its recommendations, the data for atomic bomb survivors, which is the data concerning a single exposure, what should be controlled is mostly a long-term gradual exposure. Therefore, the ICRP makes adjustments to offset mitigated effects due to low doses and low dose rates. Various values have been reported as a result of animal testing and experiments using human cells to induce chromosomal abnormalities or mutations, but the dose and dose-rate effectiveness factor for radiological protection has been defined as 2 (p.116 of Vol. 1, “Cancer-promoting Effects of Low-dose Exposures”). In other words, if the total exposure dose is the same, long-term low-dose exposure would cause half the effects as those caused by exposure at one time.

As a result of the abovementioned adjustments, risks of fatal cancer are considered to increase by approx. 5% per sievert at low doses and low dose rates.

(Related to p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects”)

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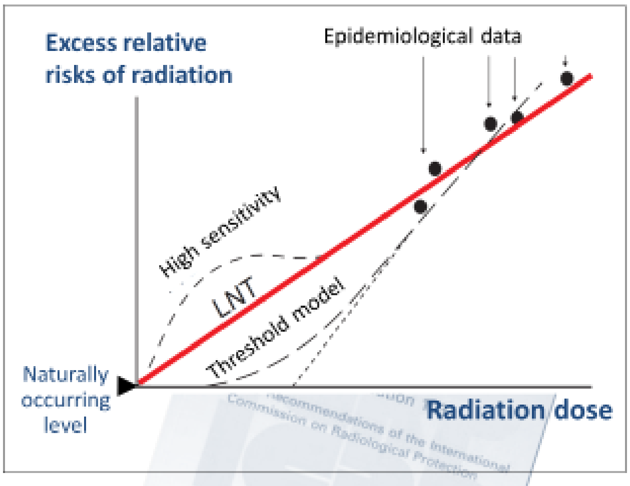
Principles of Radiological Protection

Disputes over the LNT Model

◎ Affirmative positions:
National Academy of Sciences (2006)
There is no specific safety dose for radiation exposure.

◎ Critical positions:
Académie de Médecine; Académie de Science (2005)
Exposure to radiation below a certain dose does not actually cause cancer, leukemia, etc. and therefore, the LNT model represents overestimation not suited to the reality.



⇒The International Commission on Radiological Protection (ICRP) adopts the linear non-threshold (LNT) model as a simple and reasonable assumption for the purpose of radiological protection.

Disputes over the appropriateness of adopting the linear non-threshold (LNT) model for the evaluation of risks of stochastic effects for radiation below 100 mSv have not been settled scientifically. For example, in 2006, the National Academy of Sciences (NAS) publicized its position that the LNT model is scientifically appropriate, stating that there is epidemiological evidence to prove that radiation below 100 mSv also increases cancer risks. In 2017 onward, papers have been published such as one showing the dose-effect relation in a low-dose region of 100 mGy or lower[1,2] and one stating that it is impossible to rule out threshold models.[1]

On the other hand, the Académie de Médecine and the Académie de Science jointly publicized their position in 2005, stating that exposure to radiation below a certain dose does not actually cause cancer, leukemia, etc. and therefore that the LNT model represents overestimation not suited to the reality. As the grounds for their position, they cited such facts as that increases in cancer risks are not observed in data for residents in high natural radiation areas in India and China and that defensive biological reactions against low-dose radiation have been found one after another.

The ICRP Recommendations are intended to achieve a practical aim of radiological protection, i.e., the provision of a simpler and more reasonable assumption for the management of risks of low-dose exposure, by adopting the LNT model and defining the dose and dose-rate effectiveness factor as 2. On the other hand, the Recommendations also state that it is judged inappropriate for public health planning to estimate hypothetical incidences of cancer or hereditary diseases among a large number of people due to long-term exposure to very low doses of radiation in consideration of the uncertainties concerning low-dose exposure.
(Related to p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects”)

1. Lubin et al.: J. Clin. Endocrinol Metab. 102(7): 2575–2583, 2017.
2. Lene H. S. Veiga et al.: Radiat. Res. 185(5): 473–484, 2016.
Source
• The National Academy of Sciences, “Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2”, 2006.
• Aurengo, A. et al., “Dose–effect relationships and estimation of the carcinogenic effects of low doses of ionizing radiation”, Académie des Sciences - Académie nationale de Médecine, 2005.
• ICRP Publication 103, “The 2007 Recommendations of the International Commission on Radiological Protection” (ICRP, 2007)

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Updated on March 31, 2022

Principles of Radiological Protection

Three Fundamental Principles of Radiological Protection

ICRP's three fundamental principles of radiological protection

- **Justification**
- **Optimization**
- **Application of dose limits**

Source: ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

In cases of cancer and heritable effects, effects appear stochastically. At present, the linear non-threshold (LNT) model is adopted in radiological protection even for low doses (p.164 of Vol. 1, “Disputes over the LNT Model”), due to which the safety and the danger cannot be clearly divided. Therefore, the protection level is considered based on the idea that risks cannot be completely eliminated and on an assumption that such risks can be tolerated. This is the very basis of the principles of radiological protection, placing emphasis on the “justification,” “optimization” and “application of dose limits” (p.166 of Vol. 1, “Justification of Radiological Protection,” p.167 of Vol. 1, “Optimization of Radiological Protection,” and p.169 of Vol. 1, “Application of Dose Limits”).

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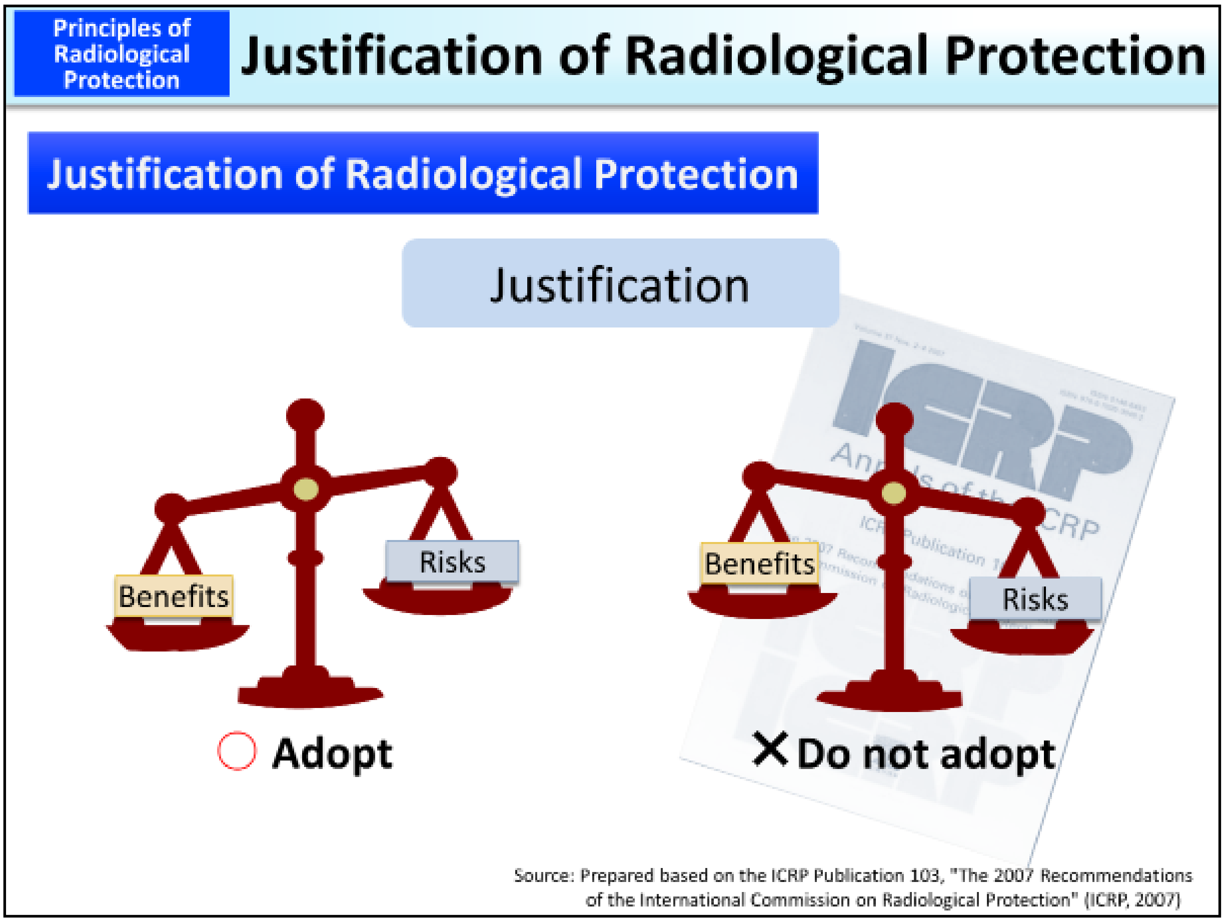

