Illustrated Handbook

Vol. 1

BOOKLET to Provide Basic Information
Regarding Health Effects of Radiation

Basic Knowledge and Health Effects of Radiation

Radiation Health Management Division, Ministry of the Environment, Government of Japan
National Institutes for Quantum Science and Technology

The booklet is also available on the website.

▸ https://www.env.go.jp/en/chemi/rhm/basic-info/

Introduction

Fourteen years have passed since the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station. In 2020, evacuation orders for Preparation Areas for Lifting of Evacuation Orders and Habitation Restricted Areas, except for Restricted Areas, were all lifted, and in 2023 evacuation orders for Specified Reconstruction and Revitalization Base Areas were also lifted. From September 2023 to February 2024, Plans for Reconstruction and Revitalization of the Specific Revitalized Residential Areas were approved for Okuma Town, Futaba Town, Namie Town, and Tomioka Town. Thus, steady progress has been made in the reconstruction and recovery of Fukushima Prefecture. The national government must ensure that residents who have returned home can rebuild their lives smoothly without worries about their health due to the radioactive materials discharged by the accident. For that purpose, the national government and the local government are committed to properly responding to their health problems and providing correct information in an easy-to-understand manner on a timely basis.

Based on the Policy Package on Radiation Risk Communication for Achieving Residents' Return (2014), the national government has endeavored to disseminate correct and easy-to-understand information and has strengthened risk communication among a small number of people.

The Radiation Health Management Division, Environmental Health Department, Minister's Secretariat, Ministry of the Environment has collected and compiled basic knowledge on radiation, and scientific expertise and initiatives of relevant ministries and agencies concerning health effects of radiation, and has prepared a booklet to provide basic information since 2012 and has updated the booklet with the latest information and statistical data, together with the National Institutes for Quantum Science and Technology. This booklet has been utilized in training sessions targeting people engaging in health and medical care, welfare, and education or on other occasions with the aim of fostering personnel who can respond to residents' worries and concerns about their health in Fukushima and neighboring prefectures.

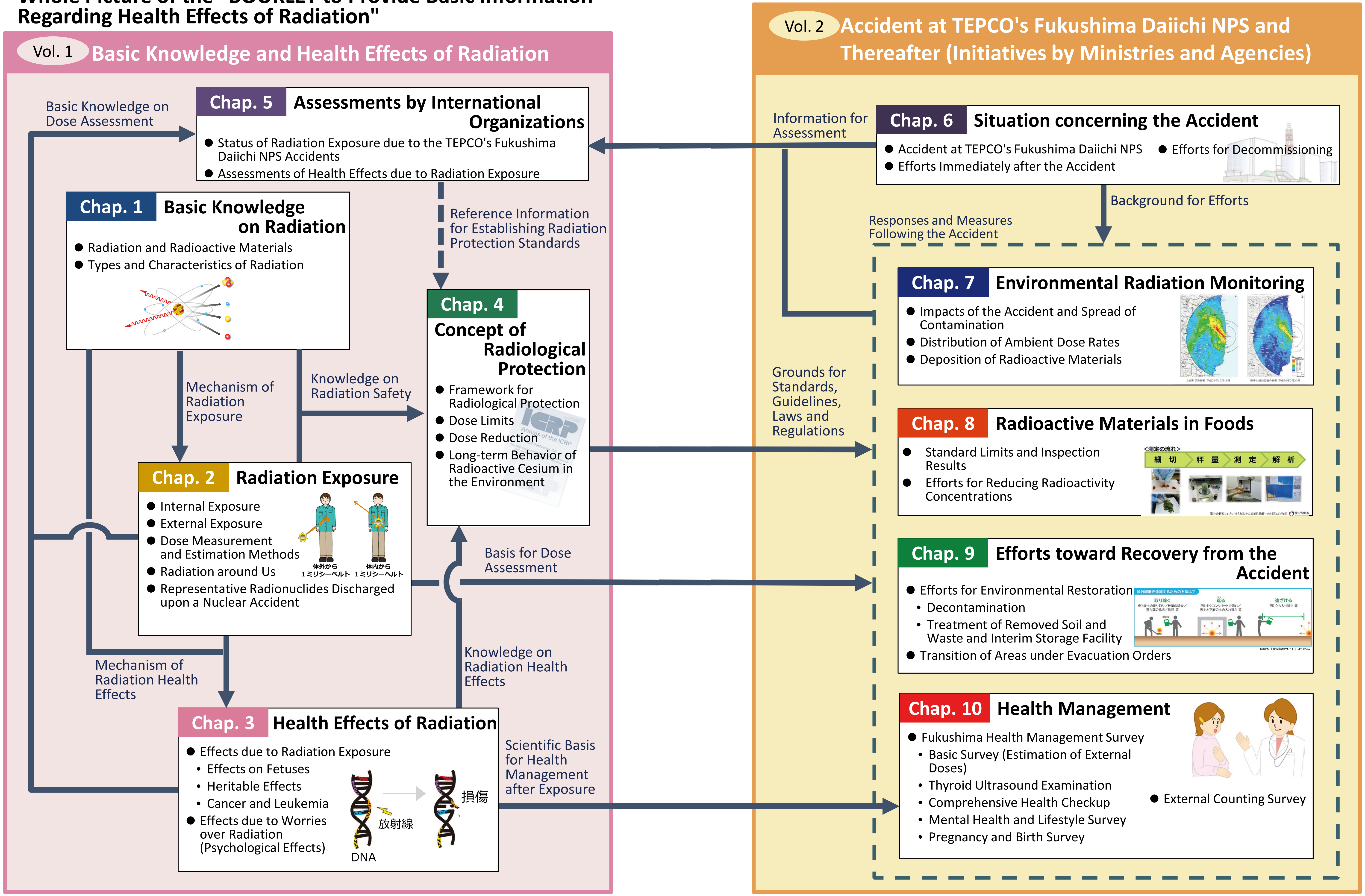
The Radiation Health Management Division and the National Institutes for Quantum Science and Technology have jointly publicized the English version of the booklet, with cooperation of a group of experts, so that foreign nationals residing in Japan or visiting Japan or those interested in Japan can obtain basic knowledge on health effects of radiation and correctly understand changes in circumstances and efforts being made in Japan. As terms used in this field are highly professional and difficult, we also prepared a glossary. We would like to extend our gratitude to the people who offered cooperation in checking the translation and preparing the glossary.

The booklet is also available on the website of the Ministry of the Environment, from which you can download the content for use in training and classwork. We hope that this booklet will be utilized in diverse occasions.

(*) In this booklet, in some parts where the names of data sources and quotations are indicated, "Chornobyl" is spelled as "Chernobyl."

March 2025
Radiation Health Management Division,
Environmental Health Department,
Minister's Secretariat,
Ministry of the Environment,
Government of Japan
&
National Institutes for Quantum Science and Technology

Whole Picture of the "BOOKLET to Provide Basic Information Regarding Health Effects of Radiation"



Vol. 1 Basic Knowledge and Health Effects of Radiation

Basic Knowledge on Dose Assessment

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Vol. 2 Accident at TEPCO's Fukushima Daiichi NPS and Thereafter (Initiatives by Ministries and Agencies)

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- Standard Limits and Inspection Results
- Efforts for Reducing Radioactivity Concentrations

Chap. 9 Efforts toward Recovery from the Accident

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Chap. 10 Health Management

- Fukushima Health Management Survey
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  - Thyroid Ultrasound Examination
  - Comprehensive Health Checkup
  - Mental Health and Lifestyle Survey
  - Pregnancy and Birth Survey
- External Counting Survey

This BOOKLET compiles basic knowledge on radiation, scientific knowledge on health effects of radiation, and initiatives by relevant ministries and agencies into one page for each item.

Please select and refer to sections according to your interests.

Outline of Each Chapter

Vol. 1 Basic Knowledge and Health Effects of Radiation

Chap. 1 Basic Knowledge on Radiation

Chapter 1 explains radiation, its difference from radioactivity and radioactive materials, and the types and characteristics of radiation.
You can learn basic knowledge on familiar terms such as "radiation," "radioactivity," and "radioactive materials," and can deepen your knowledge and understanding of radiation itself.

Chap. 2 Radiation Exposure

Chapter 2 explains the mechanism of radiation exposure and measurement and calculation methods for exposure doses, and also provides explanations about radiation around us and representative radionuclides discharged upon a nuclear accident.
You can learn about radiation exposure, and on what occasion and to what extent you may be exposed to radiation. This chapter helps you understand what measuring devices and what calculation methods are used for obtaining radiation doses and exposure doses.

Chap. 3 Health Effects of Radiation

Chapter 3 explains radiation effects on the human body and mechanism of generating effects.
You can understand the health effects of radiation based on scientific grounds, including data on the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, atomic bomb survivors, and the Chernobyl NPS Accident.
You can also understand the relation between types of exposure (affected body parts, exposure dose and period) and health effects and psychological effects due to worries over radiation.

Chap. 4 Concept of Radiological Protection

Chapter 4 explains the framework of radiological protection, dose limits and dose reduction.
You can obtain knowledge on principles for protecting human health against radiation effects and methods for reducing exposure doses. Please refer to this chapter when you want to understand the concept of dose limits that served as the basis for standards for distribution restrictions for foods and designation of Areas under Evacuation Orders after the accident at TEPCO's Fukushima Daiichi NPS or the concept of radiological protection.

Chap. 5 Assessments by International Organizations

Chapter 5 outlines the assessments on radiation exposure made by the World Health Organization (WHO) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) after the accident at TEPCO's Fukushima Daiichi NPS.
You can grasp an outline of how the status and effects of radiation exposure due to the accident are assessed internationally, including the latest reports by international organizations.

Vol. 2 Accident at TEPCO's Fukushima Daiichi NPS and Thereafter (Initiatives by Ministries and Agencies)

Chap. 6 Situation concerning the Accident

Chapter 6 explains the accident at TEPCO's Fukushima Daiichi NPS, responses immediately after the accident, and efforts for decommissioning.
You can understand what happened at the NPS at the time of the accident, and the current status of the NPS. In particular it goes into details about management of decommissioning, contaminated water and treated water.

Chap. 7 Environmental Radiation Monitoring

Chapter 7 explains environmental radiation monitoring being conducted after the accident at TEPCO's Fukushima Daiichi NPS and the results thereof.
You can understand how impacts of the accident spread and the status of contamination in the surrounding environment near the NPS, and changes over time after the accident.

Chap. 8 Radioactive Materials in Foods

Chapter 8 explains the standard limits for radioactive materials in foods, results of inspections, and efforts for reducing radioactive concentrations in foods.
You can understand the framework to ensure the safety of foods distributed on the market and concrete measures being taken after the accident at TEPCO's Fukushima Daiichi NPS, and inspection results regarding to what extent there have been foods with radioactive concentrations exceeding the standard limits after the accident up to the present.

Chap. 9 Efforts toward Recovery from the Accident

Chapter 9 explains efforts toward recovery from the accident, such as measures against environmental contamination by radioactive materials discharged due to the accident at TEPCO's Fukushima Daiichi NPS and transition of Areas under Evacuation Orders.
You can understand how to recover areas contaminated with radioactive materials, how to treat waste, and what measures are being taken at present in Areas under Evacuation Orders and surrounding areas.

Chap. 10 Health Management

Chapter 10 outlines the Fukushima Health Management Survey and other surveys and examinations that are conducted for the purpose of promoting the health of the residents of Fukushima Prefecture and ensuring their safety in light of the effects of radiation due to the accident at TEPCO's Fukushima Daiichi NPS.
You can understand Fukushima Prefecture's efforts for health management in order to promote and maintain residents' good health toward the future.

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Chapter 2 Radiation Exposure

Chapter 3 Health Effects of Radiation

3.6 Heritable Effects

3.7 Cancer and Leukemia

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Chapter 1

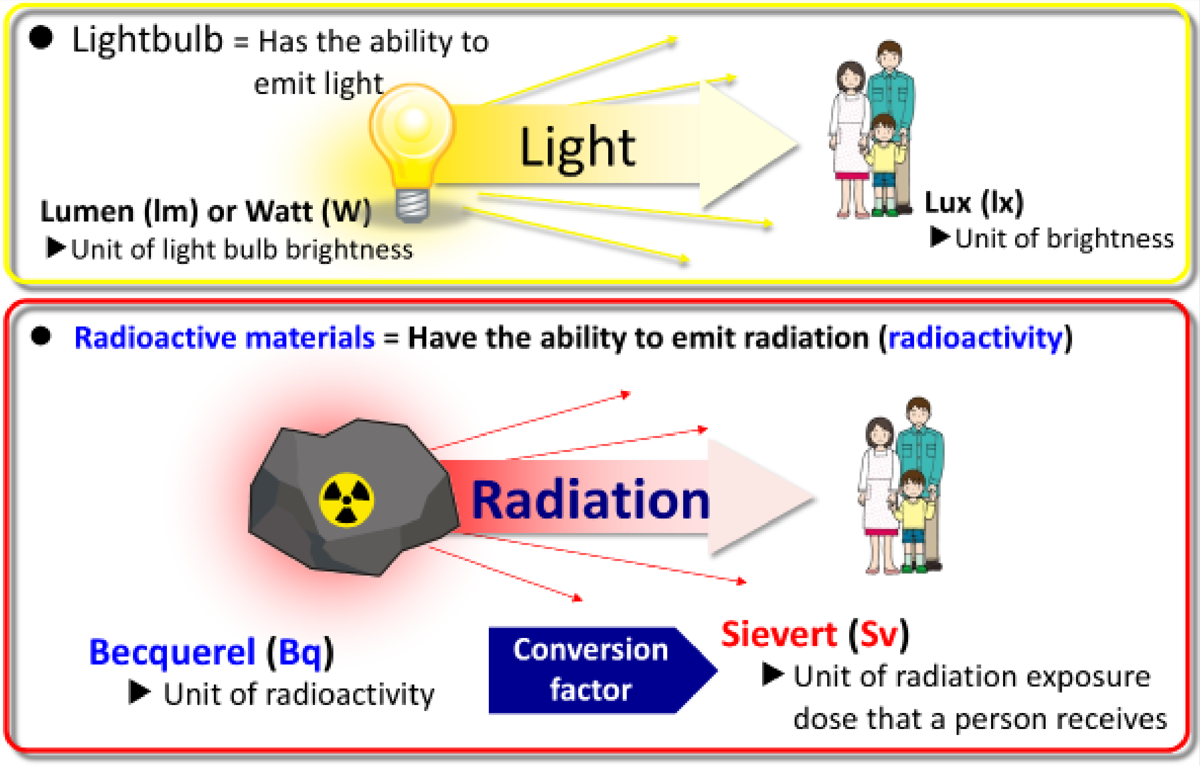
Basic Knowledge on Radiation

Chapter 1 explains radiation, its difference from radioactivity and radioactive materials, and the types and characteristics of radiation.

You can learn basic knowledge on familiar terms such as “radiation,” “radioactivity,” and “radioactive materials,” and can deepen your knowledge and understanding of radiation itself.

Radiation and Radioactivity

Radiation, Radioactivity and Radioactive Materials



*Sievert is associated with radiation effects.

Radiation, radioactivity and radioactive materials are outlined below.

A light bulb, an object familiar to everyone, has the ability to emit light. Light bulb brightness is expressed in the unit of “Lumens” or “Watts.” People receive the light and feel the brightness. The unit in this case is “Lux.”

The units related to radiation, such as becquerel and sievert, which we often hear about lately, also have a similar relation to the above. For example, when a rock emits radiation, this rock is called a “radioactive material” (p.3 of Vol. 1, “Units of Radiation and Radioactivity”).

Radioactive materials emit radiation, and this ability is called “radioactivity.” In this case, it is expressed as “This rock has radioactivity” or “This rock emits radiation.” This ability of emitting radiation is expressed in the unit of “Becquerel (Bq).”

“Sievert (Sv)” is used as the unit of the radiation exposure dose necessary to know the effect of radiation to which a person is exposed. There is a special conversion factor to calculate “Sv” from “Bq.”

Higher radioactivity (value expressed in becquerels) means that the relevant radioactive material emits more radiation, but radiation exposure dose (value expressed in sieverts) varies depending on the distance between the radioactive material and the person exposed thereto. The intensity of radiation rises when the person is closer to the thing emitting radiation, and the intensity weakens as the distance becomes larger. This is the same as a bright light bulb appearing dim at a distance.

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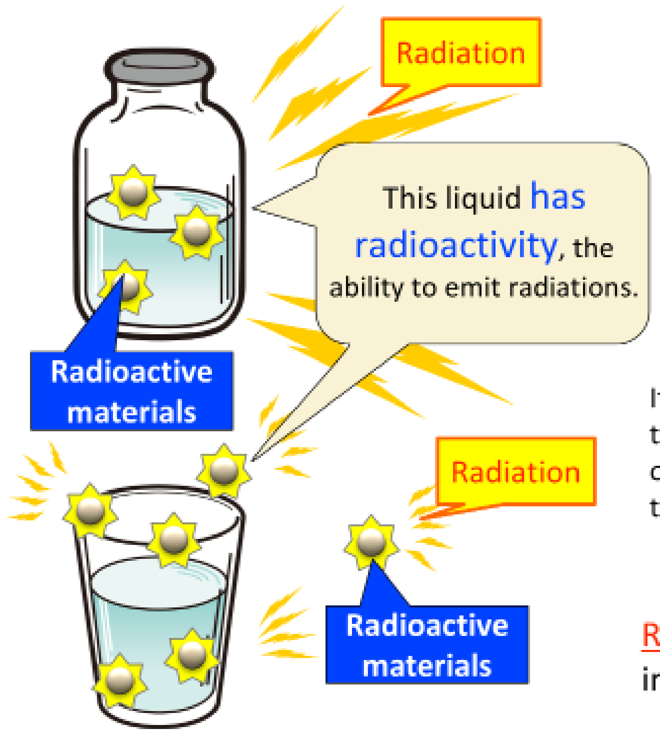
Radiation and Radioactivity

Difference between Radiation and Radioactive Materials



Radioactive materials themselves emit radiation.

If radionuclides are incorporated into the body, they will be partly removed outside the body (excreted) or be transferred to particular organs/tissues.

Radiation itself does not remain in the body.

Radioactive materials are materials that emit radiation. For example, the term is used as follows: “This water contains radioactive materials.” Although the term “radioactivity” is sometimes used in the meaning of radioactive materials, in the field of natural sciences, the term only refers to the ability to emit radiation.

If a sealed container contains water with radioactive materials, radiation may leak from the container, but radioactive materials do not come out. If a container without a lid contains water with radioactive materials, there is a possibility that radioactive materials may spread due to spilling, etc.

Radioactive materials incorporated into the body may remain in the body for a certain period of time and move between organs but some of them are excreted or lose radioactivity as a result of emitting radiation. Effects of radiation may partially remain in cells but radiation itself does not remain in the body. Health effects of radiation are detailed in Chapter 3.

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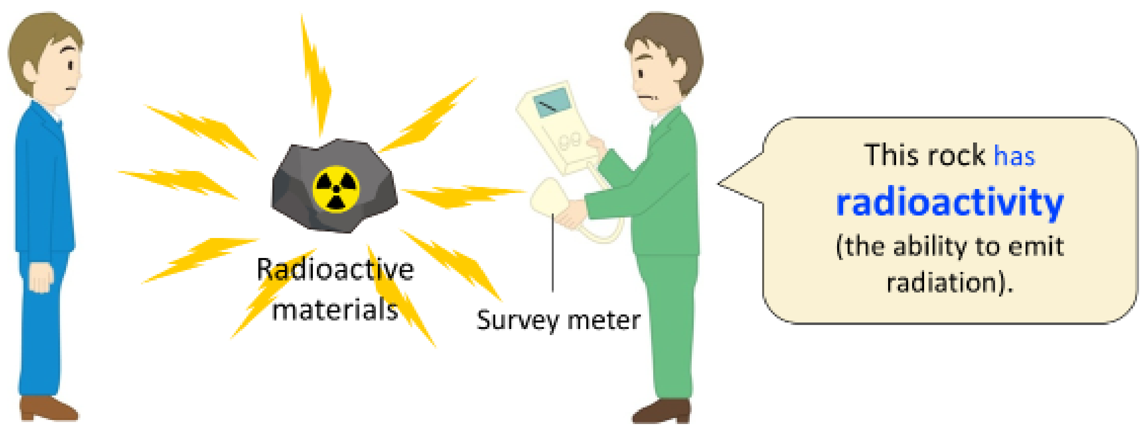
Radiation and Radioactivity

Units of Radiation and Radioactivity



Becquerel (Bq)
Unit for intensity of radiation:
one nucleus decays (disintegrates) per second = 1 becquerel

Sievert (Sv)
Unit of radiation exposure dose which a person receives:
associated with radiation effects

Humans cannot sense radiation with their five senses because radiation is invisible and odorless. However, it has a feature that makes measuring easy.