The first principle is the justification of radiological protection. This is the fundamental principle that an act of using radiation is permitted only when the benefits or merits outweigh the radiation risks.

This principle is applied not only to acts of using radiation but also to all activities that bring about changes in exposure situations. In other words, this is also applied to emergency exposure situations and existing exposure situations, as well as to planned exposure situations. For example, justification is required even in the case of considering decontamination of contaminated areas.

(Related to p.98 of Vol. 1, “Risks of Health Effects of Radiation”)

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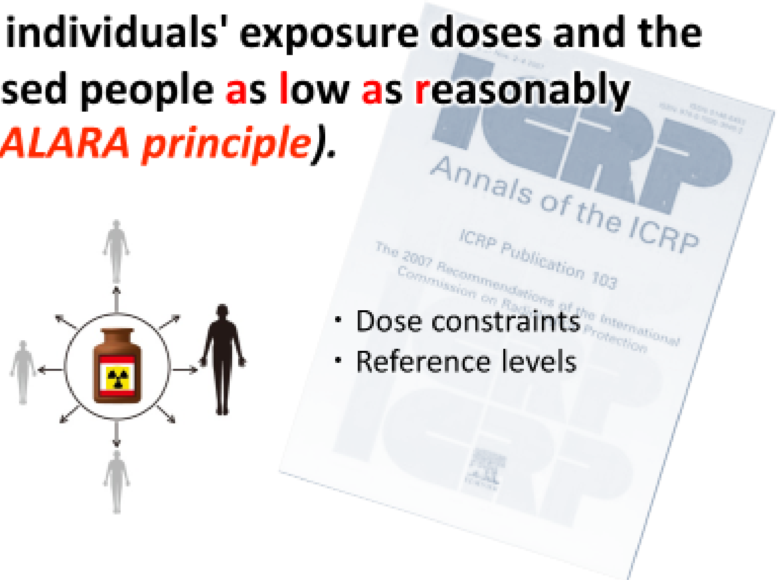
Principles of Radiological Protection

Optimization of Radiological Protection

Optimization of Radiological Protection

In consideration of economic and social factors, strive to reduce individuals' exposure doses and the number of exposed people as low as reasonably achievable *(the ALARA principle)*.



Source: Prepared based on the ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

The second principle is the optimization of radiological protection. When merits of an act of using radiation outweigh radiation risks, it is decided to use radiation by taking measures to reduce exposure doses as low as reasonably achievable. This is called the ALARA principle. The optimization of radiological protection means to strive to reduce exposure doses as low as possible, while taking into consideration social and economic balances, and does not necessarily mean to minimize exposure doses.

In order to promote the optimization of radiological protection, dose constraints and reference levels are utilized. Reference levels are adopted as indicators to limit individuals' doses from specific radiation sources in decontamination work, for example.

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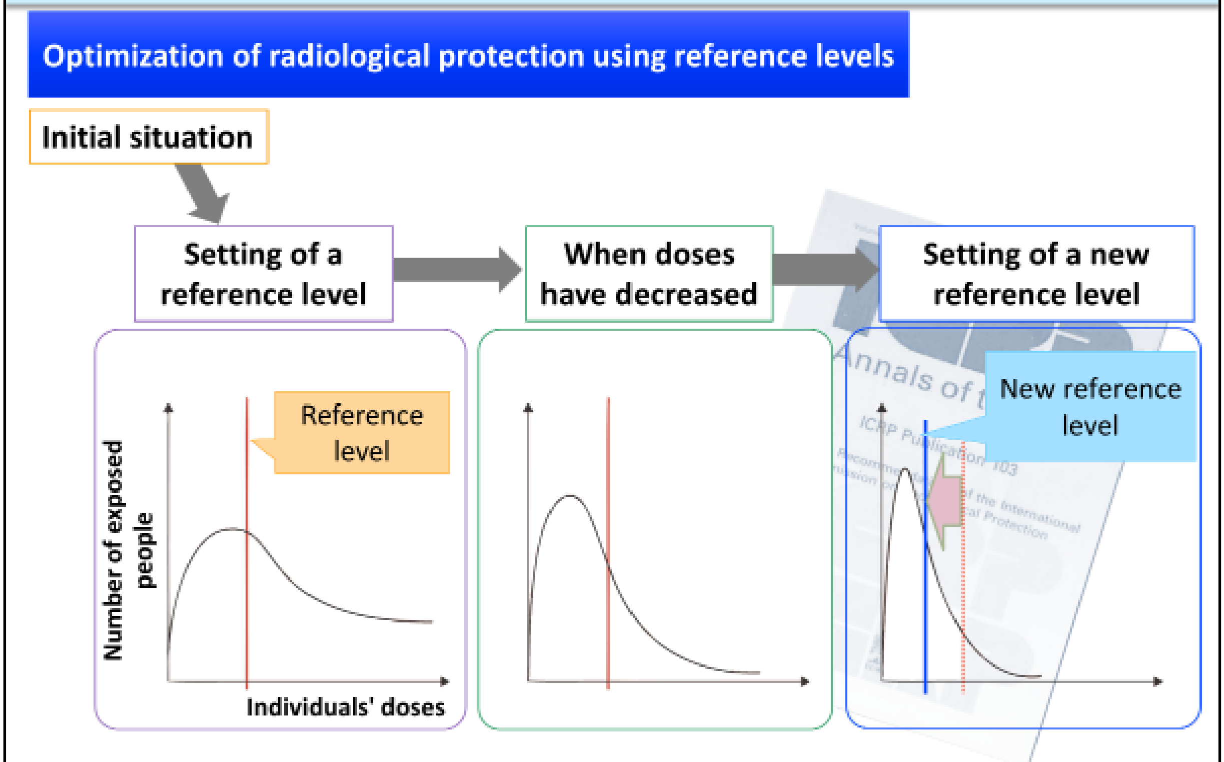
Principles of Radiological Protection

Reduction of Exposure Doses Using Reference Levels



Source: Prepared based on the ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

The concept of reference levels as suggested in the 2007 Recommendations of the ICRP has been adopted in promoting measures to reasonably reduce exposure doses due to nuclear power plant accidents, etc. In an emergency such as an accident or nuclear terrorism (emergency exposure situations), the focus is placed on measures to prevent serious physical disorders. Therefore, dose limits (limits for exposure to all regulated radiation sources under planned exposure situations) are not applied. Instead, a reference level is set within the range of annual doses of 20 to 100 mSv for the public and protection activities are carried out so as to limit individuals' doses below that level. Physical disorders that would never be seen in normal times may develop in an emergency. Accordingly, measures to prevent such physical disorders are prioritized over measures to be taken in normal times (to reduce risks of developing cancer in the future). Thereafter, in the recovery and reconstruction period (existing exposure situations), a reference level is set within the range of annual doses of 1 to 20 mSv for the public, and efforts for the optimization of radiological protection are commenced.

Reference levels aim to ensure that no one receives an unduly high dose in a circumstance where exposure doses among individuals are not even. When considering protection measures for the entirety, if there are people who are likely to receive doses exceeding the predetermined reference level, countermeasures for those people are preferentially taken. If dose disparity within a group diminishes as a result of such intensive countermeasures, and there is almost no one who receives a high dose exceeding the reference level, a new lower reference level is set as necessary to further reduce exposure doses as a whole. In this manner, exposure dose reduction can be achieved efficiently by setting appropriate reference levels depending on the circumstances.

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Principles of Radiological Protection

Application of Dose Limits

Dose limits are applied under planned exposure situations.

◯ **Occupational exposure (effective dose)**

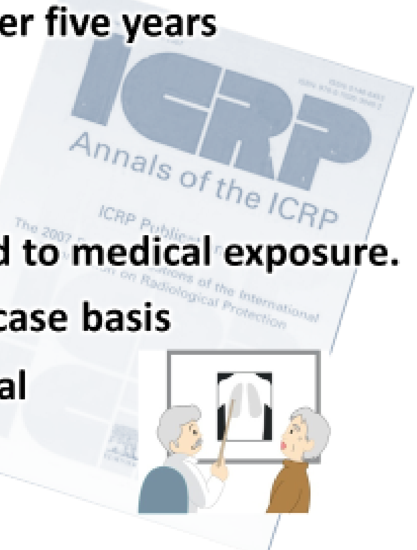
50 mSv per year and 100 mSv per five years

◯ **Public exposure (effective dose)**

1 mSv per year

(Exception) Dose limits are not applied to medical exposure.

- Justification on a case-by-case basis
- Optimization of radiological protection is important.



Source: Prepared based on the ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

The third principle of radiological protection is the application of dose limits. The 2007 Recommendations of the ICRP specify the effective dose limit for occupational exposure (excluding radiation work in an emergency) as 100 mSv per five years and 50 mSv for the specific one year.

The effective dose limit for public exposure is specified as 1 mSv per year.

Dose limits are the standard limits below which the total exposure to all radiation sources under management is to be controlled. The goal is not to merely keep the total exposure below those dose limits but continued efforts are required to reduce exposure doses through further optimizing radiological protection. In this sense, dose limits do not stand for permissible exposure doses, nor do they represent the threshold to divide the safety and the danger.

Regarding medical exposure in treatment or health checkups, dose limits are not applied. This is because the application of dose limits to medical exposure may hinder patients from receiving necessary inspections or treatment and is sometimes detrimental to them. Accordingly, the justification is to be made from three viewpoints (the fact that radiation use in medicine is more beneficial than harmful to patients; application of specific methods to patients exhibiting specific symptoms; and application of methods customized for respective patients), and doses are to be optimized by applying diagnostic reference levels, etc.

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Dose Limits: Comparison between ICRP Recommendations and Domestic Laws and Regulations

mSv: millisieverts

		Occupational exposure		Public exposure	
		ICRP	Laws and regulations concerning the prevention of radiation hazards (Japan)	ICRP	Laws and regulations concerning the prevention of radiation hazards (Japan)
Effective dose limits		The average annual dose for the prescribed five years should not exceed 20 mSv. The annual dose for any single year should not exceed 50 mSv. (*1)	The average annual dose for the prescribed five years should not exceed 20 mSv. The annual dose for any single year should not exceed 50 mSv. (*3)	1 mSv/year (In special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year.) (*1)	No dose limit is specified, but doses at the boundaries of the site, including those due to exhaust gas and discharged water, are regulated not to exceed the dose limit of 1 mSv/year. (*3)
Equivalent dose limits	The Lens of the Eye	The average annual dose for the five years should not exceed 20 mSv/year and the annual dose for any single year should not exceed 50 mSv. (*2)	The average annual dose for the five years should not exceed 20 mSv/year and the annual dose for any single year should not exceed 50 mSv. (*3)	15 mSv/year (*1)	—
	Skin	500 mSv/year (*1)	500 mSv/year (*3)	50 mSv/year (*1)	—
	Fingers and toes	500 mSv/year (*1)	—	—	—
Dose limits for female radiation workers		The effective dose of an embryo/a fetus during gestation after reporting pregnancy should not exceed 1 mSv. (*1)	5 mSv/3 months Equivalent dose limit for the abdominal surface after coming to know of pregnancy until delivery: 2 mSv Internal exposure: 1 mSv (*3)	—	—

Source: Prepared based on the following:
*1 2007 Recommendations of the ICRP;
*2 ICRP Publication 118 "ICRP Statement on Tissue Reactions and Early and Late Effects of Radiation in Normal Tissues and Organs - Threshold Doses for Tissue Reactions in a Radiation Protection Context"; and
*3 Japanese laws and regulations concerning the prevention of radiation hazards (as of December 2021)

Present laws and regulations in Japan have not yet completed the incorporation of the 2007 Recommendations of the ICRP, but dose limits specified in the 2007 Recommendations are mostly the same as those in the 1990 Recommendations. Therefore, dose limits in Japan also mostly coincide with those specified in the 2007 Recommendations. Japan has uniquely specified dose limits for female radiation workers (5 mSv per three months).

The ICRP Statement on Tissue Reactions provides recommendations concerning the equivalent dose limit for the lens of the eye under planned occupational exposure. Following the Statement, in Japan, the Radiation Council compiled and provided some insights on “Approach to Radiation Protection of the Lens of the Eye” in 2018, for relevant administrative bodies, and all related laws and regulations (the Regulation on Prevention of Ionizing Radiation Hazards, etc.) were amended in 2021.

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Dose Limits ICRP Recommendations and Responses of the Japanese Government

	2007 Recommendations of the ICRP		Responses at the time of the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS
Occupational exposure	Rescue activities (Volunteers who have obtained the relevant information)	When benefits for other people outweigh the rescuers' risks, dose limits are not applied.	Special Provisions of the Ordinance on Prevention of Ionizing Radiation Hazards (Ministry of Health, Labour and Welfare) The emergency exposure dose limit was temporarily raised to **250 mSv** from the conventional level of **100 mSv** (from March 14 to December 16, 2011). The Ordinance on Prevention of Ionizing Radiation Hazards was partially amended to raise the exceptional emergency dose limit to **250 mSv** (enforced on April 1, 2016).
	Other emergency activities	1,000 mSv or 500 mSv	
Public exposure	Emergency exposure situations	The limit is to be set within the range of **20 to 100** mSv/year.	e.g. Standards for evacuation in Deliberate Evacuation Areas: **20 mSv**/year
	Reconstruction period (Existing exposure situations)	The limit is to be set within the range of **1 to 20** mSv/year.	e.g. Additional exposure dose to be achieved in the long term: **1 mSv**/year

mSv: millisieverts

Source: Prepared based on the 2007 Recommendations of the ICRP and the Special Provisions of the Ordinance on Prevention of Ionizing Radiation Hazards (Ministry of Health, Labour and Welfare: MHLW)

The accident at TEPCO's Fukushima Daiichi NPS occurred while deliberations were continuing over the incorporation of the 2007 Recommendations of the ICRP into domestic laws and regulations.

The accident changed exposure situations, and the idea of reference levels, which had been unfamiliar to Japanese laws and regulations, was adopted for public exposure. In exposure dose control using reference levels, an initial reference level is first set based on the standards for respective exposure situations specified in the 2007 Recommendations of the ICRP so as to ensure that no one receives an unduly high dose. Secondly, if the situation has improved and there is almost no one who receives a high dose exceeding the reference level, a new lower reference level is set as necessary to efficiently achieve exposure dose reduction.