"Becquerel" and "Sievert," which we have often heard about and seen recently, are units related to radiation. For example, radiation in soil or food can be measured using a special measuring device to find how much radioactive materials are contained in them. The becquerel is a unit to express the intensity of such radiation. The sievert is a unit to express the effect on the human body (for details, refer to Vol. 1, "2.3 Units of Radiation").

Places where a large amount of radioactive materials exist can be identified with a handheld survey meter. Additionally, the intensity and types of radiation emitted from radioactive materials, as well as personal exposure doses, can be checked with various types of survey meters (for details, refer to Vol. 1, "2.4 Dose Measurement and Calculation").

Furthermore, based on the results of various investigative studies, radiation doses due to the effect of the accident and natural radiation doses, as well as the total thereof, can be obtained separately.

Means for radiation management and radiation protection are devised taking advantage of this feature of radiation, i.e., the easiness of measurement.

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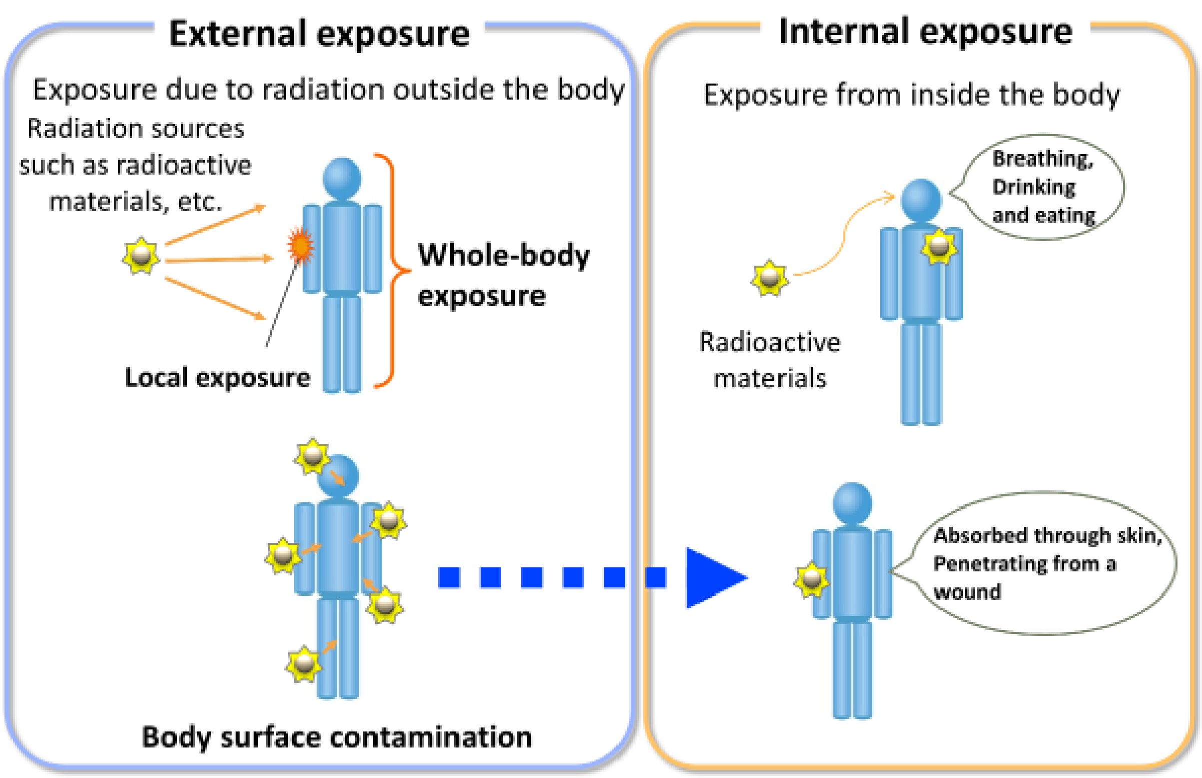
Radiation and Radioactivity

Types of Exposure



To receive radiation from radioactive materials is called radiation exposure. On the other hand, radioactive contamination means that matter, including people and places, is contaminated with radioactive materials. In other words, radioactive contamination suggests that some radioactive materials exist in places where radioactive materials do not usually exist.

To receive radiation from radioactive materials outside the body is called external exposure.

If a person breathes in radioactive materials in the air or takes contaminated food or drink into their body, he/she will be exposed to radiation from inside their body. In addition, radioactive materials can also enter the body from wounds. Receiving radiation in this way is called internal exposure.

For internal and external exposures, the relevant radiation types (α (alpha)-particles, β (beta)-particles and γ (gamma)-rays) (for details, refer to Vol. 1, “1.3 Radiation”) and radioactive materials (radionuclides) are different, because the ability to pass through the air or the body differs by radiation type.

In addition, the state in which radioactive materials adhere to the surface of the human body is called body surface contamination. If radioactive materials that adhere to the surface of the human body enter inside through the nose, mouth or wounds, internal contamination arises and this may cause internal exposure.
(Related to p.2 of Vol. 1, “Difference between Radiation and Radioactive Materials,” and p.23 of Vol. 1, “Internal and External Exposure”)

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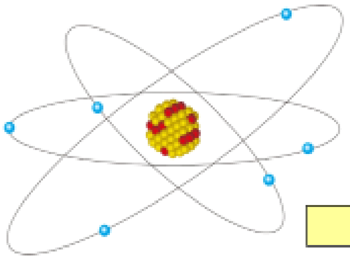
Radioactive Materials

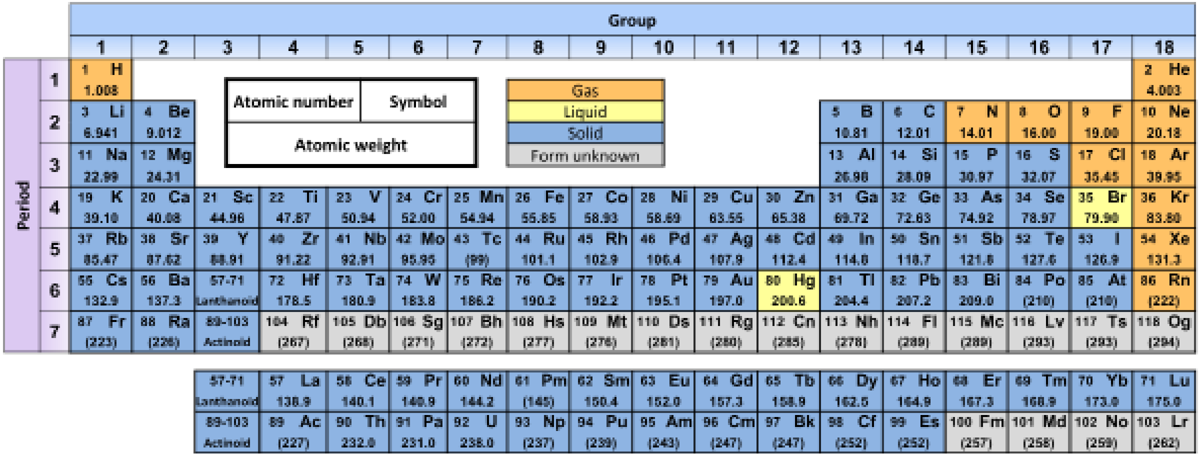
Atomic Structure and Periodic Law



				Charge
Atom	Nucleus	Proton	🔴	+
		Neutron	🟡	0
	Electron		🔵	−

The number of protons (atomic number) determines the chemical properties.

Periodic Table of Elements



Atomic number	Symbol
Atomic weight	

🟧 Gas
🟨 Liquid
🟦 Solid
⬜ Form unknown

Group

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc (99)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57-71 Lanthanoid	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89-103 Actinoid	104 Rf (267)	105 Db (268)	106 Sg (271)	107 Bh (272)	108 Hs (277)	109 Mt (276)	110 Ds (281)	111 Rg (280)	112 Cn (285)	113 Nh (278)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (293)	118 Og (294)

57-71 Lanthanoid	57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
89-103 Actinoid	89 Ac (227)	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (239)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (252)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

The numbers in parentheses are the nuclear numbers of the typical radioisotopes of the elements (IUPAC).
Prepared based on "One Periodic Table per One Household (13th Edition)": Ministry of Education, Culture, Sports, Science and Technology (MEXT)

An atom is composed of a nucleus and electrons that go around the former. The nucleus is composed of protons with a positive charge and neutrons without charge, and the number of protons (atomic number) determines the chemical properties of the atom (element type).

For example, carbon has six protons, but there are also types of carbon with five, six, seven or eight neutrons. All of them have the same chemical properties.

When calling them distinctively, they are called Carbon 11, Carbon 12, Carbon 13 and Carbon 14, adding the nuclear number (total of protons and neutrons) after the element name, which is a nominal designation that covers the same types of atoms. Carbon 12 is the one that most commonly exists in nature.

Carbon 14 is a radionuclide which exists in nature and is made through a process where a proton of Nitrogen 14 is hit and removed by a neutron created as a result of collisions of cosmic rays and the atmosphere. Carbon 14 has six protons and eight neutrons, and the state is energetically unstable because of the unbalance of both numbers.

If one neutron of Carbon 14 changes to a proton, the element becomes stable because the numbers of protons and neutrons are both seven. At this time, an electron is emitted as extra energy. This is the identity of β (beta)-particles. In other words, Carbon 14 returns to nitrogen having seven protons by emitting β-particles, and becomes energetically stable.

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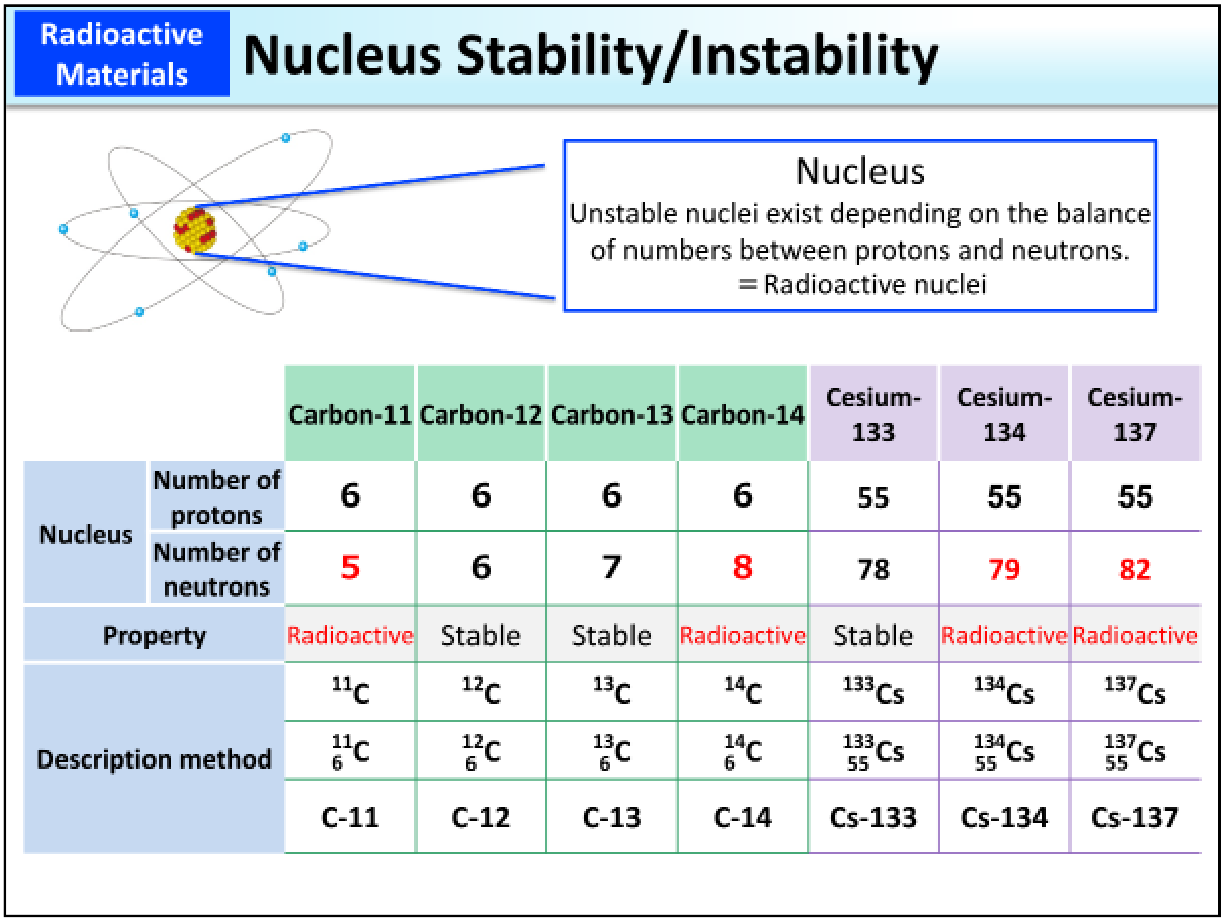

Radioactive Materials

Nucleus Stability/Instability

Nucleus

Unstable nuclei exist depending on the balance of numbers between protons and neutrons.
= Radioactive nuclei

		Carbon-11	Carbon-12	Carbon-13	Carbon-14	Cesium-133	Cesium-134	Cesium-137
Nucleus	Number of protons	6	6	6	6	55	55	55
	Number of neutrons	5	6	7	8	78	79	82
Property		Radioactive	Stable	Stable	Radioactive	Stable	Radioactive	Radioactive
Description method		^{11}C	^{12}C	^{13}C	^{14}C	^{133}Cs	^{134}Cs	^{137}Cs
		$^{11}_{6}C$	$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$	$^{133}_{55}Cs$	$^{134}_{55}Cs$	$^{137}_{55}Cs$
		C-11	C-12	C-13	C-14	Cs-133	Cs-134	Cs-137

Nuclei having the same atomic number (the number of protons) but differing in the number of neutrons are called "isotopes" to each other. There are "radioisotopes" that emit radiation upon radioactive disintegration and "stable isotopes" that do not emit radiation and so do not change in atomic weight.

Radionuclides emit radiation such as α (alpha)-particles, β (beta)-particles, and γ (gamma)-rays to mitigate or terminate their unstable states. Radionuclides turn into different atoms after emission of α-particles or β-particles but such change does not occur after emission of γ-rays. The radiation type to be emitted is dictated for each radionuclide (p.8 of Vol. 1, "Naturally Occurring or Artificial," and p.13 of Vol. 1, "Where does Radiation Come from?").

Carbon is an element having six protons but there are also variants having five to eight neutrons. Cesium is an element having fifty-five protons, and its variants having fifty-seven to ninety-six neutrons have been found so far. Among them, only Cesium-133 having seventy-eight neutrons (55 protons plus 78 neutrons = 133) is stable, and all the rest are radioisotopes that emit radiation. In the event of a nuclear plant accident, Cesium-137 and Cesium 134 that is made through a process where fission products are hit by a neutron may be released into the environment. They emit β-particles and γ-rays.
(Related to p.30 of Vol. 1, "Products in Nuclear Reactors")

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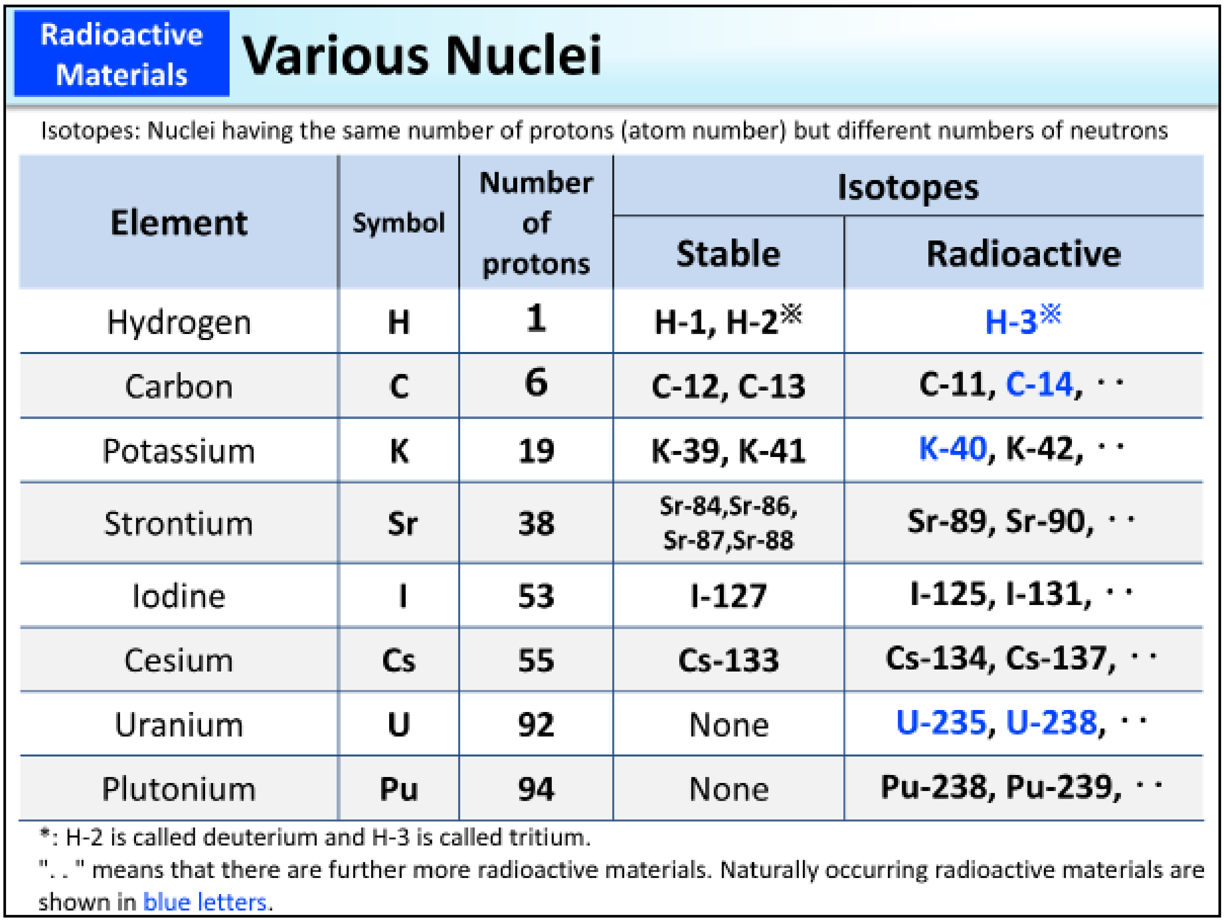

Radioactive Materials

Various Nuclei

Isotopes: Nuclei having the same number of protons (atom number) but different numbers of neutrons

Element	Symbol	Number of protons	Isotopes	
			Stable	Radioactive
Hydrogen	H	1	H-1, H-2※	H-3※
Carbon	C	6	C-12, C-13	C-11, C-14, ・・
Potassium	K	19	K-39, K-41	K-40, K-42, ・・
Strontium	Sr	38	Sr-84,Sr-86, Sr-87,Sr-88	Sr-89, Sr-90, ・・
Iodine	I	53	I-127	I-125, I-131, ・・
Cesium	Cs	55	Cs-133	Cs-134, Cs-137, ・・
Uranium	U	92	None	U-235, U-238, ・・
Plutonium	Pu	94	None	Pu-238, Pu-239, ・・

*: H-2 is called deuterium and H-3 is called tritium.

". . " means that there are further more radioactive materials. Naturally occurring radioactive materials are shown in blue letters.

While most hydrogen atoms are H-1 whose nucleus has only one proton, there are also H-2 (deuterium) that has one proton and one neutron and H-3 (tritium) that has one proton and two neutrons. Only H-3 (tritium) emits radiation among these isotopes.

Like hydrogen, there are elements (collectively referring to the same type of atoms) having only one type of radioactive nucleus, but there are also many elements having multiple types of radioactive nuclei. Some elements with a large atomic number such as uranium and plutonium do not have stable nuclei that do not emit radiation.

While most naturally occurring radionuclides have existed since the birth of the earth, there are some that are still being created by the interaction between cosmic rays and the atmosphere, such as Carbon-14.