In the meantime, regarding occupational exposure, the emergency dose limit was temporarily raised from 100 mSv to 250 mSv as an exception for an unavoidable case for the purpose of preventing the expansion of the disaster at the NPS. Later, as the work to achieve stable cold shut-down conditions of the reactors was completed, this exceptional measure was abandoned.

Considering the need to develop regulations on the prevention of radiation hazards during emergency work in preparation for any possible nuclear emergencies at nuclear facilities in the future, the Ordinance on Prevention of Ionizing Radiation Hazards was partially amended to raise the exceptional emergency dose limit to 250 mSv. The amended Ordinance was put into force on April 1, 2016.

(Related to p.168 of Vol. 1, "Reduction of Exposure Doses Using Reference Levels")

Included in this reference material on March 31, 2013
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Dose Limits — Indices Concerning Radioactive Materials in Foods

Radionuclide	Japan	Codex Alimentarius Commission	EU	US
Radioactive cesium (Bq/kg)	Milk 50 Infant foods 50 General foods 100	Infant foods 1,000 General foods 1,000	Milk 1000 Infant foods 400 General foods 1,250	All foods 1,200
Upper limits for additional doses	1mSv	1mSv	1mSv	5mSv
Assumed percentages of foods containing radioactive materials	50%	10%	10%	30%

* The Codex Alimentarius Commission is an intergovernmental body created in 1963 by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) for the purpose of protecting consumers' health and ensuring fair-trade practices in the food trade, etc.; The Commission establishes international standards for foods.
* Standard limits incorporate effects of the amount of food intake and assumed percentages of foods containing radioactive materials. Therefore, the values are not suitable for inter-comparison.
* Indicated standard limits for drinking water are the WHO guidance levels of radioactive materials, which are referred to in respective countries, and standard limits for radioactive materials vary by country due to differences in adopted preconditions. Therefore, the values are not suitable for inter-comparison.

Source: Modified "Food and Radiation Q&A" published by Consumer Affairs Agency

In Japan, the new standard limits for radionuclides in foods were established and were put into force on April 1, 2012. Under the new standard limits, foods are classified into four categories, and the standard limit for drinking water, which people take most frequently, was set at 10 Bq/kg.

The standard limit for general foods was set at 100 Bq/kg. However, for "infant foods" consumed by infants under one year old and for "milk" whose intake by children is extremely high, the standard limit was set at 50 Bq/kg, respectively.

All foods other than infant foods were categorized as general foods based on the idea to minimize gaps in additional doses caused by differences in individuals' eating habits. The value was set with sufficient room to ensure safety no matter what foods people eat as long as radioactive Cs concentrations therein are within the standard limit.

The standard limits vary by country due to differences in annual exposure dose limits based on which the respective countries set their standard limits and in contamination rates in foods, etc. (In Japan, regulation values were set on the safe side based on the annual exposure dose limit of 1 mSv and on the assumption that 50% of general foods and 100% of milk and infant foods are contaminated. On the other hand, the Codex Alimentarius Commission specifies the annual exposure dose limit as 1 mSv and assumes that 10% of foods are contaminated.)

(Related to p.55 of Vol. 2, "Standard Limits Applied from April 2012," p.61 of Vol. 2, "Approach for the Calculation of the Standard Limits (1/2)," and p.62 of Vol. 2, "Approach for the Calculation of the Standard Limits (2/2)")

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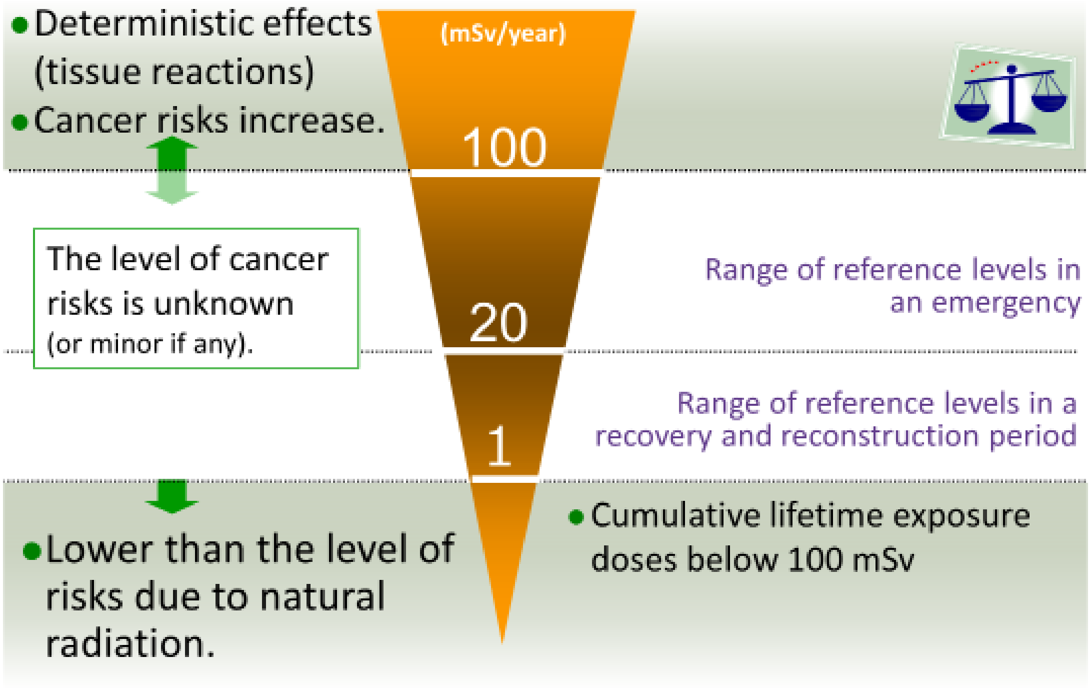
Dose Limits | Relation between Exposure Doses and Health Risks



Source: Prepared based on the 2007 Recommendations of the ICRP

There is scientific evidence for the fact that radiation doses of 100 to 200 mSv or over in a relatively short time increase deterministic effects (tissue reactions) and cancer risks. Therefore, in an emergency due to a radiation accident, the initial reference level is set to avoid annual exposure doses of 100 mSv or over in order to prevent serious physical disorders. When the situation improves as the accident is brought under control and there is almost no one who receives a high dose exceeding the initial reference level, a new lower reference level (such as 1 to 20 mSv per year) is set to curb increases in risks of any possible cancer in the future, thereby further promoting exposure dose reduction (p.162 of Vol. 1, “Exposure Situations and Protection Measures”).

As the standard limit in normal times, 1 mSv/year is adopted. As a result, some misunderstand that radiation exposure exceeding 1 mSv per year is dangerous or that they may be exposed to radiation up to that level. However, dose limits do not represent the threshold dividing the safety and the danger.

It is not that radiation exposure up to 1 mSv per year is permissible. Principally, radiation exposure should be reduced as low as practically achievable in light of various circumstances.

(Related to p.117 of Vol. 1, “Relationship between Solid Cancer Deaths and Doses”)

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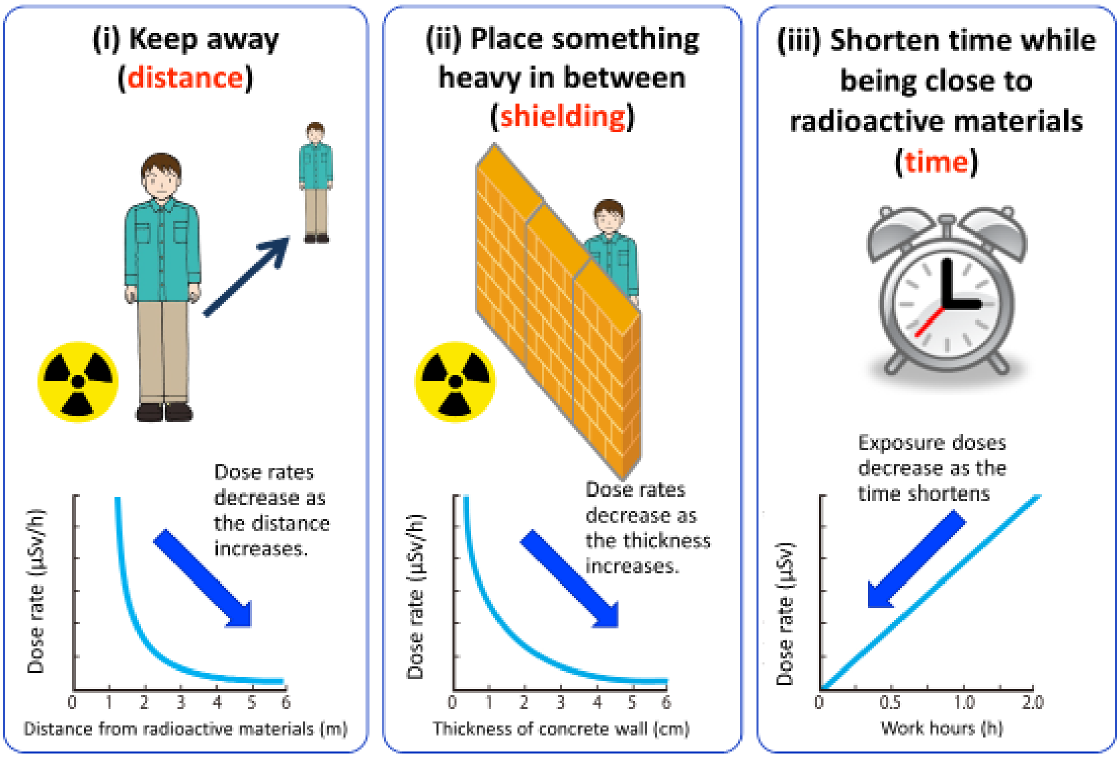
Dose Reduction

Three Principles of Reduction of External Exposure



There are three ways to reduce external exposure doses.

The first is to keep away from radioactive materials such as by removing soil contaminated with radioactive materials and isolate it from people's living environment.

The second is to shield radiation such as by staying indoors, replacing topsoil contaminated with radioactive materials with subsoil, and using uncontaminated soil as a shielding material.

The third is to shorten the time to stay at places with high ambient dose rates.

(Related to p.50 of Vol. 1, "Characteristics of External Exposure Doses")

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Dose Reduction

Reduction of Internal Exposure

- ◯ Prevent radioactive materials from entering the body through the mouth, nose or wounds, in principle.
- ◯ Wash off soil immediately from the body, shoes and clothes.
- ◯ Be aware of the information on the release and pollution of radioactive materials.
- ◯ Be careful not to lose nutritional balance, being excessively worried about a small amount of radioactive materials below the standard limit.

As causes of internal exposure, both intake through inhalation and oral intake through ingestion of foods and drinks need to be taken into consideration. After a nuclear disaster, radioactive materials remaining on the ground pose a problem, but intake through inhalation of resuspended radioactive materials is scarce. Proper daily hygienic control (such as washing hands and taking a bath, etc.) is also effective in reducing internal exposure.

In the meantime, regarding the possibility of internal exposure caused by ingestion of foods, attention needs to be paid to foods from which radioactive cesium is detected at high levels. In particular, special attention is required for ferns and mushrooms, which have a property to concentrate cesium. In the aftermath of a nuclear disaster, radioactivity concentrations in foods are inspected by individual prefectures based on inspection plans they formulate in light of the inspection items and the system presented by the national government. Inspection results are released via the websites of the Ministry of Health, Labour and Welfare, the Ministry of Agriculture, Forestry and Fisheries, and individual local governments (p.54 of Vol. 2, “Publication of the Inspection Results Concerning Radioactive Materials in Foods”).

Internal exposure due to radioactive cesium can be measured with a whole-body counter (WBC). Some local governments and private hospitals, etc. provide opportunities for checking internal exposures using WBCs.

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

Dose Reduction

Reduction of Exposure Indoors due to Radioactive Materials Released into the Environment

■ Studies on reduction of external exposure indoors

- ✓ From the results of measurements of ambient doses inside and outside of buildings, the reduction coefficient*1 in wooden and light-gauge steel houses is evaluated as 0.38 on the first floor and 0.49 on the second floor.
  (Source: N. Matsuda et al.: *J Environ Radioact* 166: 427-435, 2017.)
- ✓ From the results of measurements of ambient doses inside and outside of buildings, the median value of the reduction coefficient for wooden houses is evaluated as 0.43.
  (Source: H. Yoshida et al.: *SCIENTIFIC REPORTS* 4: 7541, 2014.)

■ Studies on reduction of internal exposure indoors

- ✓ From the results of measurements of radioactivity concentrations inside and outside of buildings, the decontamination factor*2 for radioactive materials in the air is evaluated as 0.64 for particulate I-131 and 0.58 for Cs-137.
  (Source: T. Ishikawa et al.: Environ Sci Technol 48:2430-2435, 2014.)
- ✓ As factors for internal exposure indoors, the natural ventilation rate, temperature differences between inside and outside of rooms, wind speed, and the total coverage and ages of buildings, etc. were set as parameters and were examined experimentally, thereby evaluating the coefficient of reduction of internal exposure (varying within the range of 0.1 to 1).
  (Source: J. Hirouchi et al.: *ASRAM2018-010*, 2018.)

*1: Ratio of a dose within a building when assuming the dose outdoors as 1
*2: Ratio of the concentration within a building when assuming the concentration outdoors as 1

When being indoors, radiation from radioactive materials released into the environment that are suspended in outdoor air or deposited on the ground surface, etc. is shielded by the building and the external exposure dose decreases. Additionally, the concentration of radioactive materials suspended in indoor air is lower than that outdoors thanks to the airtightness of the building, and the internal exposure dose through inhalation also decreases.

The value, 0.4, which is used as the coefficient of reduction of external exposure for typical Japanese wooden houses when considering radiological protection, is said to be based on the IAEA-TECDOC-225 (1979) (p.53 of Vol. 1, "Shielding and Reduction Coefficient"). As recent studies on the reduction of exposure indoors, the outcomes of studies concerning the coefficient of reduction of external exposure[1,2] are reported.

Additionally, as the effects of reducing internal exposure indoors, not only external exposure, the outcomes of studies concerning the effects of reducing radioactivity concentrations[3] and the coefficient of reduction of internal exposure[4] are also reported. It is reported that the effects of reducing internal exposure indoors vary by individual buildings' ages, wind speed, temperature differences between inside and outside of rooms, and other factors.

1. N. Matsuda et al.: J Environ Radioact 166: 427-435, 2017.
2. H. Yoshida et al.: SCIENTIFIC REPORTS 4: 7541, 2014.
3. T. Ishikawa et al.: Environ Sci Technol 48:2430-2435, 2014.
4. J. Hirouchi et al.: ASRAM2018-010, 2018.

Included in this reference material on March 31, 2023

Dose Reduction

Removal of Radioactive Cesium through Cooking and Processing of Foods

Radioactive materials can be reduced through cooking.

Item	Cooking/Processing methods	Removal rate (%)
Leaf vegetables (spinach, etc.)	Washing - Boiling	7～78
Bamboo shoots	Boiling	26～36
Japanese radish	Peeling	24～46
Nameko mushrooms (raw)	Boiling	26～45
Fruits (grape, persimmon, etc.)	Peeling	11～60
Marron	Boiling - Peeling astringent skin	11～34
Japanese plum	Salting	34～43
Cherry leaves	Salting	78～87
Fish	Cooked lake smelt soaked in Japanese sweet and peppery vegetable sauce	22～32

● Avoid eating wild foods too much.

$$\text{Removal rate (\%)} = \left(1 - \frac{\text{Total amount of radioactivity in cooked or processed foods (Bq)}}{\text{Total amount of radioactivity in raw materials (Bq)}}\right) \times 100$$

Source: Prepared based on the "Environmental Parameters Series Expanded Edition (2013): Radionuclide Removal Rates through Cooking and Processing of Foods - Centered on Data on Radioactive Cs Removal Rates in Japan -" (September 2013), Radioactive Waste Management Funding and Research Center

Immediately after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, radioactive materials detected from vegetables were only attached to the surface thereof, and such radioactive materials could be washed off to some extent.