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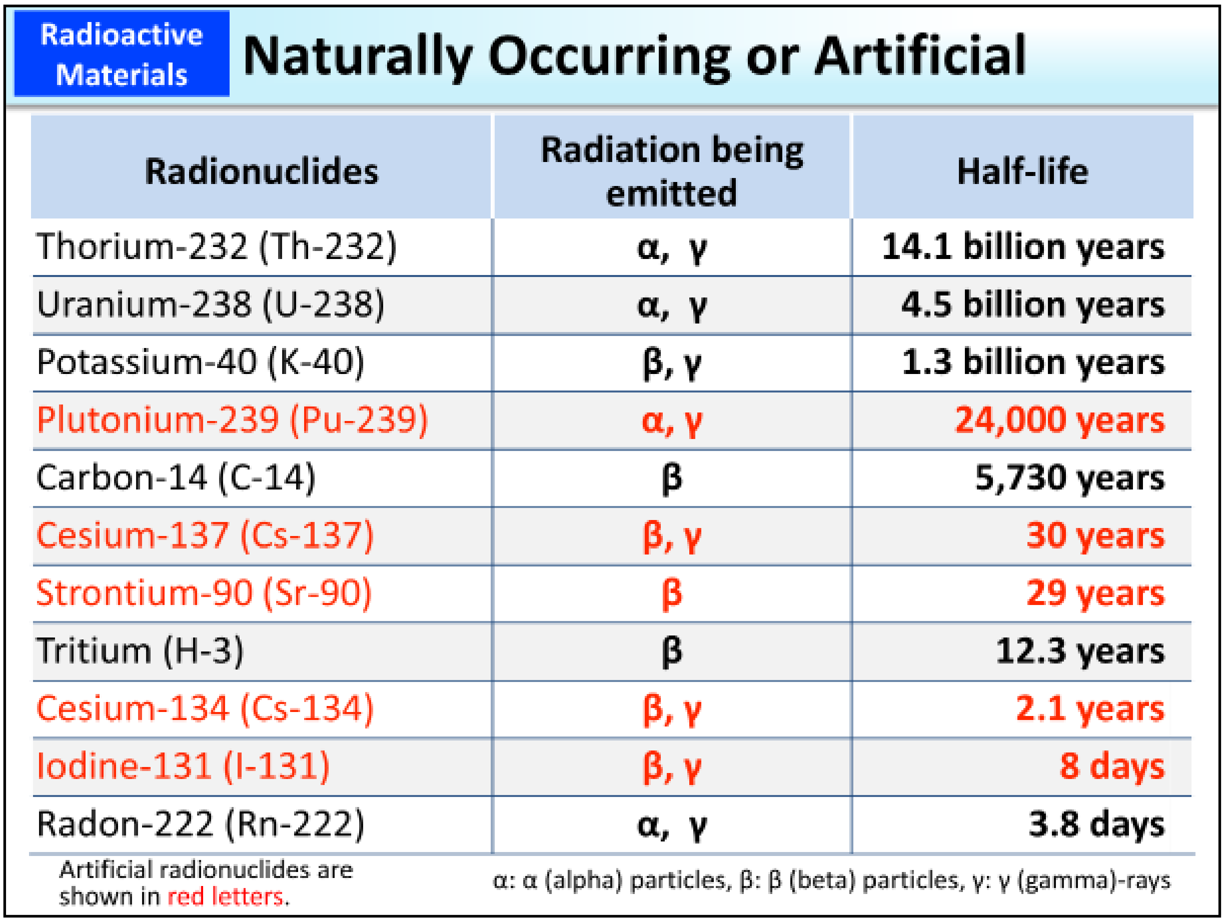

Radioactive Materials

Naturally Occurring or Artificial

Radionuclides	Radiation being emitted	Half-life
Thorium-232 (Th-232)	α, γ	14.1 billion years
Uranium-238 (U-238)	α, γ	4.5 billion years
Potassium-40 (K-40)	β, γ	1.3 billion years
Plutonium-239 (Pu-239)	α, γ	24,000 years
Carbon-14 (C-14)	β	5,730 years
Cesium-137 (Cs-137)	β, γ	30 years
Strontium-90 (Sr-90)	β	29 years
Tritium (H-3)	β	12.3 years
Cesium-134 (Cs-134)	β, γ	2.1 years
Iodine-131 (I-131)	β, γ	8 days
Radon-222 (Rn-222)	α, γ	3.8 days

Artificial radionuclides are shown in red letters.

α: α (alpha) particles, β: β (beta) particles, γ: γ (gamma)-rays

Radionuclides with long half-lives, such as Thorium-232 in the thorium series, Uranium-238 in the uranium series, and Potassium-40, were created in the universe in the distant past and taken into the earth when the earth was born.

Thorium-232 and Uranium-238 transform into various radionuclides by emitting α (alpha)-particles, β (beta)-particles, and γ (gamma)-rays before transforming into Lead-208 and Lead-206, respectively.

Carbon-14, which is also a naturally occurring radionuclide, is created when nitrogen that accounts for 78% of the atmosphere is hit by a neutron created as a result of collisions of cosmic rays and the atmosphere. Carbon-14 returns to nitrogen by emitting β-particles.

Cesium-134, Cesium-137, Strontium-90, Iodine-131, and Plutonium-239 can be released into the environment in the event of a nuclear plant accident. Some artificial radionuclides, such as Plutonium-239, have very long half-lives.

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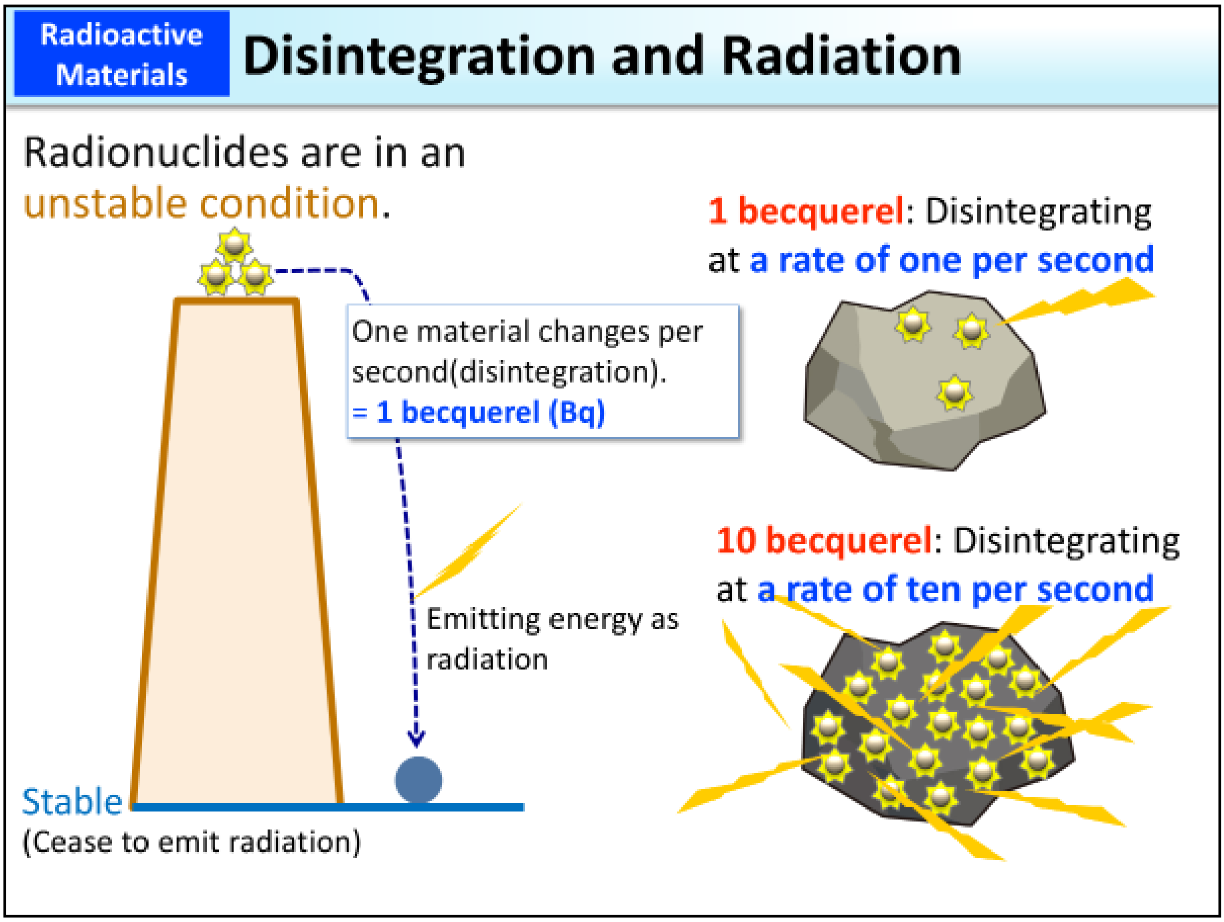
Updated on March 31, 2019



Radioactive Materials

Disintegration and Radiation

Radionuclides are in an unstable condition.

One material changes per second(disintegration).
= 1 becquerel (Bq)

Emitting energy as radiation

Stable
(Cease to emit radiation)

1 becquerel: Disintegrating at a rate of one per second

10 becquerel: Disintegrating at a rate of ten per second

A nucleus of a radionuclide is energetically unstable. In order to become stable, it releases extra energy in the form of radiation.

Becquerel is a unit used to quantify radiation intensity. One becquerel is defined as an amount that "one nucleus changes (disintegrates) per second." Since nuclei often emit radiation during disintegration, the becquerel is used as a unit to express the ability to emit radiation. In a rock with 1 Bq of radioactivity, for example, each nucleus of the radionuclide contained in the rock will disintegrate per second. 10 Bq means that 10 nuclei will disintegrate per second.

Once nuclei of a radionuclide disintegrate and the radionuclide becomes stable by emitting radiation, it will no longer emit radiation. Some types of radionuclides repeat disintegration multiple times until becoming stable.
(Related to p.10 of Vol. 1, "Parent and Daughter Nuclides")

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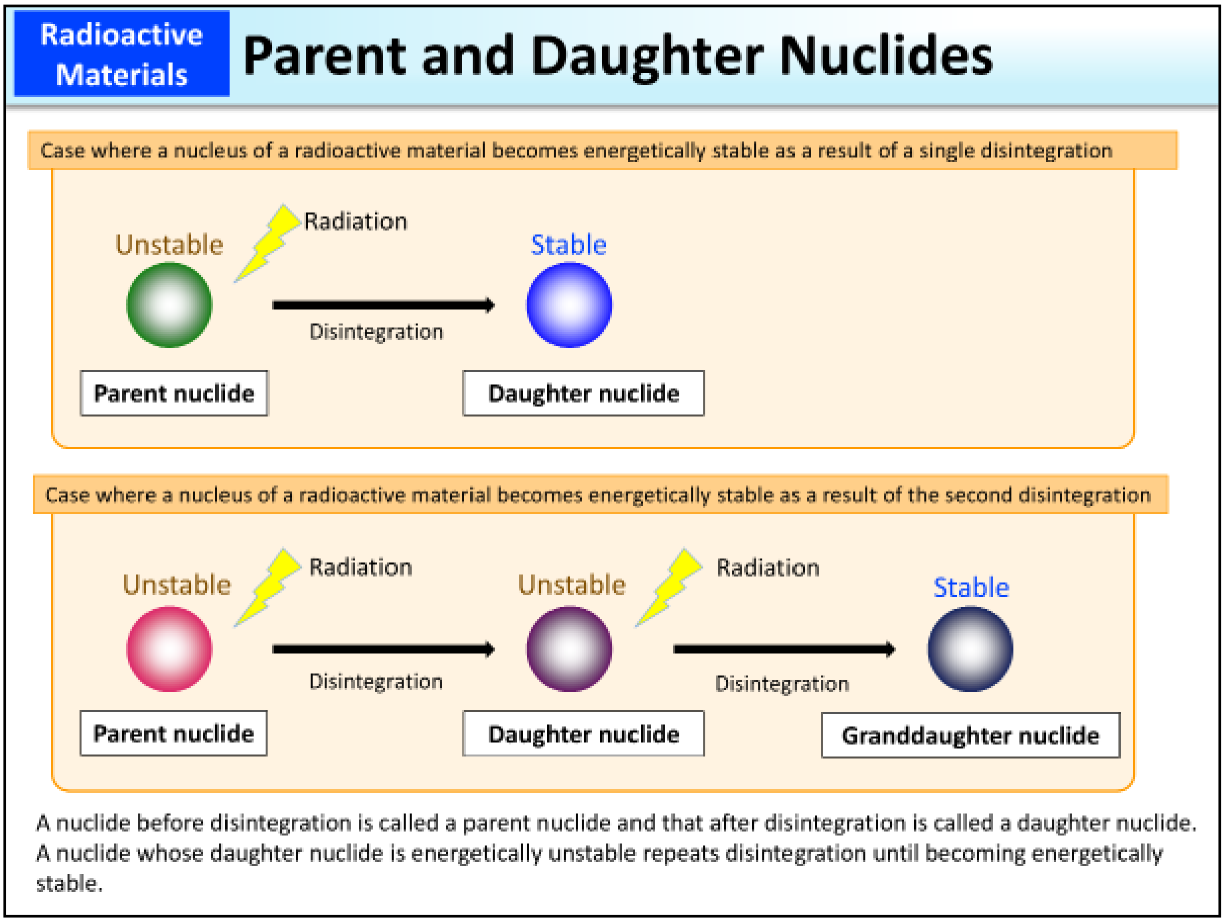


Radioactive Materials

Parent and Daughter Nuclides

Case where a nucleus of a radioactive material becomes energetically stable as a result of a single disintegration

Unstable
Radiation
Disintegration
Stable
Parent nuclide
Daughter nuclide

Case where a nucleus of a radioactive material becomes energetically stable as a result of the second disintegration

Unstable
Radiation
Disintegration
Unstable
Radiation
Disintegration
Stable
Parent nuclide
Daughter nuclide
Granddaughter nuclide

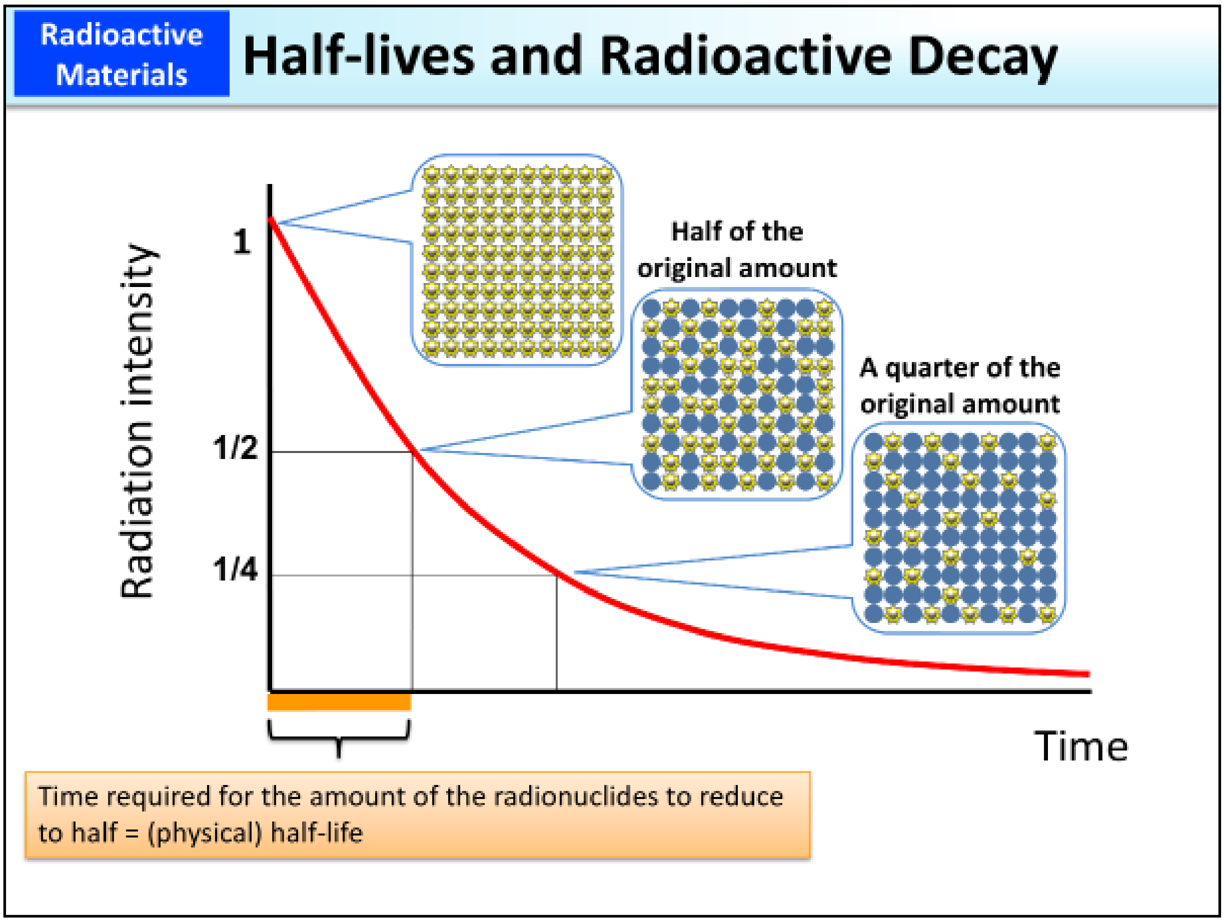
A nuclide before disintegration is called a parent nuclide and that after disintegration is called a daughter nuclide. A nuclide whose daughter nuclide is energetically unstable repeats disintegration until becoming energetically stable.

Types of atoms and nuclei classified depending on the number of protons and neutrons are called nuclides. For example, Carbon-12 and Carbon-14 are both carbons but are different nuclides. Carbon-14 is a radionuclide as it is energetically unstable.

The phenomenon wherein a radionuclide emits radiation and transforms into a different nuclide is called disintegration. A nuclide before disintegration is called a parent nuclide and that after disintegration is called a daughter nuclide.

Some radionuclides remain energetically unstable even after disintegration, which means that the original radionuclides have transformed into other types of radionuclides. These types of radionuclides repeat disintegration until becoming energetically stable. A nuclide resulting from the disintegration of a daughter nuclide (seen from a parent nuclide) is sometimes called a granddaughter nuclide, and such daughter nuclide and granddaughter nuclide are collectively called progeny nuclides.

Included in this reference material on February 28, 2018



Radioactive Materials

Half-lives and Radioactive Decay

Time required for the amount of the radionuclides to reduce to half = (physical) half-life

An atom that has become stable in terms of energy by emitting radiation will no longer emit radiation. The amount of a radionuclide decreases over time and radioactivity weakens. The time required for radioactivity to weaken and reduce to half is called a (physical) half-life.

Upon the elapse of a period of time equal to the half-life, the radioactivity will be halved, and when a period of time twice as long as the half-life lapses, the radiation will reduce to a quarter of the original state. A graph with the horizontal axis representing the elapsed time and the vertical axis representing the radiation intensity demonstrates exponential radioactivity decreases in a curve as shown in the slide.

(Physical) half-lives vary depending on the types of radionuclides. For instance, the half-life is approximately 8 days for Iodine-131, approximately 2 years for Cesium-134, and approximately 30 years for Cesium-137.

Radioactive materials taken into the body will be excreted after being taken into various organs and tissues. The time required for the amount of radioactive materials in the body to reduce to half through excretion is called biological half-life and varies depending on their chemical forms and/or particle sizes (p.27 of Vol. 1, “Internal Exposure and Radioactive Materials”).

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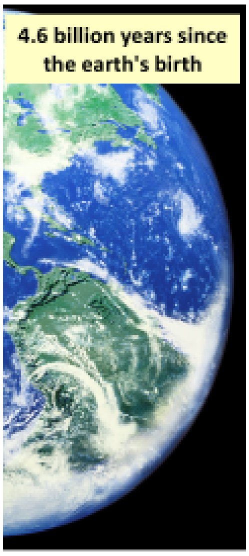
Updated on March 31, 2019

Radioactive Materials

Nuclei with Long Half-lives

Example Radioactive materials that had existed in the universe since before the birth of the earth and were taken into the earth upon its birth



4.6 billion years since the earth's birth

Series A radioactive nucleus repeats disintegration until becoming stable, accompanying changes in nuclides each time.

- Uranium-238 — Half-life: 4.5 billion years
- Thorium-232
- Uranium-235

Non-series A radioactive nucleus directly disintegrates into a stable nucleus.

- Potassium-40 — Half-life: 1.3 billion years
- Rubidium-87, etc.

Some nuclei that emit radiation have very long half-lives. Uranium-238 has a half-life of 4.5 billion years. Since the earth is about 4.6 billion years old, the amount of Uranium-238 that had existed at the time of the earth's birth has now reduced to half.

Some radionuclides become stable after a single emission of radiation, while some transform into various radionuclides as they disintegrate many times, until becoming stable.

For example, Uranium-238 emits α (alpha)-particles and transforms into Thorium-234, which is also a radionuclide. Thorium-234 further emits β (beta)-particles and transforms into Protactinium-234, which is also a radionuclide. They constitute a series in which the original element transforms into different atoms more than 10 times before becoming stable Lead-206.

Potassium-40 also has a long half-life of 1.3 billion years. This is another naturally occurring radionuclide that was taken into the earth upon its birth. Potassium-40 transforms into stable Calcium-40 or Argon-40 through a single disintegration without constituting a series.