At present, radioactive materials are seldom attached to the surface of vegetables, but some radioactive materials in soil may be taken into vegetables through their roots. However, radioactive cesium absorbed into vegetables from the roots can be removed through cooking or processing with some ingenuity.

The table above shows removal rates of radioactive cesium in foods.

When boiling vegetables, the longer the boiling time is, the larger the removal rate is. This is considered to be because radioactive cesium in vegetable cells comes out into the boiling water as vegetable cells break. Also in the case of salted vegetables, the longer the salting time is, the larger the removal rate is. This is considered to be because radioactive cesium in vegetables is replaced with sodium in salt.

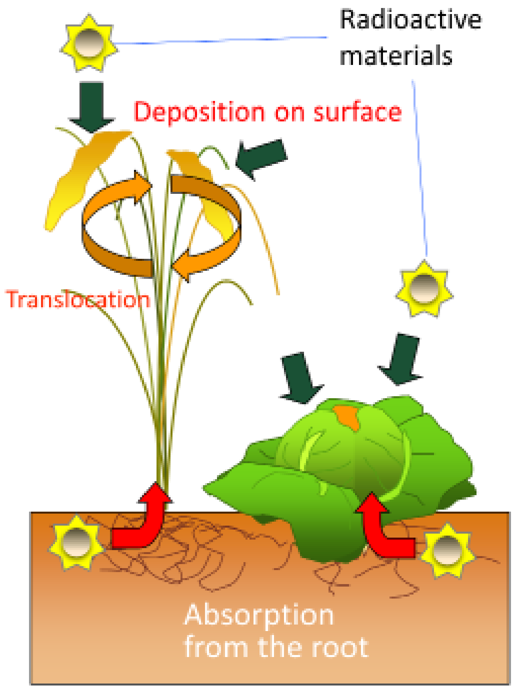
When cooking meat or fish, the amount of radioactive materials can be halved by discarding the cooking liquid. It is known that the removal rate is higher when boiling or cooking than grilling them.

Refer to the webpage (https://www.rwmc.or.jp/library/other/kankyo/, in Japanese) for the details of the related data.

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

Long-term Effects

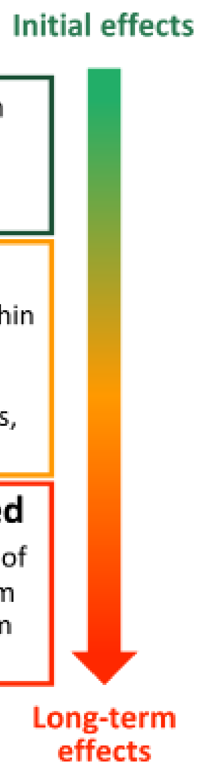
Transfer to Plants



Direct route (Deposition on leave surface directly from the air): Major route immediately after the release into the air

Route through translocation (Transfer within a plant): Radioactive materials absorbed into leaves and bark transfer to new leaves and fruits, etc.

Route of being absorbed from the root (Absorption of radioactive materials in soil from the root): Medium- to long-term transfer route after an accident



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

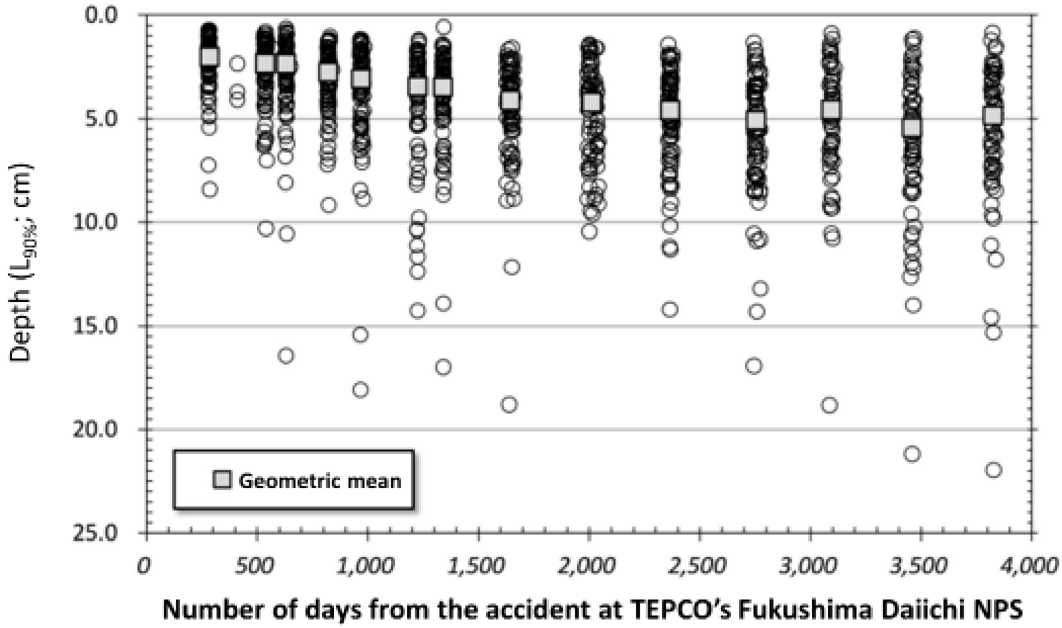


Figure: Data on changes over time in depth ($L_{90\%}$)* since December 2011 (85 locations at uncultivated land in Fukushima Prefecture, the southern part of Miyagi Prefecture and the northern part of Ibaraki Prefecture)

(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 FY2021 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 2021 was 4.85 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.180 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.

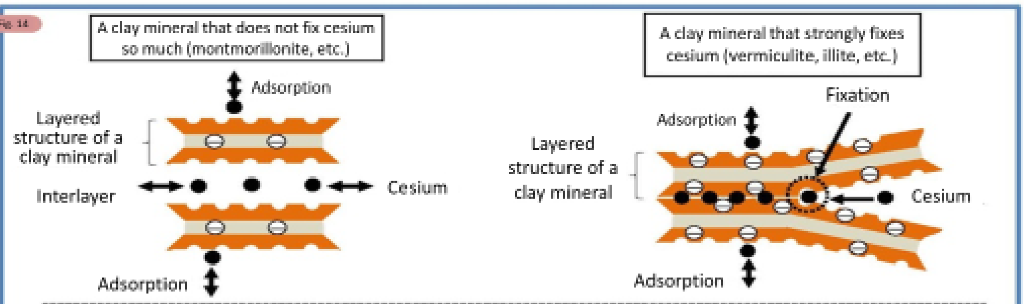
The survey on effects of the Chornobyl NPS Accident that occurred in 1986 revealed that approx. 80% of Cs-137 deposited on soil due to the accident had been staying within 10 cm from the ground surface even after 14 years from the accident (Report of the Chornobyl Forum Expert Group (2006), International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

Included in this reference material on March 31, 2017
Updated on March 31, 2023

Long-term Effects | Behavior of Radioactive Cesium in the Environment: Adsorption and Fixation by Clay Mineral

Adsorption and fixation of cesium

Fig. 14



[Explanation]
- A clay mineral on its surface has a negative charge and can adsorb cesium and part of the clay mineral can also incorporate and fix cesium in itself over time.
- Adsorbed cesium can be absorbed by plants, but once fixed, not so much is absorbed.