(Related to p.10 of Vol. 1, "Parent and Daughter Nuclides," and p.11 of Vol. 1, "Half-lives and Radioactive Decay")

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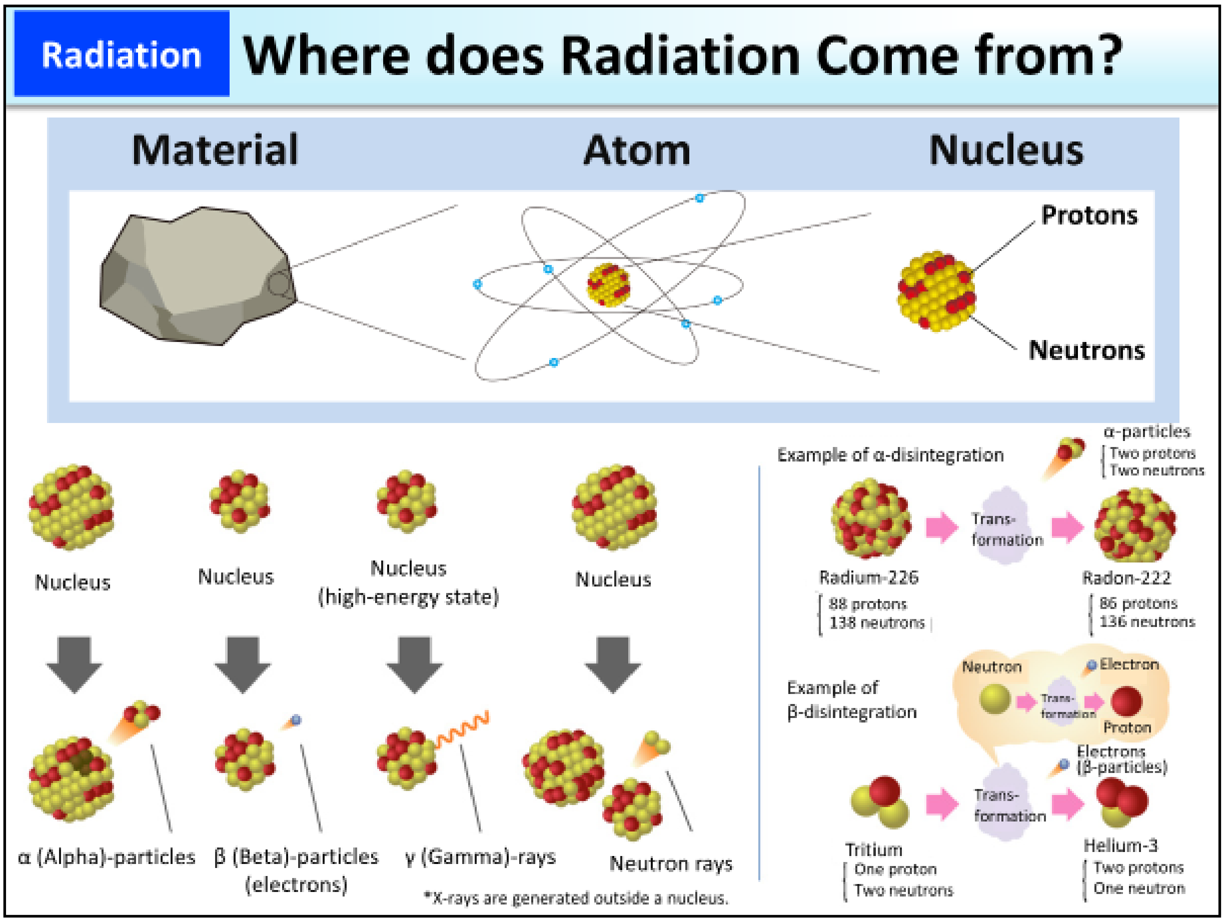

Radiation Where does Radiation Come from?

α (alpha)-particles, β (beta)-particles, γ (gamma)-rays, and X-rays were the names given to them because they were not elucidated at the time of their discoveries. Today, α-particles are found to be helium nuclei with two protons and two neutrons, flying out at high speed; β-particles are electrons that are ejected from a nucleus. A helium nucleus weighs about 7,300 times more than an electron. Normally, nuclei have high energy and are therefore still unstable immediately after emission of α-particles or β-particles, so they will further emit γ-rays in order to become stable. However, some do not emit γ-rays.

While α-particles, β-particles, and γ-rays are emitted from a nucleus, X-rays are electromagnetic waves that are generated outside a nucleus. Unlike X-rays, γ-rays are generated from a nucleus, but both are electromagnetic waves. A neutron is a particle that constitutes a nucleus. Neutrons that are ejected from a nucleus with kinetic energy, e.g. during the fission of the nucleus, are called neutron beams.

(Related to p.14 of Vol. 1, “Types of Radiation,” and p.15 of Vol. 1, “Types of Ionizing Radiation”)

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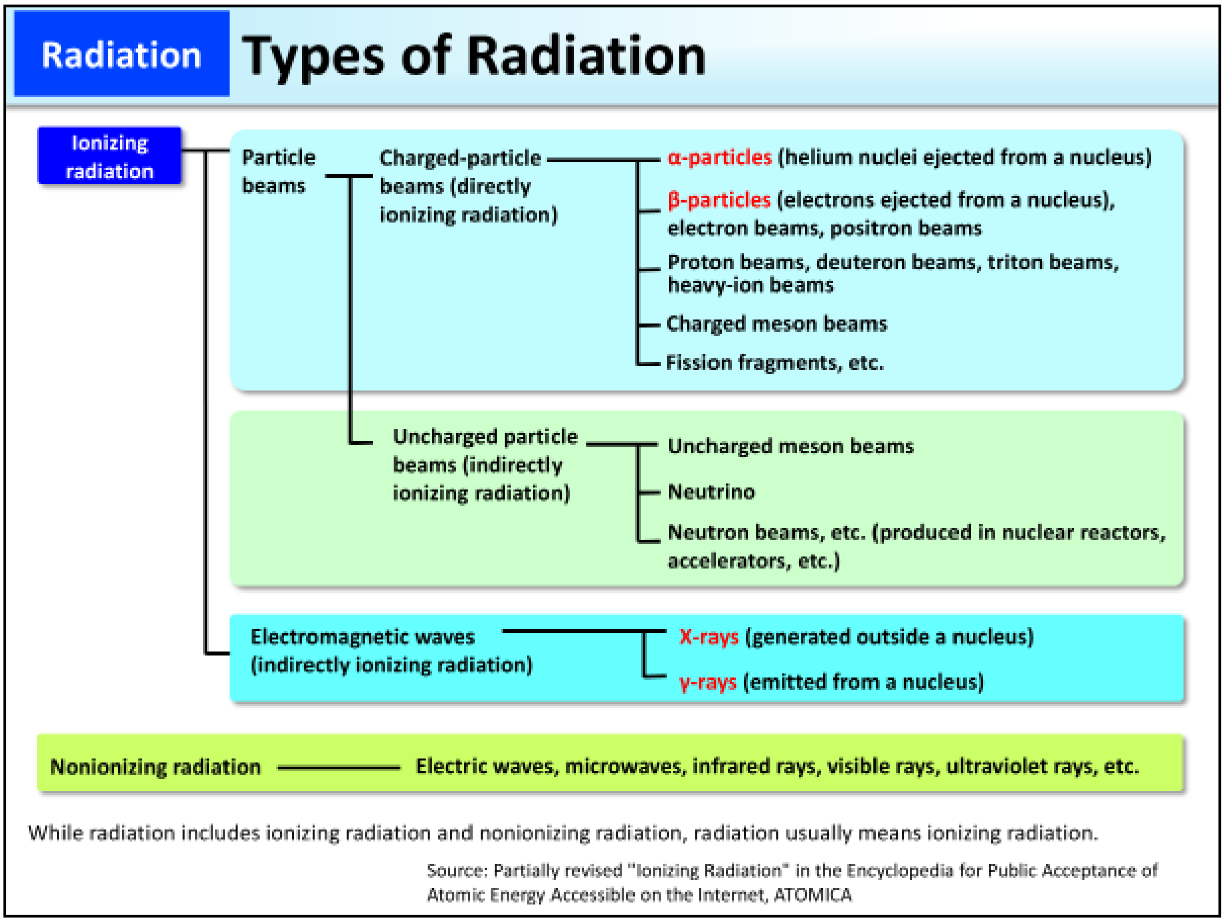

Radiation Types of Radiation

Ionizing radiation

- Particle beams
  - Charged-particle beams (directly ionizing radiation)
    - α-particles (helium nuclei ejected from a nucleus)
    - β-particles (electrons ejected from a nucleus), electron beams, positron beams
    - Proton beams, deuteron beams, triton beams, heavy-ion beams
    - Charged meson beams
    - Fission fragments, etc.
  - Uncharged particle beams (indirectly ionizing radiation)
    - Uncharged meson beams
    - Neutrino
    - Neutron beams, etc. (produced in nuclear reactors, accelerators, etc.)
- Electromagnetic waves (indirectly ionizing radiation)
  - X-rays (generated outside a nucleus)
  - γ-rays (emitted from a nucleus)

Nonionizing radiation — Electric waves, microwaves, infrared rays, visible rays, ultraviolet rays, etc.

While radiation includes ionizing radiation and nonionizing radiation, radiation usually means ionizing radiation.

Source: Partially revised "Ionizing Radiation" in the Encyclopedia for Public Acceptance of Atomic Energy Accessible on the Internet, ATOMICA

Radiation generally means ionizing radiation. Ionizing radiation, which has the ability to ionize atoms that make up a substance (separate the atoms into positively charged ions and negatively charged electrons), is categorized into particle beams and electromagnetic waves.

Particle beams include α (alpha)-particles, β (beta)-particles, neutron beams, etc. (p.13 of Vol. 1, “Where does Radiation Come from?”). Particle beams include charged (ionized) particle beams and uncharged particle beams. γ (gamma)-rays and X-rays are types of electromagnetic waves.

Some forms of electromagnetic waves, such as electric waves, infrared rays, and visible rays, do not cause ionization, and they are called nonionizing radiation. Ultraviolet rays are generally categorized as nonionizing radiation although some ultraviolet rays do cause ionization (p.15 of Vol. 1, “Types of Ionizing Radiation”).
(Related to p.19 of Vol. 1, “Types of Radiation and Biological Effects,” and p.20 of Vol. 1, “Penetrating Power of Radiation”)

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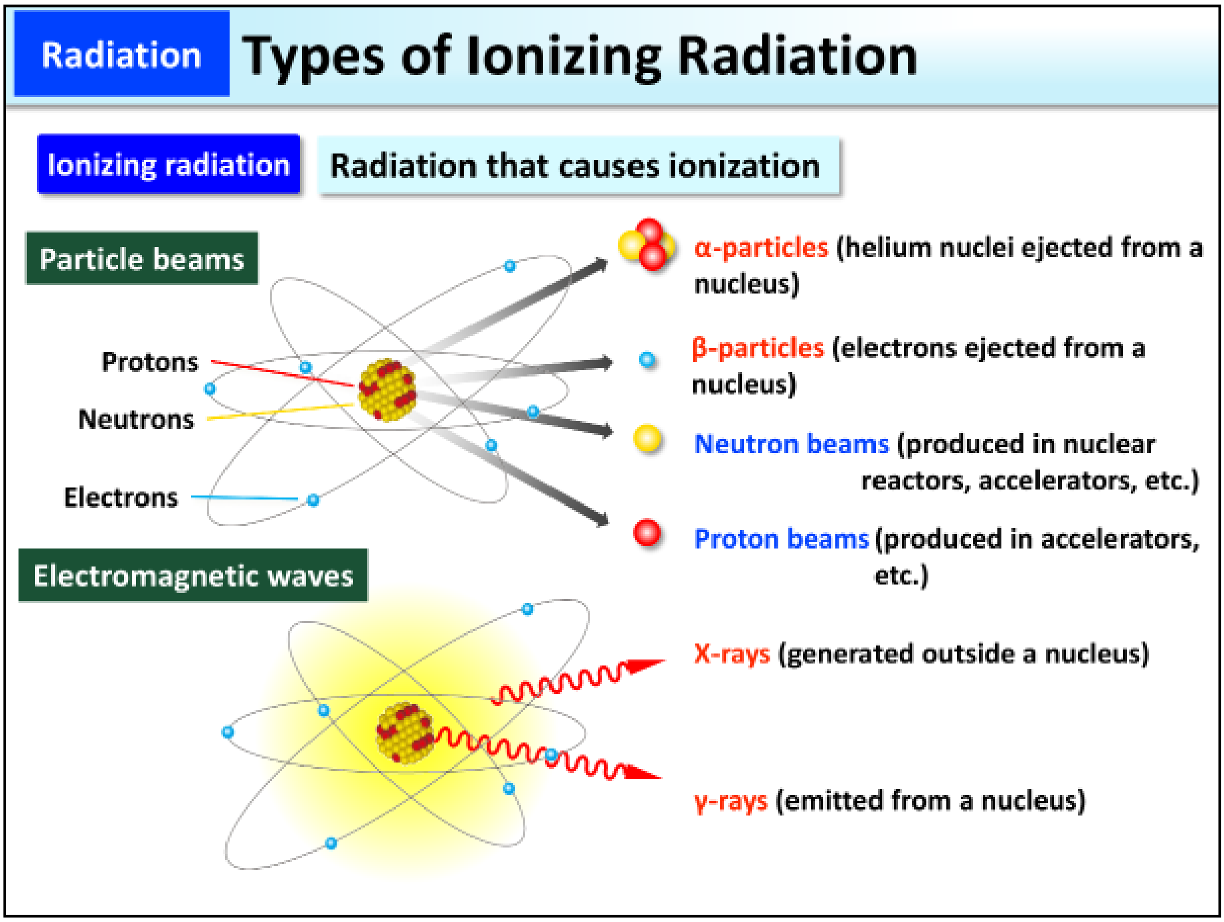

Radiation Types of Ionizing Radiation

Ionizing radiation Radiation that causes ionization

Particle beams

Protons

Neutrons

Electrons

α-particles (helium nuclei ejected from a nucleus)

β-particles (electrons ejected from a nucleus)

Neutron beams (produced in nuclear reactors, accelerators, etc.)

Proton beams (produced in accelerators, etc.)

Electromagnetic waves

X-rays (generated outside a nucleus)

γ-rays (emitted from a nucleus)

Particle beams include α (alpha)-particles, β (beta)-particles, neutron beams, etc.

α-particles are helium nuclei consisting of two protons and two neutrons that have been ejected at high speed, while β-particles are electrons ejected from a nucleus. Particle beams also include neutron beams and proton beams.

γ-rays and X-rays are types of electromagnetic waves. While α-particles, β-particles, and γ-rays are emitted from a nucleus, X-rays used in X-ray examination for medical checkups and the like are electromagnetic waves generated outside a nucleus. X-rays generated in X-ray tubes are used in X-ray examination. X-rays include braking X-rays and characteristic X-rays (p.16 of Vol. 1, “X-rays for Medical Use and Generators”).
(Related to p.13 of Vol. 1, “Where does Radiation Come from?,” and p.14 of Vol. 1, “Types of Radiation”)

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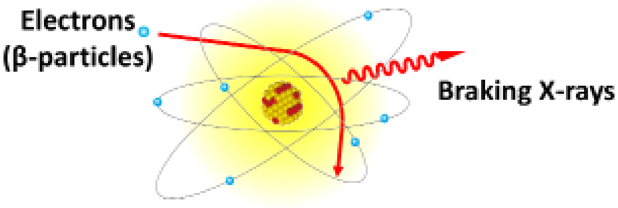
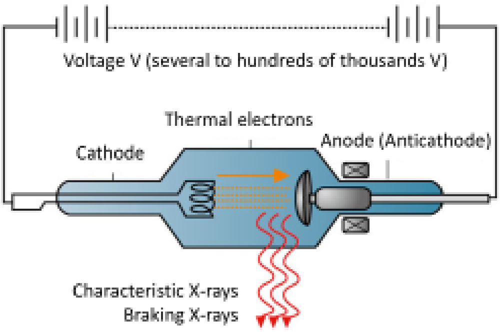
Updated on March 31, 2019

Radiation X-rays for Medical Use and Generators

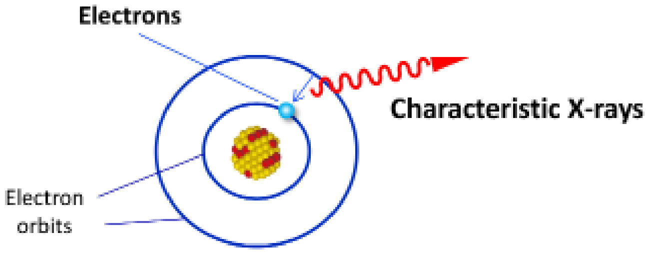
Braking X-rays



Structural drawing of an X-ray generator



Characteristic X-rays



X-ray examination uses X-rays generated in X-ray tubes. A high voltage is applied between a cathode and an anode (tungsten, molybdenum, copper, etc.) inside an X-ray tube so that thermal electrons migrate from the cathode to the anode in a vacuum at high speed. X-rays generated when the direction of propagation of the thermal electrons changes as they are attracted to the nucleus of the anode are called braking X-rays. When an electron is ejected from the inner electron orbit of the anode nucleus, another electron migrates (transitions) to this vacancy from the outer electron orbit. X-rays generated thereby are called characteristic X-rays. Most of the X-rays generated in X-ray tubes are braking X-rays.

Generation of X-rays stops when the X-ray tube is switched off.

X-ray generators used in the field of medicine are either for diagnosis or for treatment. The energy and amount of X-rays are adjusted to match the purpose of imaging and the part to be imaged. In chest roentgenography (diagnosis), the amount of radiation a patient receives in one imaging session is approx. 0.06 mSv.

(Related to p.63 of Vol. 1, “Exposure Dose from Natural and Artificial Radiation,” and p.76 of Vol. 1, “Radiation Doses from Medical Diagnosis”)

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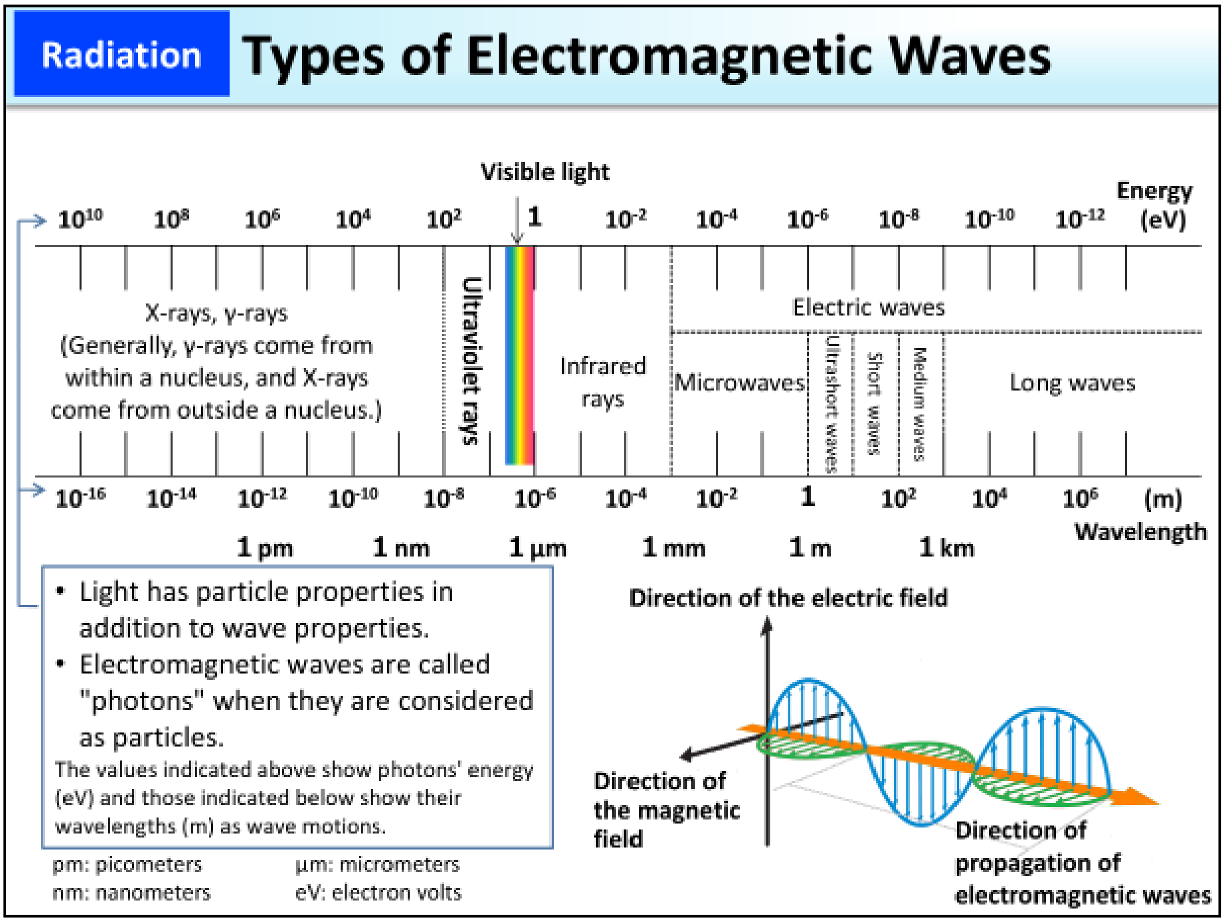

Radiation Types of Electromagnetic Waves

- Light has particle properties in addition to wave properties.
- Electromagnetic waves are called "photons" when they are considered as particles.

The values indicated above show photons' energy (eV) and those indicated below show their wavelengths (m) as wave motions.

pm: picometers
nm: nanometers
μm: micrometers
eV: electron volts

Electromagnetic waves are waves that propagate through space while an electric field and a magnetic field interact with each other. The shorter the wavelength is (the higher the frequency is), the higher the energy of an electromagnetic wave. The energy of radiation is expressed in electron volts (eV). 1 eV equals 1.6 x 10^{-19} Joule (J).

While X-rays and γ-rays differ in the mechanisms of how they are generated, they are both electromagnetic waves with high energy.

Thus, an electromagnetic wave sometimes behaves like a wave and may be expressed as a waveform perpendicular to its direction of propagation, as shown in the figure above.

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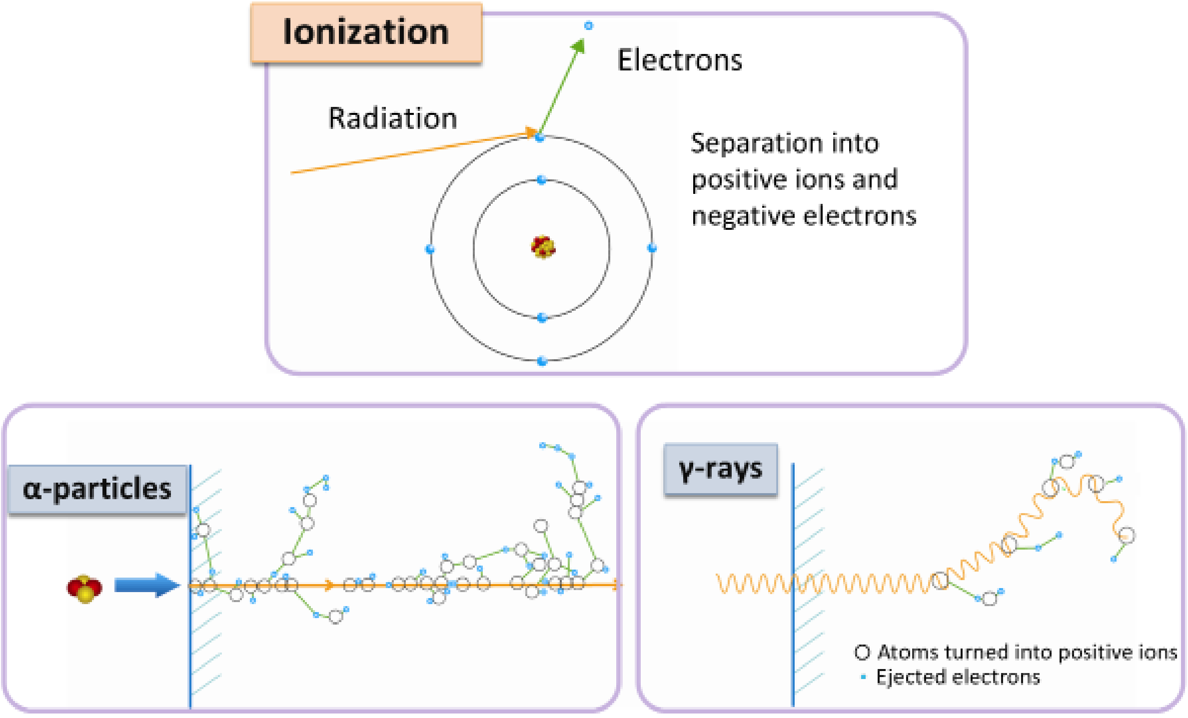
Radiation

Ionization of Radiation - Property of Ionizing Radiation



When radiation passes through a substance, its energy causes ejection of orbital electrons of the atoms that make up the substance, separating the atoms into positively charged atoms (or positive ion molecules) and free electrons. This is called ionization.

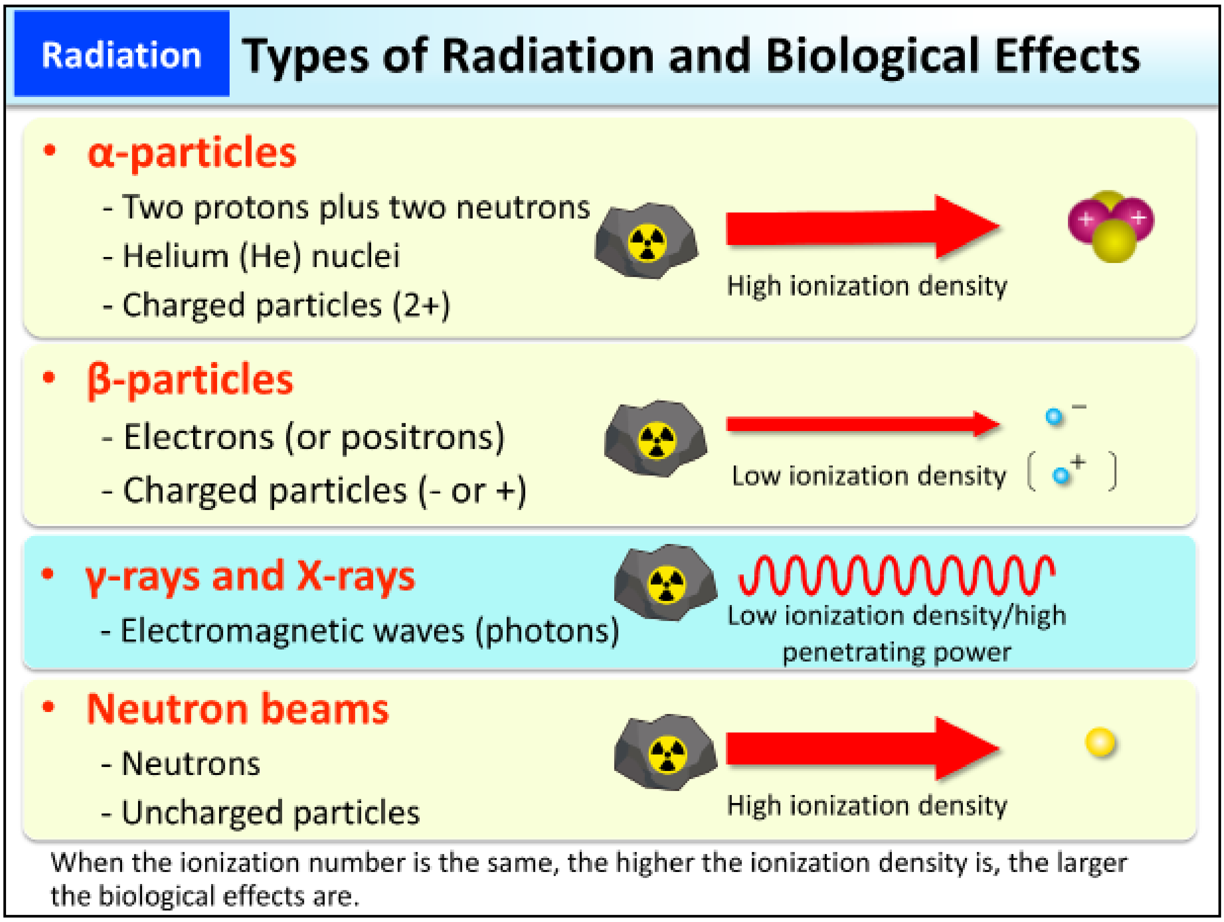
Ionizing radiation that causes ionization ionizes substances either directly or indirectly.

Charged particle beams, such as α (alpha)-particles and β (beta)-particles, ionize substances directly. In particular, α-particles have high ionization density, causing ionization at a density hundreds of times as high as that of β-particles, etc.

γ-rays and X-rays ionize substances indirectly using secondary electrons generated through their interaction with the substances.

(Related to p.14 of Vol. 1, “Types of Radiation”)

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



Radiation Types of Radiation and Biological Effects

- **α-particles**
  - Two protons plus two neutrons
  - Helium (He) nuclei
  - Charged particles (2+)

High ionization density

- **β-particles**
  - Electrons (or positrons)
  - Charged particles (- or +)

Low ionization density

- **γ-rays and X-rays**
  - Electromagnetic waves (photons)

Low ionization density/high penetrating power

- **Neutron beams**
  - Neutrons
  - Uncharged particles

High ionization density

When the ionization number is the same, the higher the ionization density is, the larger the biological effects are.

External exposure to α (alpha)-particles does not cause problems because α-particles have weak penetrating power against biological tissues and cannot penetrate the horny layer of the skin (layer of dead cells on the skin surface). However, internal exposure to any radioactive material that emits α-particles causes large amounts of local ionization, i.e., high-density ionization, within tissues, providing concentrated energy. This significantly damages DNA and has strong biological effects.

β (beta)-particles cause direct ionization of the substance it passes through, as do α-particles, but because of their low ionization density, their biological effects are not as strong as those of α-particles. Penetrating power of β-particles is also weak but stronger than that of α-particles, and external exposure to β-particles could affect the skin and subcutaneous tissues.

γ-rays and X-rays reach deep organs and tissues because of their strong penetrating power but do not have high ionization density. Their biological effects are similar to those of β-particles.

Since a neutron has a mass almost equal to that of a proton, a neutron beam stops efficiently when colliding with a proton. Since the human body contains a large amount of water, neutrons lose their energy as they collide with hydrogen nuclei (protons) that make up water molecules.

(Related to p.15 of Vol. 1, “Types of Ionizing Radiation,” and p.18 of Vol. 1, “Ionization of Radiation - Property of Ionizing Radiation”)

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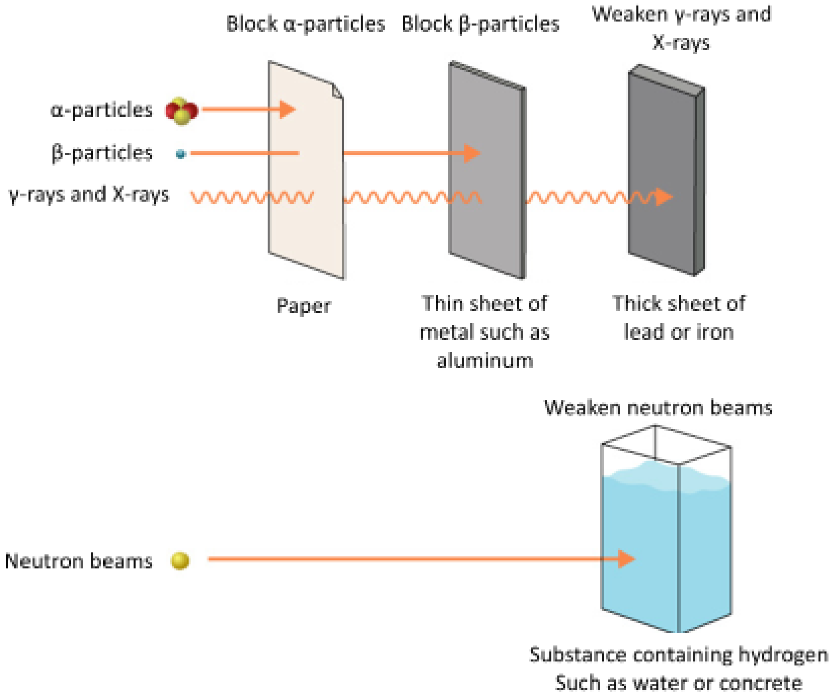
Radiation

Penetrating Power of Radiation

Radiation can be blocked by various substances.



Charged particles or electromagnetic waves interact with a substance, lose their energy (speed), and eventually stop.

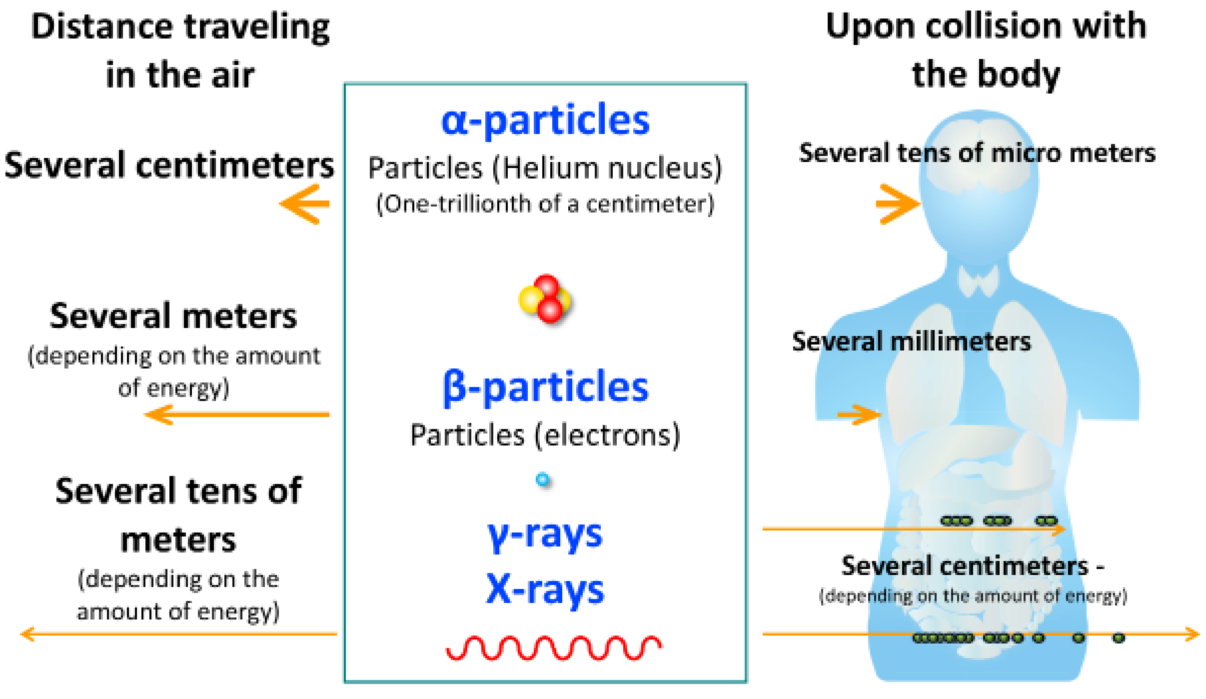
Since α (alpha)-particles cause a large amount of ionization, a sheet of paper is enough to stop them. β (beta)-particles travel several meters in the air, and a 1 cm thick plastic sheet or a 2-4 mm thick aluminum plate is enough to stop them, depending on how much energy they have. γ-rays and X-rays have higher penetrating power than α-particles or β-particles, travel several tens to hundreds of meters in the air (depending on their energy) and gradually lose their energy as they collide with atoms in the air. As γ-rays and X-rays can be shielded using thick plates of high-density lead or iron, those from radiation generators can be blocked using iron and the like.

Uncharged neutrons lose their energy through collision and are absorbed through interaction with substances. That is, neutrons lose their energy (speed) by directly colliding with nuclei that make up substances. They lose their energy most effectively by colliding with protons (hydrogen nuclei) that are almost equal in mass to them.

(Related to p.21 of Vol. 1, “Penetrating Power of Radiation within the Body”)

Included in this reference material on March 31, 2013
Updated on March 31, 2016

Radiation Penetrating Power of Radiation within the Body



Distance traveling in the air

Several centimeters

Several meters
(depending on the amount of energy)

Several tens of meters
(depending on the amount of energy)

α-particles
Particles (Helium nucleus)
(One-trillionth of a centimeter)

β-particles
Particles (electrons)

γ-rays
X-rays

Upon collision with the body

Several tens of micro meters

Several millimeters

Several centimeters -
(depending on the amount of energy)

The easiness to penetrate through the air or the human body varies depending on the types of radiation. Therefore, the types of radiation (α (alpha)-particles, β (beta)-particles, or γ-rays) and radioactive materials (nuclides) that cause problems differ for external exposure and internal exposure.

α-particles can travel only several centimeters in the air and a sheet of paper is enough to stop them. In the case of external exposure, α-particles do not reach deeper than the layer of dead cells (horny layer) on the skin surface and do not cause effects. However, if an alpha-emitting radionuclide enters the body, it will provide energy intensively to nearby cells where it is deposited.

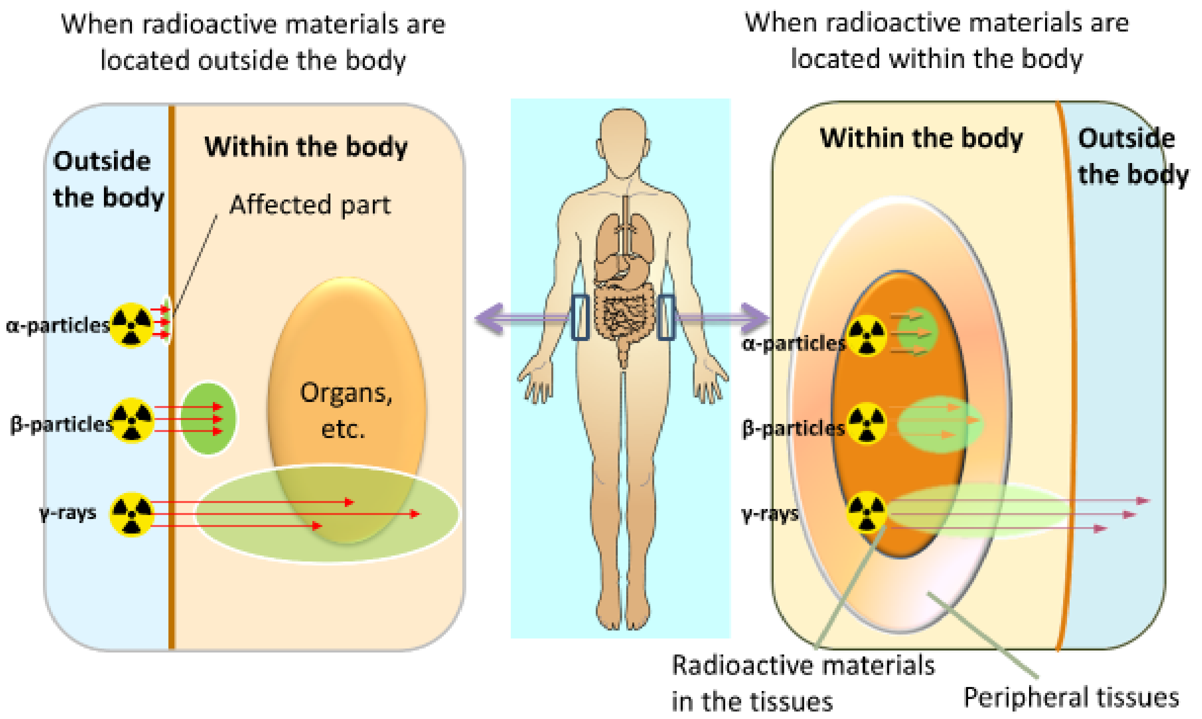
Since β-particles travel only several meters in the air, they hardly contribute to exposure when a radiation source is located away from the body. When the surface of the body is exposed to β-particles, their energy is imparted to the skin and subcutaneous tissues; when β-particles enter the body, their energy is imparted to a radius of several millimeters around the relevant spot.

γ-rays and X-rays have high penetrating power and travel several tens to hundreds of meters in the air. When they collide with the human body, they can reach deep into the body or sometimes pass through it. Their energy is imparted to the part they pass through. In X-ray examination, the parts of the body X-rays can easily pass through (lungs, etc.) appear in black while the parts they cannot easily pass through (bones, etc.) appear in white.
(Related to p.22 of Vol. 1, “Penetrating Power and Range of Effects on the Human Body”)

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

Radiation

Penetrating Power and Range of Effects on the Human Body



In the case of external exposure, α (alpha)-particles do not have any effect as they stop at the horny layer on the surface of the body (the penetrating distance of α-particles is about several tens of micrometers). β (beta)-particles pass through the skin (their penetrating distance is about several millimeters) and can cause burn-like symptoms when doses are very high, but do not reach deep into the body. γ-rays reach important organs deep inside the body. Thus, the major concern in the case of external exposure is with γ-rays.