Table 4

Soil components	Adsorption of Cs	Fixation of Cs
Soil organic matters	Strong	Weak
Clay minerals (non-micaceous)		
Kaolinite, Halloysite	Strong	Weak
Allophane, Imogolite	Strong	Weak to medium
Montmorillonite	Strong	Weak
Clay minerals (micaceous)		
Vermiculite	Strong	Strong
Illite	Strong	Medium to strong
Aluminum vermiculite	Strong	Medium to strong
Zeolite	Strong	Strong (Note)

(Note) Anchoring power of these components varies depending on production areas and qualities.

[Explanation]
- Soil organic matters and non-micaceous clay minerals, such as montmorillonite, have weak fixation power.
- Micaceous clay minerals, such as vermiculite and illite, strongly fix cesium.

Source: From the following website: https://www.maff.go.jp/j/kanbo/joho/saigai/pdf/youin_kome2.pdf (in Japanese)

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]

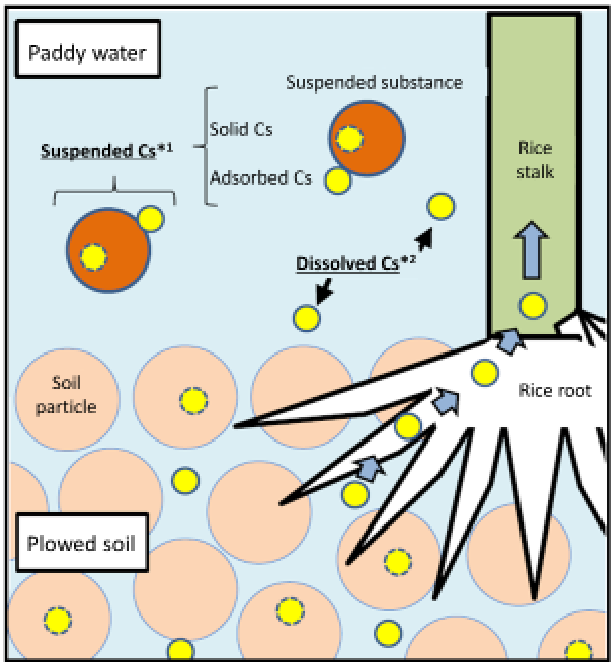
1. Outcome report of the FY2014 project, "Compilation of Data on Distribution of Radioactive Materials Released due to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS and Development of Transfer Model" commissioned by the Secretariat of the Nuclear Regulation Authority

Included in this reference material on March 31, 2017

Long-term Effects

Behavior of Radioactive Cesium in the Environment: Transfer from Water to Plants

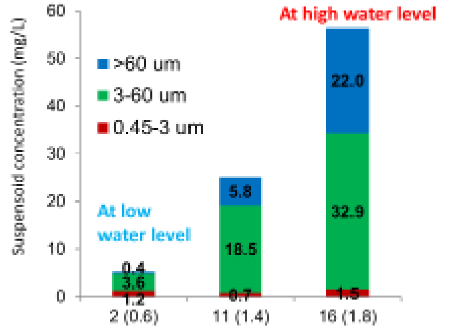
Forms of cesium in water



*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/m^2)	544	298	916	13	170-230
Amount of outflow of Cs-137*4 (kBq/m^2)	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.180 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.

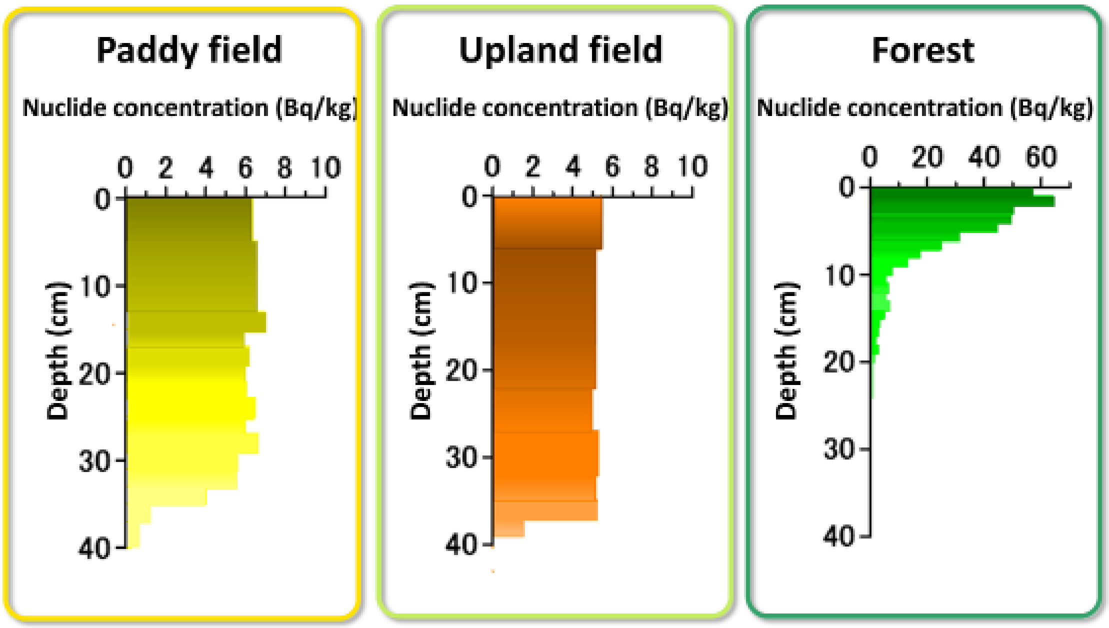
Reference

• 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.179 of Vol. 1, "Distribution of Radioactive Cesium in Soil")

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

Long-term Effects

Distribution of Radioactive Materials in Forests

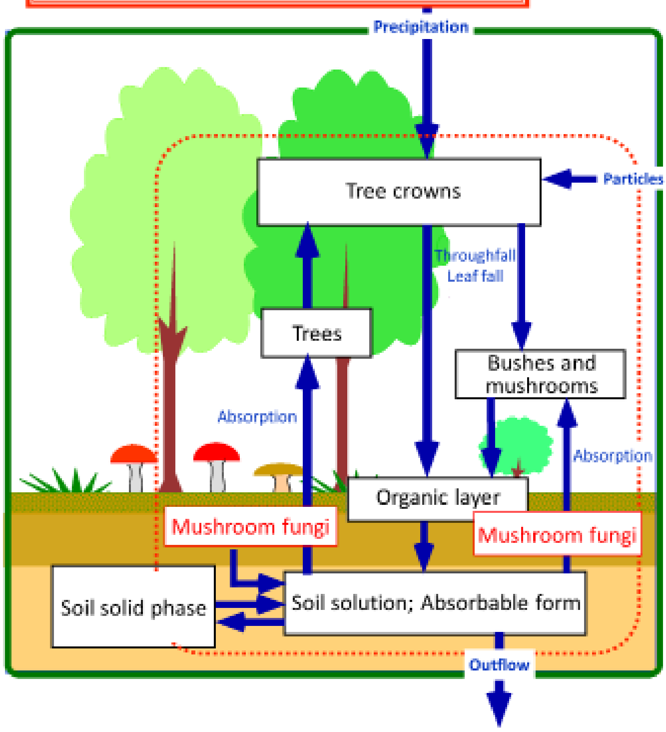
Distribution changes over time (years).

Immediately after deposition from the air:
- Leaves and branches on tree crowns (partially absorbed from their surface and translocated to other parts)
- Around the surface of the soil organic layer (mulch layer)

Thereafter:
- From tree crowns to the soil organic layer
- From the organic layer to subsoil
- Absorption into plants from the root

In the end:
- Mostly deposited in the soil surface layer including the organic layer

Dynamic transfer within the forest



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.

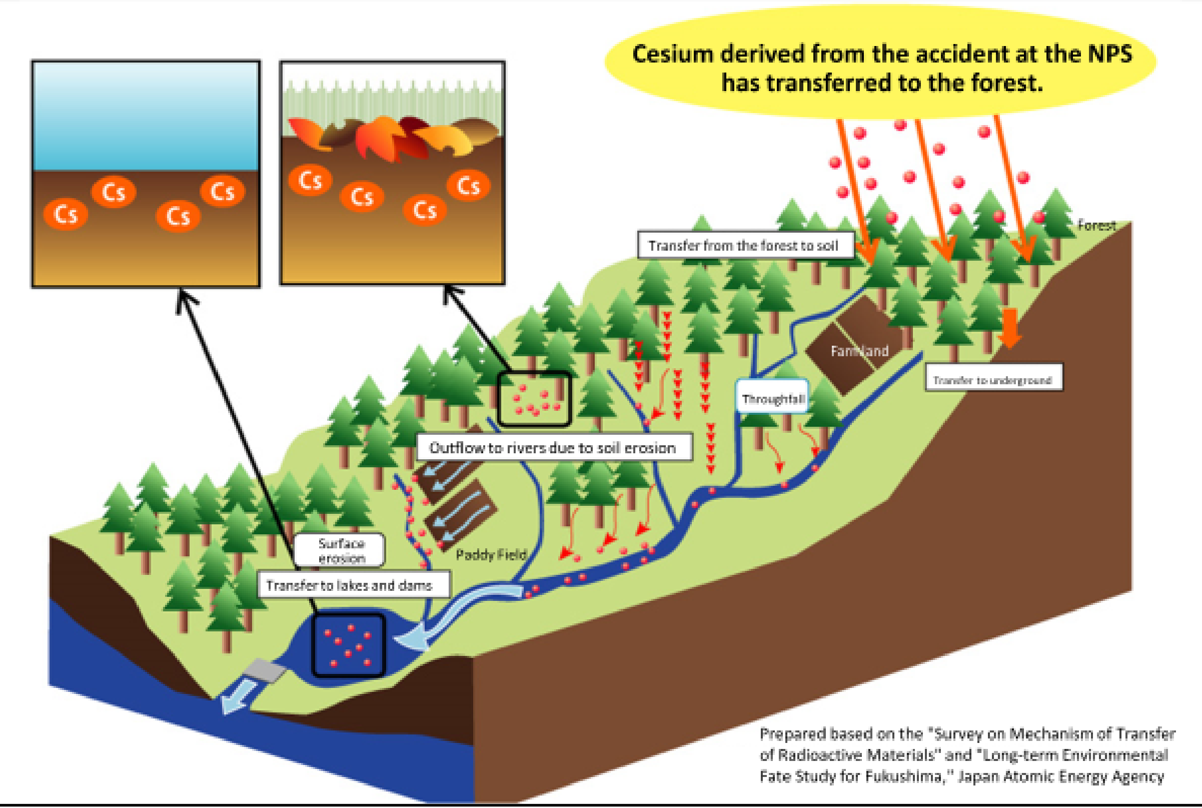
Radioactive cesium in the organic layer gradually transfers into subsoil, and plants that take root deeper than the surface layer will come to absorb such cesium.

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

Long-term Effects — Transfer of Fallen and Deposited Cesium in the Environment



Prepared based on the "Survey on Mechanism of Transfer of Radioactive Materials" and "Long-term Environmental Fate Study for Fukushima," Japan Atomic Energy Agency

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.180 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.

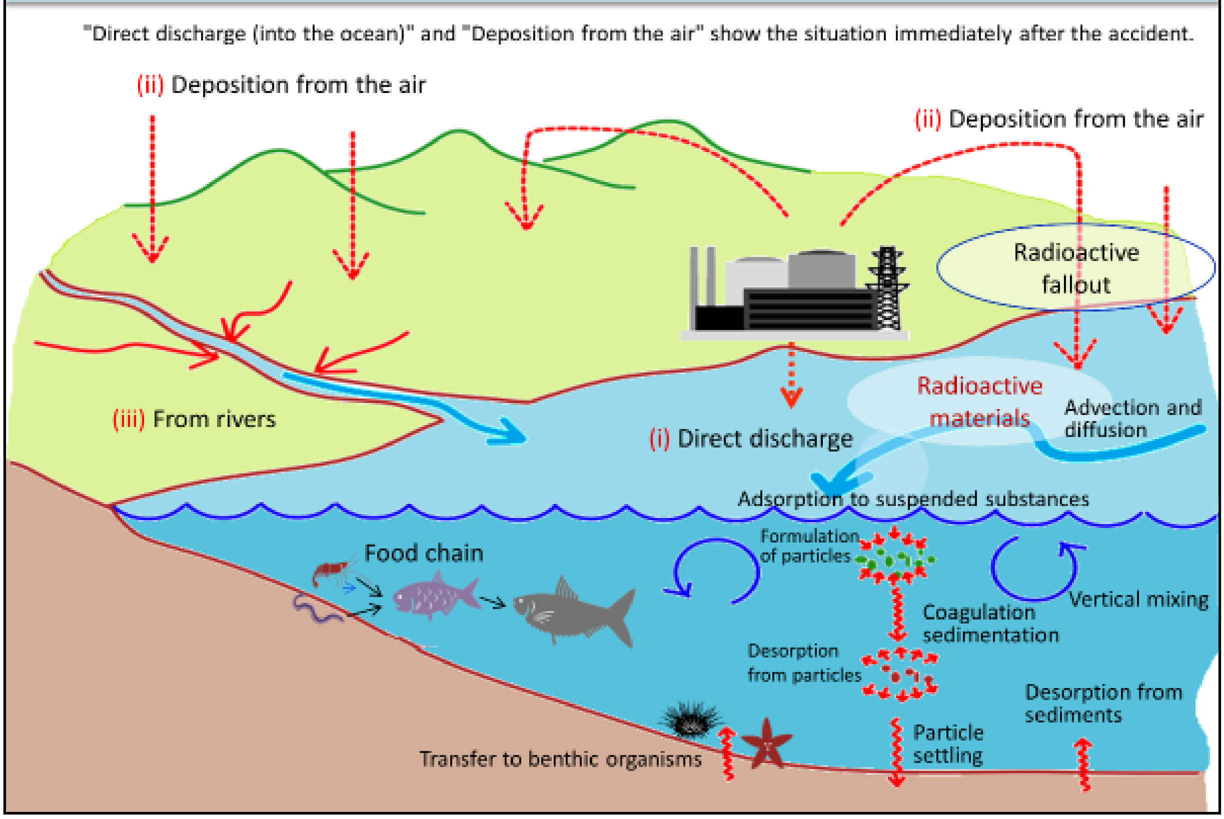
The above figure illustrates the process that fallen and deposited cesium in the forest flows from the upstream to a downstream dam lake. The two enlarged pictures show the forest floor and the sediment at the bottom of the dam lake, both indicating that cesium is deposited in the surface layer of soil.

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

Long-term Effects

Distribution of Radioactive Cesium in the Ocean



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).

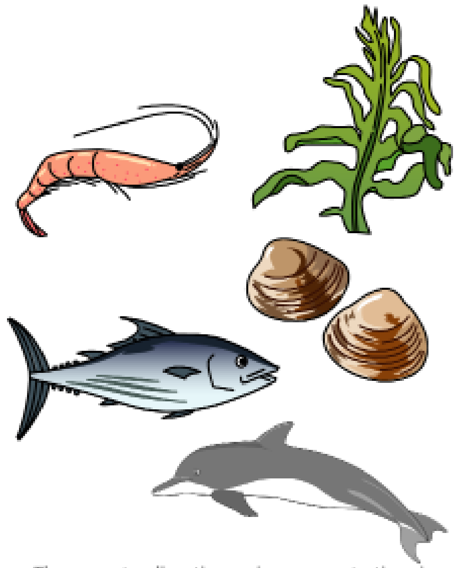
Included in this reference material on March 31, 2013
Updated on March 31, 2023

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").

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