On the other hand, in the case of internal exposure, all radioactive materials that emit α-particles, β-particles, or γ-rays could affect cells within the body. Given the distance α-particles travel, their effects are confined to tissues where radioactive materials exist, but due to their significant biological effects, particular caution is required in relation to internal exposure. γ-rays can affect the entire body because they travel long distances.

Some radioactive materials such as uranium, once entering the human body, may also cause metallic toxicity, etc., in addition to causing internal exposure.
(Related to p.21 of Vol. 1, “Penetrating Power of Radiation within the Body”)

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Chapter 2

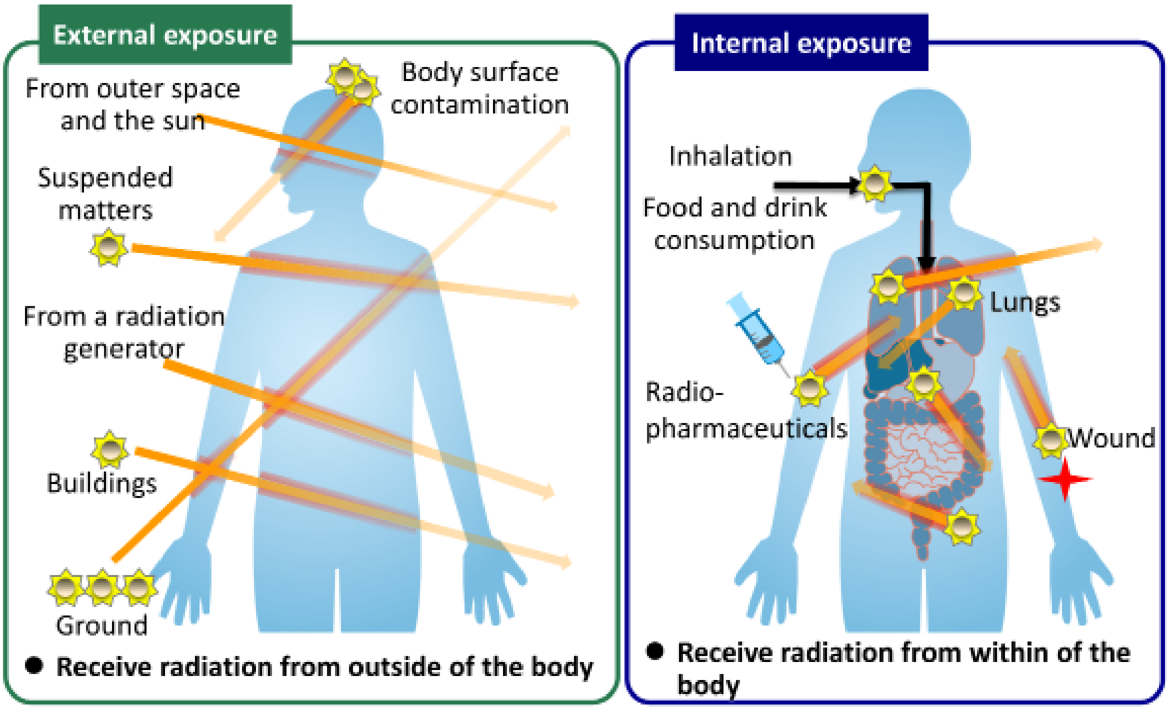
Radiation Exposure

Chapter 2 explains the mechanism of radiation exposure and measurement and calculation methods for exposure doses, and also provides explanations about radiation around us and representative radionuclides discharged upon a nuclear accident.

You can learn about radiation exposure, and on what occasion and to what extent you may be exposed to radiation. This chapter helps you understand what measuring devices and what calculation methods are used for obtaining radiation doses and exposure doses.

Exposure Routes

Internal and External Exposure



- Receive radiation from outside of the body
- Receive radiation from within of the body

The body is equally exposed to radiation in both cases.

✹ Radioactive materials

“Radiation exposure” refers to the situation where the body is exposed to radiation. There are two types of radiation exposure, “internal exposure” and “external exposure.”

External exposure means to receive radiation that comes from radioactive materials existing on the ground or in the air, or attached to clothes or the surface of the body (p.25 of Vol. 1, “External Exposure and Skin”).

Conversely, internal exposure is caused (i) when a person has a meal and takes in radioactive materials in the food or drink (ingestion); (ii) when a person breathes in radioactive materials in the air (inhalation); (iii) when radioactive materials are absorbed through the skin (percutaneous absorption); (iv) when radioactive materials enter the body from a wound (wound contamination); and (v) when radiopharmaceuticals containing radioactive materials are administered for the purpose of medical treatment. Once radioactive materials enter the body, the body will continue to be exposed to radiation until the radioactive materials are excreted in the urine or feces or as the radioactivity weakens over time (p.26 of Vol. 1, “Internal Exposure”).

The difference between internal exposure and external exposure lies in whether the source that emits radiation is inside or outside the body. The body is equally exposed to radiation in both cases (p.24 of Vol. 1, “Various Forms of Exposure”).

The terms “internal exposure” and “external exposure” are used irrespective of types of radiation, i.e., naturally occurring radiation, accident-derived radiation or medical radiation (p.63 of Vol. 1, “Exposure Dose from Natural and Artificial Radiation”).

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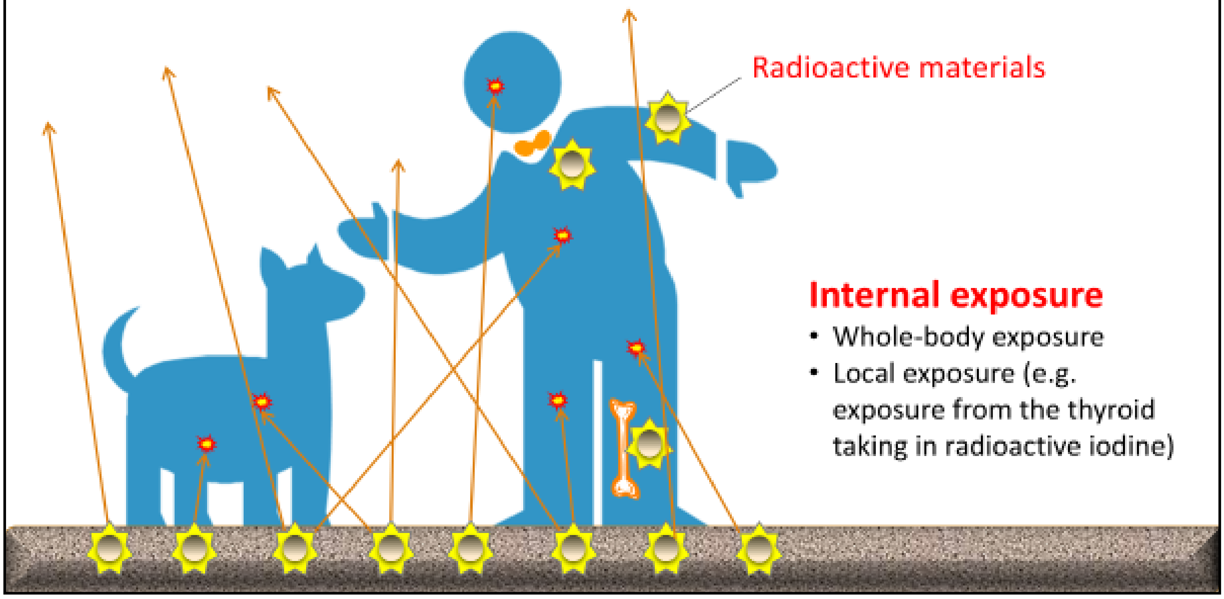
Exposure Routes

Various Forms of Exposure

External exposure

- Whole-body exposure
- Local exposure (e.g. exposure by X-ray examination or local body surface contamination)



Internal exposure

- Whole-body exposure
- Local exposure (e.g. exposure from the thyroid taking in radioactive iodine)

To what extent the body will be affected by radiation exposure depends on the location and the extent of the exposure.

Whole-body exposure refers to exposure of the entire body to radiation, while local exposure refers to exposure of a part of the body to radiation.

In whole-body exposure, all the organs and tissues may be affected by the radiation, while in local exposure, the effects are, in principle, confined to the exposed organs and tissues. If any organ of the immune system or endocrine system is included in the part exposed, distant organs or tissues could be indirectly affected, but the main concern is basically with the effects on the exposed organs and tissues.

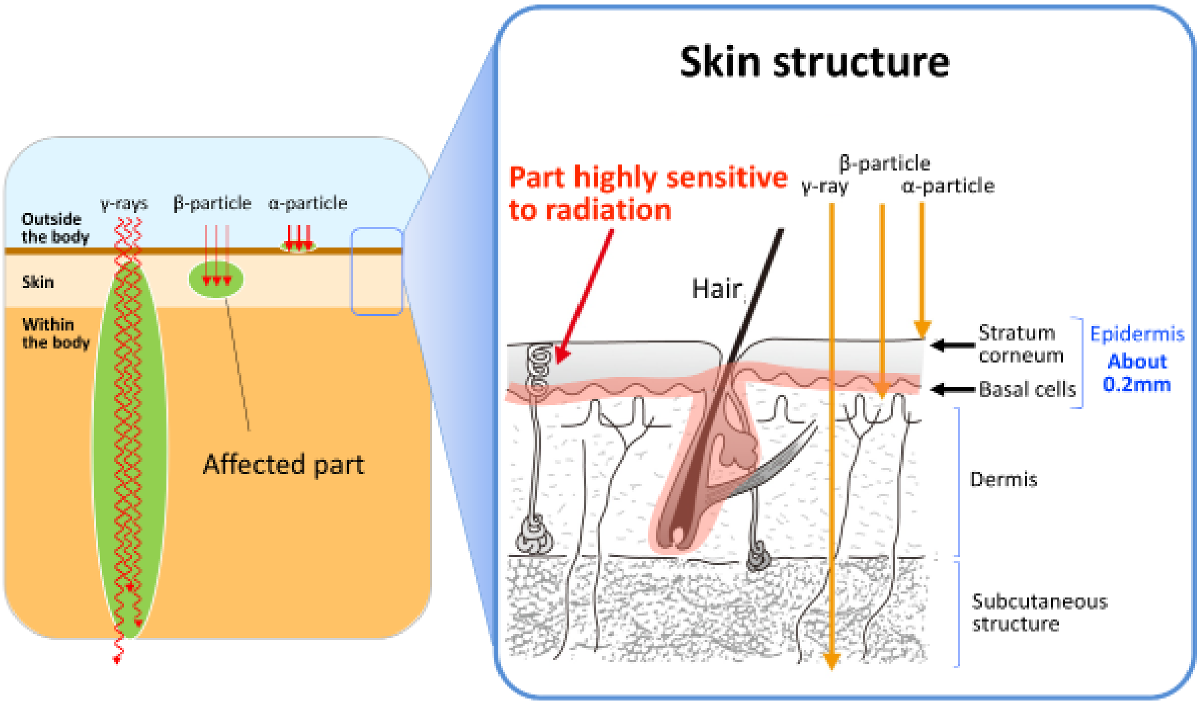
Organs differ in sensitivity to radiation. In local exposure, therefore, the extent of the effects varies greatly depending on whether the exposed part includes organs that are highly sensitive to radiation.

In internal exposure, organs and tissues where radioactive materials are likely to accumulate will receive high doses of radiation. If such organs and tissues that are prone to accumulation have high sensitivities to radiation, they are more likely to be affected by the radiation. In Belarus and Ukraine, after the Chornobyl NPS Accident, there was an increase in the number of thyroid cancer cases among children. It was due both to the tendency of radioactive iodine to accumulate in the thyroid and children's thyroids having a higher sensitivity to radiation than adults'.
(Related to p.4 of Vol. 1, "Types of Exposure")

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Exposure Routes

External Exposure and Skin



In external exposure, α (alpha)-particles having weak penetrating power stop at the epidermis and therefore do not produce any effects, but if a large amount of radioactive materials that emit β (beta)-particles adheres to the surface of the body for an extended period of time, they will affect the skin's basal cells and hair-root cells that have high sensitivity to radiation, possibly causing skin erythema that is characterized by reddening of the skin, hair loss, etc. However, such exposure is extremely rare, and the major problems with external exposure are associated with radioactive materials emitting γ-rays that affect the inside of the body.
(Related to p.21 of Vol. 1, "Penetrating Power of Radiation within the Body," and p.22 of Vol. 1, "Penetrating Power and Range of Effects on the Human Body")

Included in this reference material on March 31, 2013
Updated on March 31, 2021

Exposure Routes

Internal Exposure

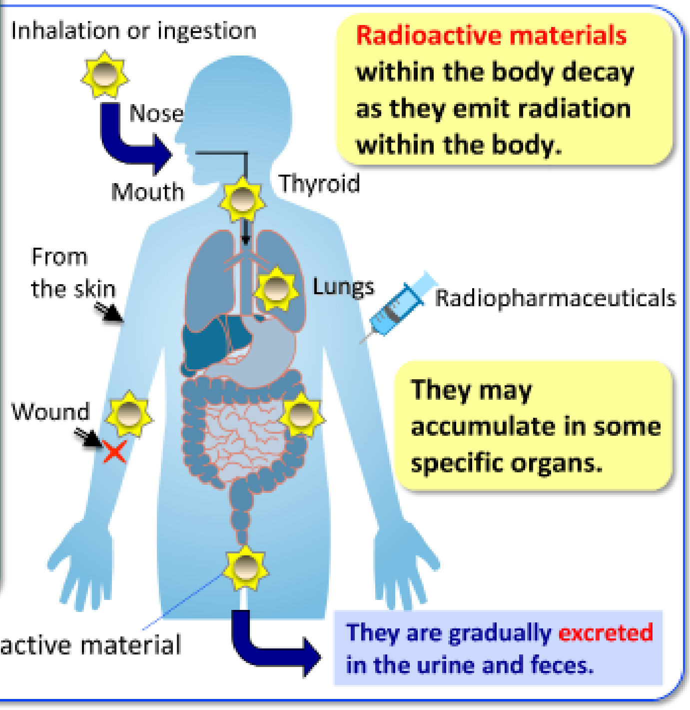
(i) Ingestion
From the mouth (swallowing)
Absorption through the digestive tract

(ii) Inhalation
Incorporation from the respiratory airways
Absorption from the lungs and the surface of the airways

(iii) Percutaneous absorption
Absorption from the skin

(iv) Wound contamination
Contamination from a wound

(v) Intake of radiopharmaceuticals
Injection, oral administration (→ (i))
Inhalation of gas (→ (ii))



Radioactive materials within the body decay as they emit radiation within the body.

They may accumulate in some specific organs.

They are gradually excreted in the urine and feces.

Internal exposure occurs due to radioactive materials being taken in the following routes: ingestion together with food (ingestion); incorporation while breathing (inhalation); absorption from the skin (percutaneous absorption); penetration from a wound (wound contamination), and administration of radiopharmaceuticals through injection, etc.

Radioactive materials incorporated into the body emit radiation within the body. Accumulation in some specific organs may occur depending on the types of radioactive materials.

This is largely due to the physicochemical properties of radioactive materials. For example, strontium, having similar properties to calcium, tends to accumulate in calcium-rich parts such as bones once it enters the body; cesium, because of its properties similar to potassium, tends to distribute throughout the body once it enters the body.

Iodine, being a constituent element of thyroid hormones, tends to accumulate in the thyroid, whether it is radioactive iodine or stable iodine (p.127 of Vol. 1, “Thyroid”).

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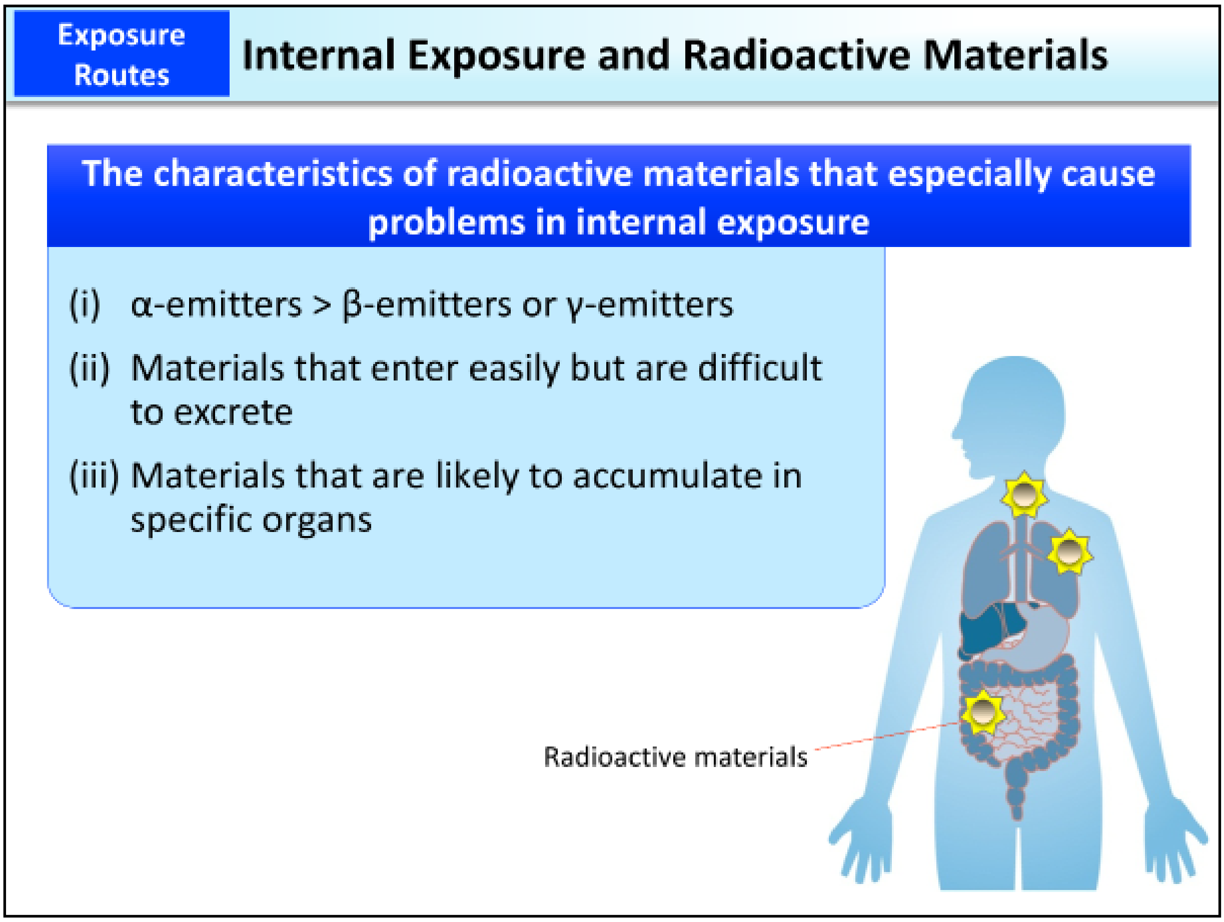

Exposure Routes

Internal Exposure and Radioactive Materials

The characteristics of radioactive materials that especially cause problems in internal exposure

(i) α-emitters > β-emitters or γ-emitters

(ii) Materials that enter easily but are difficult to excrete

(iii) Materials that are likely to accumulate in specific organs

Radioactive materials within the body disintegrate into other elements and are gradually excreted in the urine and feces through metabolism. The time required for radioactive materials to reduce to half by disintegration is called physical half-life (Tp), and the time required for radioactive materials within the body to reduce to half through metabolism is called biological half-life (Tb). Radioactive materials that enter the body decrease both through their physical half-life and biological half-life. The time required for such radioactive materials to reduce to half is called effective half-life (Te), and the following relationship is found between Tp and Tb:

$$1/Te = 1/Tp + 1/Tb$$

A major problem with internal exposure is caused by radioactive materials that have a long half-life and emit α (alpha)-particles. In terms of the chemical nature and element-specific biokinetic behavior, radioactive materials that are easily incorporated into the body but are difficult to be excreted, and also those that tend to be accumulated in particular organs/tissues cause problems as they result in increasing internal exposure doses.

Plutonium, which is not easily absorbed in the digestive tract, for example, could be a concern if taken into the lungs during inhalation rather than being taken into the body via food. It has been known that plutonium then enters blood vessels from the lungs and is transported by blood flow to bones and the liver, where it settles. Since plutonium emits α-particles within such organs, it could cause lung cancer, bone tumors or liver cancer.

Radioactive cesium, on the other hand, easily enters the body because of its properties similar to potassium but it also tends to be easily excreted. It does not accumulate in any specific organs but is taken in mainly in muscles. For adults, the time required for radioactive cesium that enters the body to reduce to half is said to be about 70 days (p.31 of Vol. 1, “Radioactive Materials Derived from Nuclear Accidents”).

Included in this reference material on March 31, 2013
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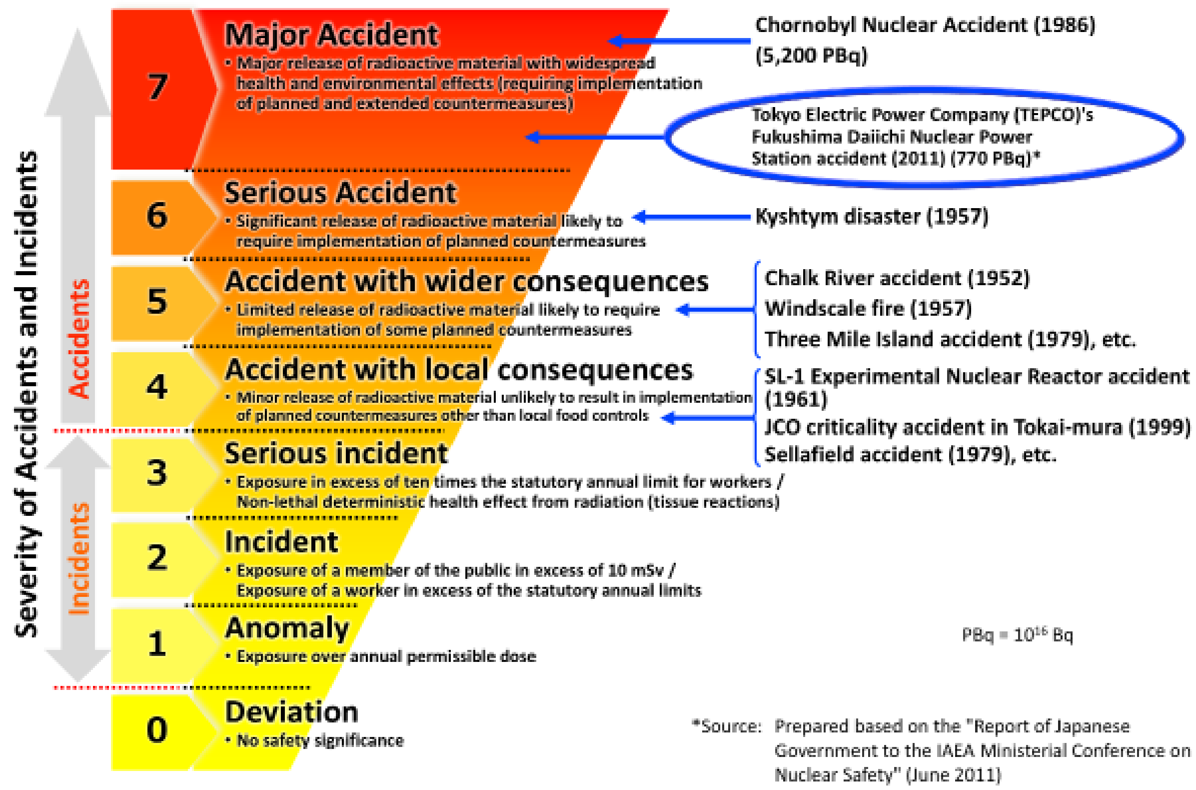
International Nuclear and Radiological Event Scale



*Source: Prepared based on the "Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety" (June 2011)

The International Nuclear and Radiological Event Scale (INES) was established by the INES (the International Atomic Energy Agency) and the OECD/NEA (Organization for Economic Co-operation and Development/Nuclear Energy Agency), and in 1992, all countries were recommended to formally adopt it.

Incidents and accidents at nuclear facilities are divided into seven categories according to their severity. Each country determines the severity of incidents or accidents using this scale and announces the results.

The accident at TEPCO's Fukushima Daiichi NPS was provisionally rated Level 7, indicating that it was the most serious accident because of the amount of radioactive materials released.

(Related to p.8 of Vol. 2, "International Nuclear and Radiological Event Scale (INES)")

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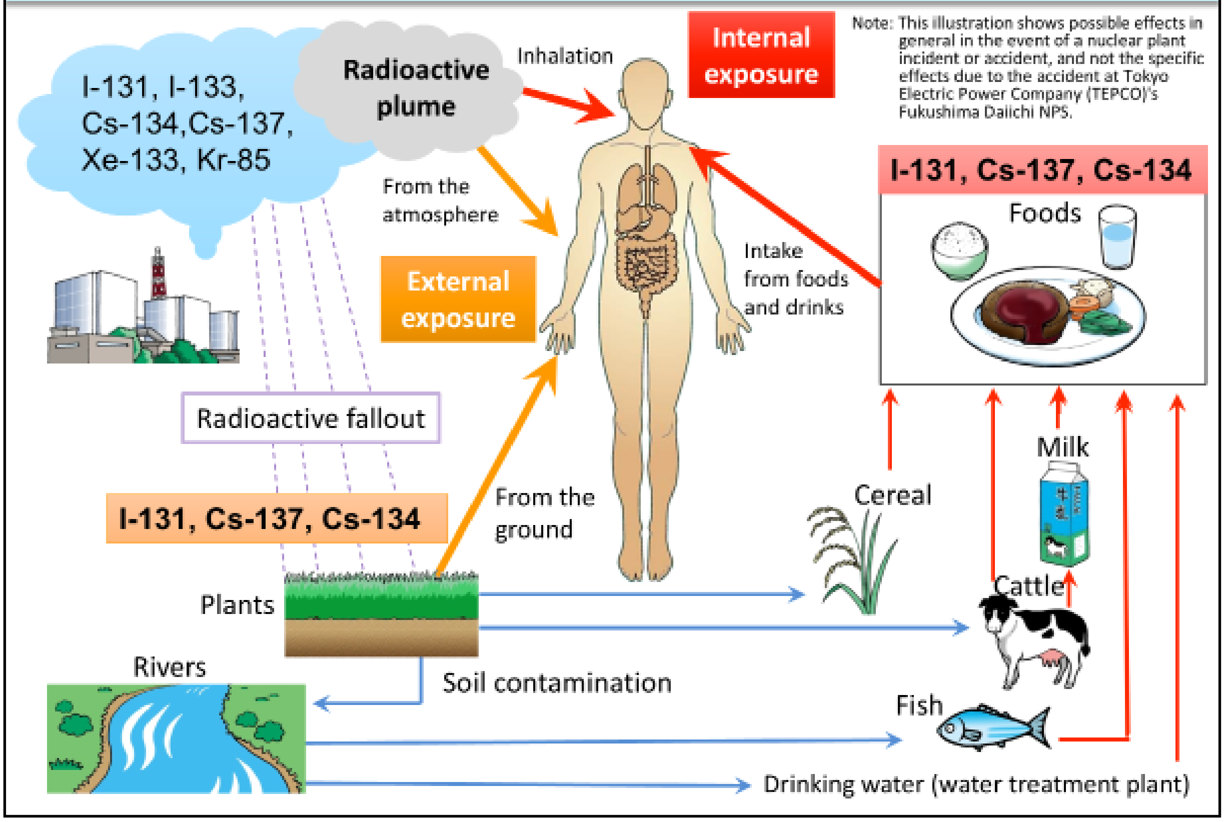
Nuclear Disaster

Effects of Reactor Accidents



Note: This illustration shows possible effects in general in the event of a nuclear plant incident or accident, and not the specific effects due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS.

If an emergency happens in a nuclear facility and radioactive gas leaks, it flows into the atmosphere in a state called “plume.” Plumes contain radioactive noble gases and aerosols (micro liquid droplets and particles), such as radioactive iodine and radioactive cesium.

When a plume passes overhead, people under it are externally exposed to radiation from radioactive materials contained therein. Additionally, people who inhale radioactive materials contained in the plume are also internally exposed to radiation.

Radioactive noble gases (krypton, xenon) are not deposited on the ground, and even if they enter the human body through inhalation, they do not remain in the body. However, aerosols, such as radioactive iodine and radioactive cesium, fall down gradually while a plume passes through and are deposited on the ground surface and plants. Therefore, external exposure from deposited radioactive materials may occur even after the plume has passed, and internal exposure may also occur if someone consumes contaminated drinking water or foods.

(Related to p.23 of Vol. 1, “Internal and External Exposure,” and p.30 of Vol. 1, “Products in Nuclear Reactors”)

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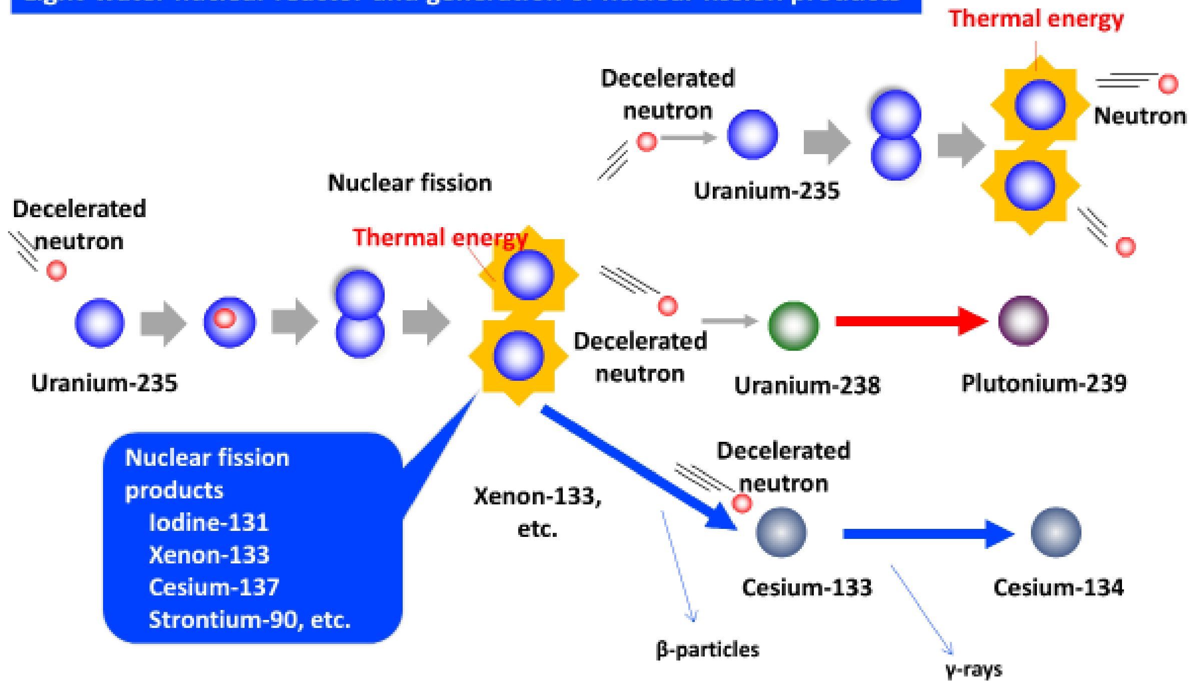
Nuclear Disaster

Products in Nuclear Reactors

Light-water nuclear reactor and generation of nuclear fission products



The light-water nuclear reactor is currently the most widely used type of reactor around the world (also used at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS). Bombarding enriched uranium fuel (Uranium-235: 3-5%; Uranium-238: 95-97%) with neutrons results in nuclear fission. Radioactive nuclear fission products such as Iodine-131, Cesium-137, and Strontium-90 are created in this process. When Uranium-238 is bombarded with neutrons, Plutonium-239 is created.

Cesium-134 is not created directly from the nuclear fission of Uranium-235. Through beta disintegration, Xenon-133 and the like, which are nuclear fission products, disintegrate into Cesium-133, and Cesium-133 then turns into Cesium-134 as decelerated neutrons are trapped.

As long as the reactor is working properly, these products remain in nuclear fuel rods and do not leak out of the reactor.

Nuclear facilities are equipped with a variety of mechanisms for preventing leakage of radioactive materials, but if they all stop functioning properly, radioactive leaks will occur.

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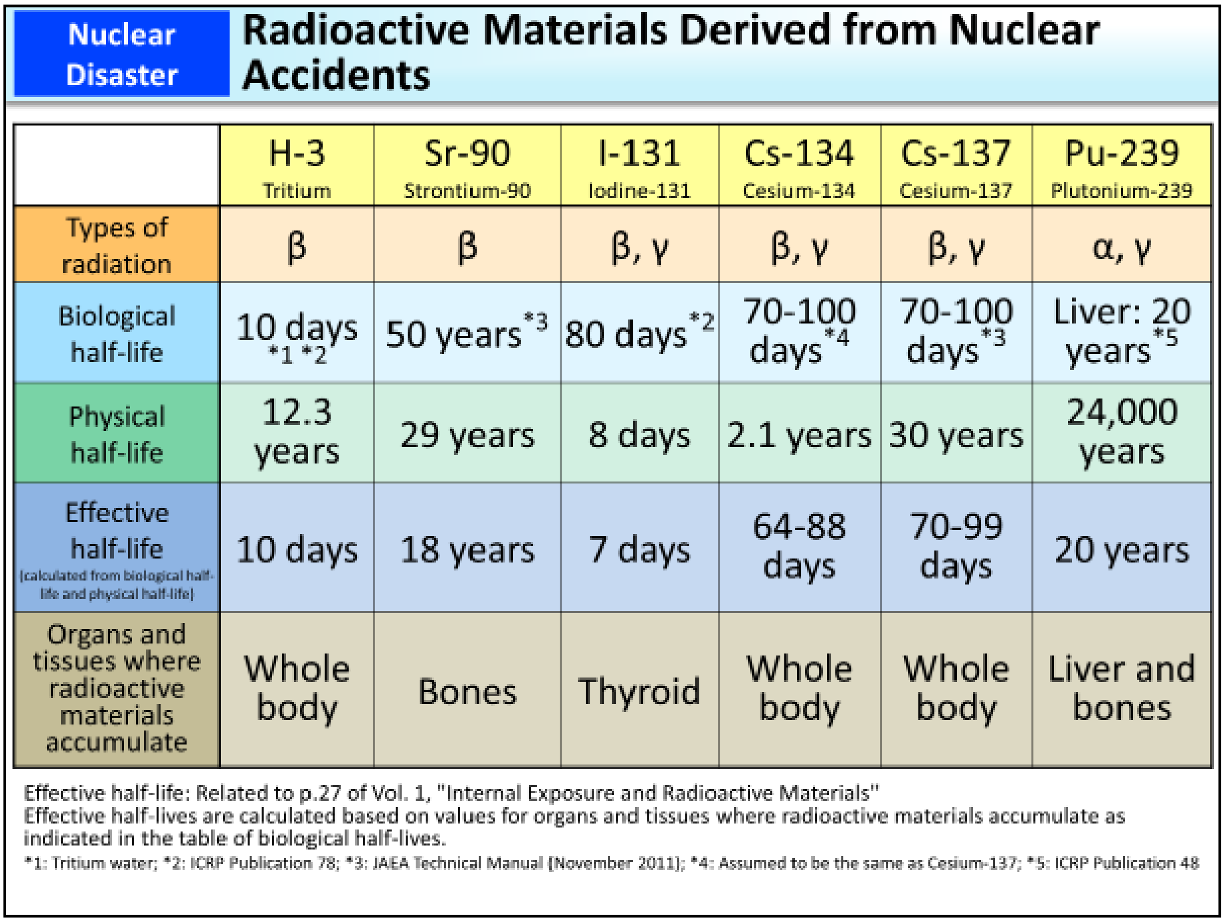

Nuclear Disaster

Radioactive Materials Derived from Nuclear Accidents

	H-3 Tritium	Sr-90 Strontium-90	I-131 Iodine-131	Cs-134 Cesium-134	Cs-137 Cesium-137	Pu-239 Plutonium-239
Types of radiation	β	β	β, γ	β, γ	β, γ	α, γ
Biological half-life	10 days[*1][*2]	50 years[*3]	80 days[*2]	70-100 days[*4]	70-100 days[*3]	Liver: 20 years[*5]
Physical half-life	12.3 years	29 years	8 days	2.1 years	30 years	24,000 years
Effective half-life (calculated from biological half-life and physical half-life)	10 days	18 years	7 days	64-88 days	70-99 days	20 years
Organs and tissues where radioactive materials accumulate	Whole body	Bones	Thyroid	Whole body	Whole body	Liver and bones

Effective half-life: Related to p.27 of Vol. 1, "Internal Exposure and Radioactive Materials"
Effective half-lives are calculated based on values for organs and tissues where radioactive materials accumulate as indicated in the table of biological half-lives.

*1: Tritium water; *2: ICRP Publication 78; *3: JAEA Technical Manual (November 2011); *4: Assumed to be the same as Cesium-137; *5: ICRP Publication 48

Four types of radioactive materials, Iodine-131, Cesium-134, Cesium-137, and Strontium-90, are the major concerns in relation to health and environmental effects of radioactive materials released into the environment due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. While various other materials were also released, they are known to have shorter half-lives than these four types or have been released in negligible amounts (p.32 of Vol. 1, "Comparison of Estimated Amounts of Released Radionuclides between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accidents").

Iodine-131 has a short physical half-life of about 8 days, but once it enters the body, 10-30% will accumulate in the thyroid (p.127 of Vol. 1, "Thyroid"). If this happens, the thyroid will continue to be locally exposed to β (beta)-particles and γ-rays for a while.

Two types of radioactive cesium, Cesium-134 and Cesium-137, are the major causes of contamination due to nuclear plant accidents. Cesium-137 has a long physical half-life of 30 years and continues to contaminate the environment for a long time. Since radioactive cesium has similar chemical properties to potassium, it will be distributed throughout the body, like potassium. The biological half-lives of cesium and iodine vary depending on the age of the person, and are known to become shorter, the younger the person is.

Strontium-90 has a long physical half-life, and once it enters the body, it accumulates in bones because of its chemical properties similar to calcium. Since it does not emit γ-rays, it is not as easy as in the case of Cesium-134 and Cesium-137 to detect where and how much it exists in the body. In a nuclear plant accident, Strontium-90 is also produced as a result of nuclear fission, though smaller in quantity than Cesium-134 and Cesium-137. Plutonium-239 and the like derived from the accident at TEPCO's Fukushima Daiichi NPS have also been detected, but detected amounts are almost equal to the results of the measurement conducted all over Japan before the accident (p.51 of Vol. 2, "Plutonium (Fukushima Prefecture)").
(Related to p.11 of Vol. 1, "Half-lives and Radioactive Decay," and p.30 of Vol. 1, "Products in Nuclear Reactors")

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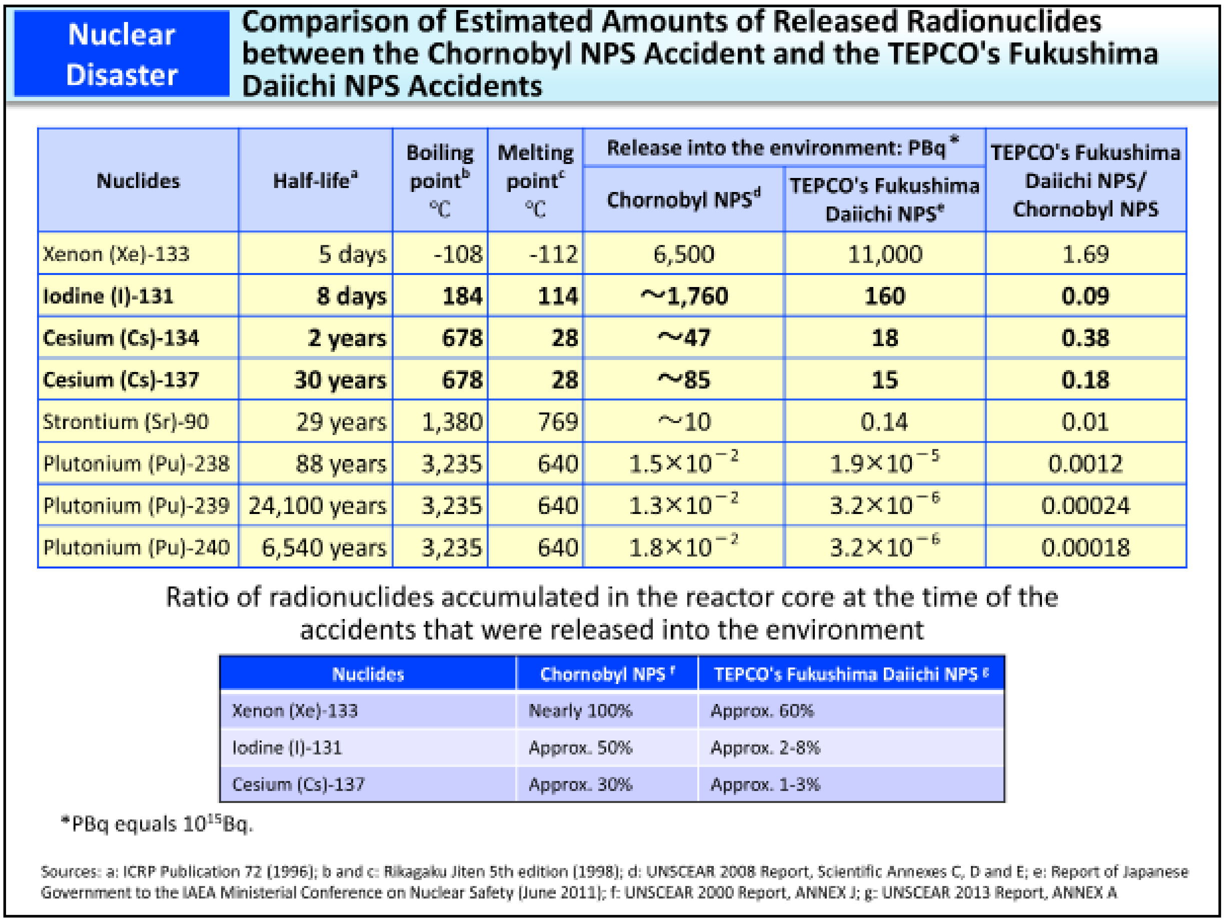

Nuclear Disaster

Comparison of Estimated Amounts of Released Radionuclides between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accidents

Nuclides	Half-life[a]	Boiling point[b] °C	Melting point[c] °C	Release into the environment: PBq*		TEPCO's Fukushima Daiichi NPS/ Chornobyl NPS
				Chornobyl NPS[d]	TEPCO's Fukushima Daiichi NPS[e]	
Xenon (Xe)-133	5 days	-108	-112	6,500	11,000	1.69
Iodine (I)-131	**8 days**	**184**	**114**	**~1,760**	**160**	**0.09**
Cesium (Cs)-134	**2 years**	**678**	**28**	**~47**	**18**	**0.38**
Cesium (Cs)-137	**30 years**	**678**	**28**	**~85**	**15**	**0.18**
Strontium (Sr)-90	29 years	1,380	769	~10	0.14	0.01
Plutonium (Pu)-238	88 years	3,235	640	1.5×10^{-2}	1.9×10^{-5}	0.0012
Plutonium (Pu)-239	24,100 years	3,235	640	1.3×10^{-2}	3.2×10^{-6}	0.00024
Plutonium (Pu)-240	6,540 years	3,235	640	1.8×10^{-2}	3.2×10^{-6}	0.00018

Ratio of radionuclides accumulated in the reactor core at the time of the accidents that were released into the environment

Nuclides	Chornobyl NPS[f]	TEPCO's Fukushima Daiichi NPS[g]
Xenon (Xe)-133	Nearly 100%	Approx. 60%
Iodine (I)-131	Approx. 50%	Approx. 2-8%
Cesium (Cs)-137	Approx. 30%	Approx. 1-3%

*PBq equals 10^{15}Bq.

Sources: a: ICRP Publication 72 (1996); b and c: Rikagaku Jiten 5th edition (1998); d: UNSCEAR 2008 Report, Scientific Annexes C, D and E; e: Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety (June 2011); f: UNSCEAR 2000 Report, ANNEX J; g: UNSCEAR 2013 Report, ANNEX A

This table shows a comparison between major radioactive materials released into the environment due to the Chornobyl NPS Accident and the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident.

Among them, Cesium-134 and Cesium-137 are the major radionuclides that could pose health threats. The table shows the melting and boiling points of the respective nuclides.

Cesium has a boiling point of 678°C and is therefore in a gaseous state when the nuclear fuel is in a molten state (its melting point is 2,850°C). When cesium in a gaseous state is released into the atmosphere, it goes into a liquid state when the temperature drops below its boiling point, and it further becomes particulate at temperatures below its melting point of 28°C. Thus, cesium is mostly in a particulate form in the atmosphere and will be diffused over wide areas by wind. This was roughly how radioactive cesium was spread to distant areas in the Fukushima Daiichi NPS Accident.

Although it is difficult to directly compare the released amount between the Chornobyl NPS Accident and the Fukushima Daiichi NPS Accident, the larger amount released at the time of the Chornobyl NPS Accident is considered to have been partly due to the fact that the core exploded and was directly exposed to the atmosphere. In contrast, a relatively small amount was released from TEPCO's Fukushima Daiichi NPS as extensive destruction of the containment vessel was barely avoided, and this is considered to have reduced releases of radioactive materials.

However, some noble gases such as Xenon-133 that are easily released into the atmosphere are considered to have been released also from the reactors at TEPCO's Fukushima Daiichi NPS at a high percentage (Fukushima Daiichi NPS: approx. 60%; Chornobyl NPS: up to 100%). The large power capacity (Fukushima Daiichi NPS: total of approx. 2,000,000 kW; Chornobyl NPS: 1,000,000 kW) and the large amount of noble gases remaining in the core at the time of the accident are considered to have caused the release of large amounts of noble gases from TEPCO's Fukushima Daiichi NPS.

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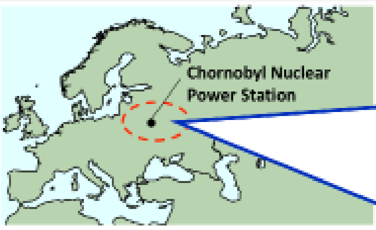
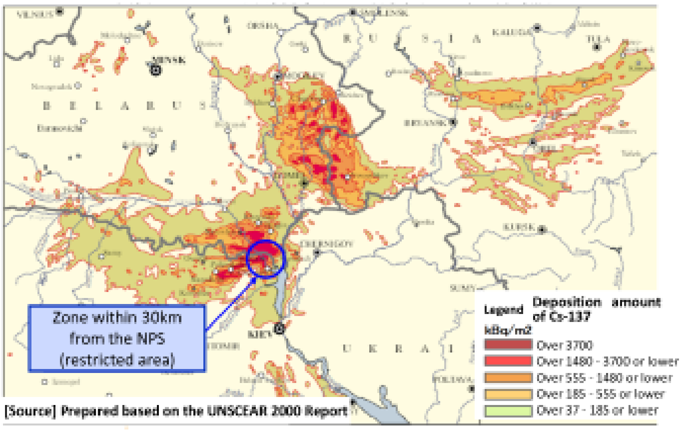
Nuclear Disaster

Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident

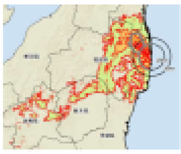


Contamination due to the Chornobyl NPS Accident (as of December 1989)



[Source] Prepared based on the UNSCEAR 2000 Report

Contamination due to the TEPCO's Fukushima Daiichi NPS Accident (as of November 2011)



[Source] Prepared based on the materials published by MEXT (November 2011)

Two figures on the same scale

Contamination concentration (kBq/m^2)	Area of the contaminated region (km^2)		Size of the TEPCO's Fukushima Daiichi NPS Accident compared with that of the Chornobyl NPS Accident
	Chornobyl NPS Accident	TEPCO's Fukushima Daiichi NPS Accident	
> 1,480	3,100	200	6 %
555 – 1,480	7,200	400	6 %
185 – 555	18,900	1,400	7 %
37 –185	116,900	6,900	6 %
Total area	146,100	8,900	6 %

Source: Prepared based on the report by the Team in Charge of Assisting the Lives of Disaster Victims, "Standard of the Annual Dose Limit of 20mSv" (March 2013)

The above figures show the contaminated regions due to the Chornobyl NPS Accident as of December 1989 and those due to Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident as of November 2011 on the same scale. The table shows areas of the contaminated regions shown in the figures.

The region affected by the Fukushima Daiichi NPS Accident is about 6% of that affected by the Chornobyl NPS Accident in terms of the total area contaminated with Cs-137. (Related to p.32 of Vol. 1, "Comparison of Estimated Amounts of Released Radionuclides between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accidents")

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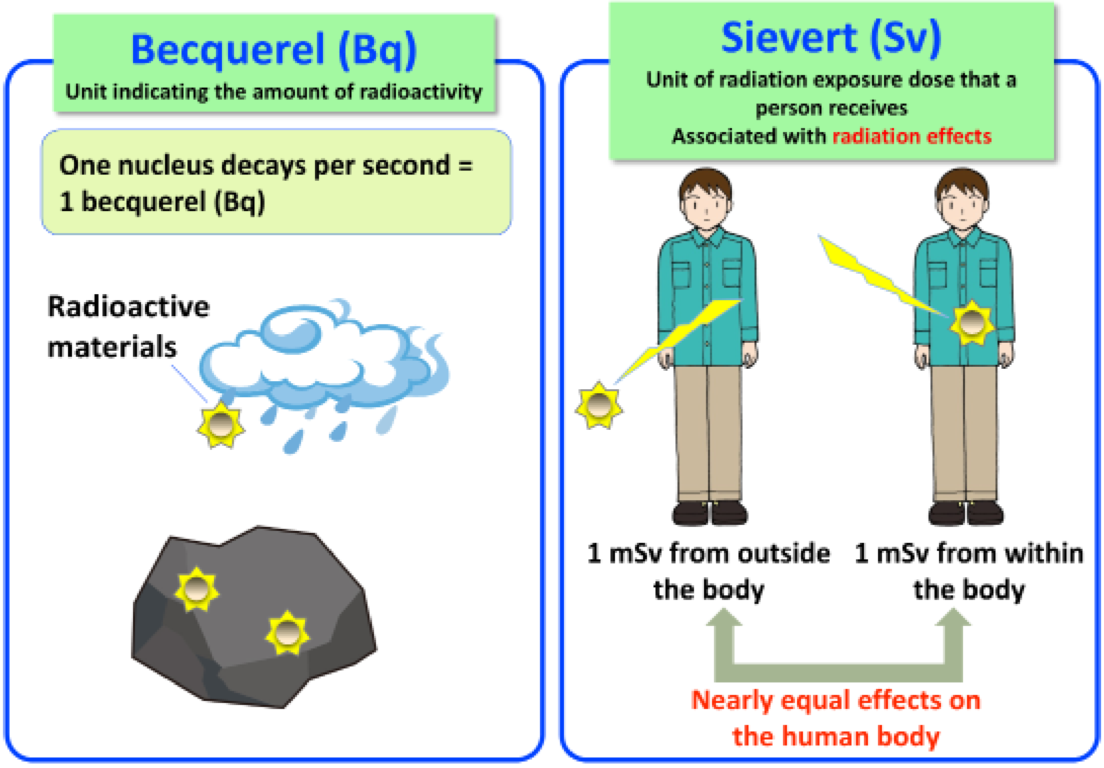
Units of Radiation

Becquerel and Sievert



Becquerel (Bq)

Unit indicating the amount of radioactivity

One nucleus decays per second = 1 becquerel (Bq)

Sievert (Sv)

Unit of radiation exposure dose that a person receives

Associated with radiation effects

1 mSv from outside the body

1 mSv from within the body

Nearly equal effects on the human body

“Becquerel” and “sievert” are the most common units of radiation. Becquerel is a unit of radioactivity and focuses on where radiation comes from. It is used to express the amount of radioactive materials contained in soil, foods, tap water, etc. The higher the value expressed in becquerels, the larger the radiation being emitted. Sievert is a unit of radiation exposure dose that a person receives and is used with regard to what is exposed to radiation, i.e. the human body. The larger the value expressed in sieverts, the larger the effects of radiation to which the human body is exposed (p.40 of Vol. 1, “Concepts of Doses: Physical Quantities, Protection Quantities and Operational Quantities”).

The extent of radiation effects on the human body varies according to the types of exposure, i.e., internal or external exposure, or whole-body or local exposure (for details, refer to Vol. 1, “2.1 Exposure Routes”), and according to the types of radiation (for details, refer to Vol. 1, “1.3 Radiation”). By using sieverts to express all types of exposure, it is possible to compare their effects on human body.

External exposure of 1 mSv and internal exposure of 1 mSv are deemed to have equal effects on the human body. Exposure to 1 mSv of radiation from outside the body and exposure to 1 mSv of radiation from within the body mean exposure to a total of 2 mSv of radiation.

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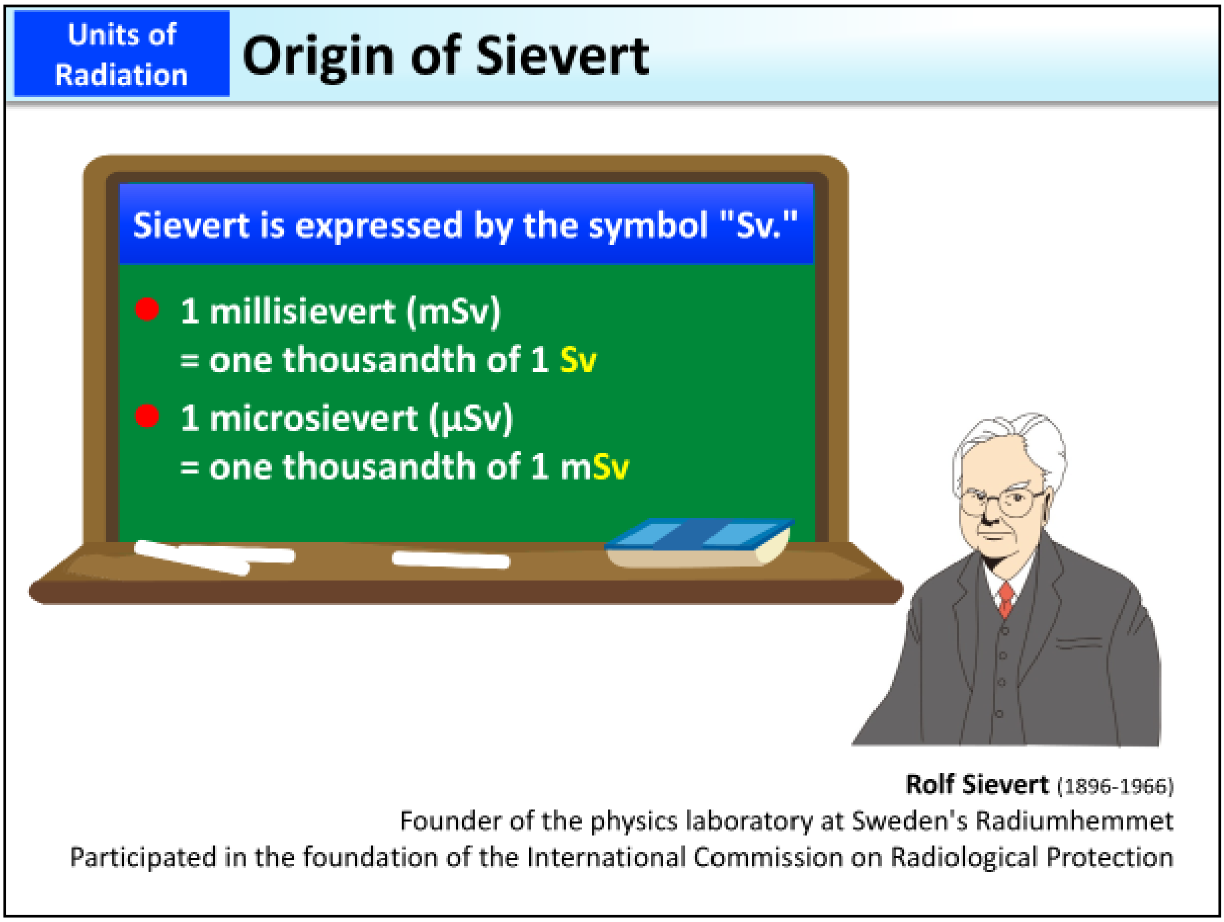

Units of Radiation

Origin of Sievert

Sievert is expressed by the symbol "Sv."

- 1 millisievert (mSv)
  = one thousandth of 1 Sv
- 1 microsievert (μSv)
  = one thousandth of 1 mSv

Rolf Sievert (1896-1966)
Founder of the physics laboratory at Sweden's Radiumhemmet
Participated in the foundation of the International Commission on Radiological Protection

The unit “sievert” is named after Rolf Sievert, a Swedish researcher on radiological protection. He served as the chairman of the International X-ray and Radium Protection Committee (IXRPC), the predecessor of the International Commission on Radiological Protection (ICRP), and participated in founding the ICRP[1]. Millisieverts (one millisievert = a thousandth of sievert) and microsieverts (one microsievert = a millionth of sievert) are mostly used to express radiation doses that people receive in their daily lives.

Becquerel (unit of radioactivity), curie (former unit of radioactivity) and gray (unit of absorbed dose) are all named after researchers who made significant contributions to the study of radiation.

1. It is said that George Kaye at the National Physical Laboratory played a central role in founding the ICRP.

(Source: ICRP Publication 109, The History of ICRP and the Evolution of its Policies, ICRP, 2009)

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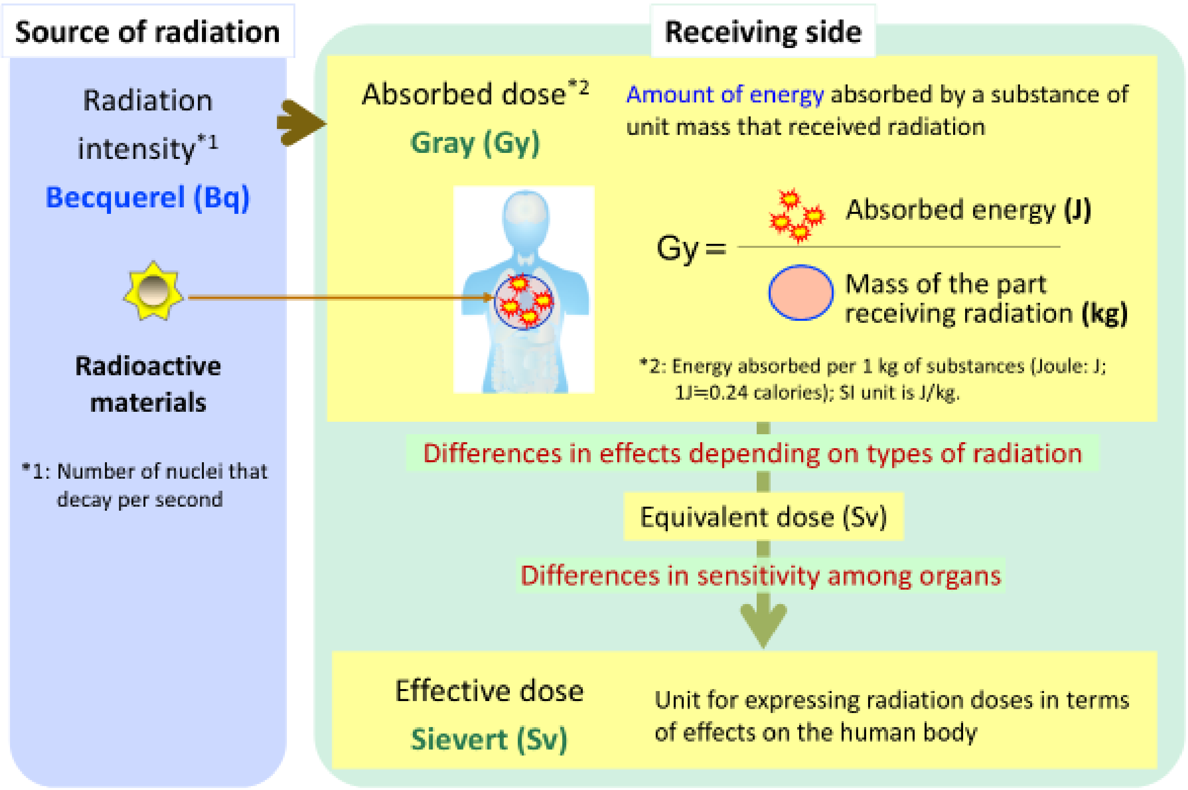
Units of Radiation

Relationship between Units



Source of radiation

Radiation intensity*1

Becquerel (Bq)

Radioactive materials

*1: Number of nuclei that decay per second

Receiving side

Absorbed dose*2

Gray (Gy)

Amount of energy absorbed by a substance of unit mass that received radiation

$$\text{Gy} = \frac{\text{Absorbed energy } \mathbf{(J)}}{\text{Mass of the part receiving radiation } \mathbf{(kg)}}$$

*2: Energy absorbed per 1 kg of substances (Joule: J; 1J=0.24 calories); SI unit is J/kg.

Differences in effects depending on types of radiation

Equivalent dose (Sv)

Differences in sensitivity among organs

Effective dose

Sievert (Sv)

Unit for expressing radiation doses in terms of effects on the human body

Units of radiation can be broadly divided into units for sources of radiation and units for the receiving side. Becquerel, a unit of radioactivity, is used for sources of radiation. Units for the receiving side are gray and sievert.

When radiation passes through something, its energy is absorbed there. Gray is a unit for indicating the absorbed dose.

The extent of effects on the human body varies depending on the types and energy quantities of radiation even if the absorbed doses are the same. Doses weighting health effects of respective types of radiation are equivalent doses (expressed in sieverts). The effective dose (expressed in sieverts) was developed for exposure management in radiological protection. In contrast to the equivalent dose, the effective dose weights differences in sensitivity among organs and tissues and sums them up to express the radiation effects on the whole body.

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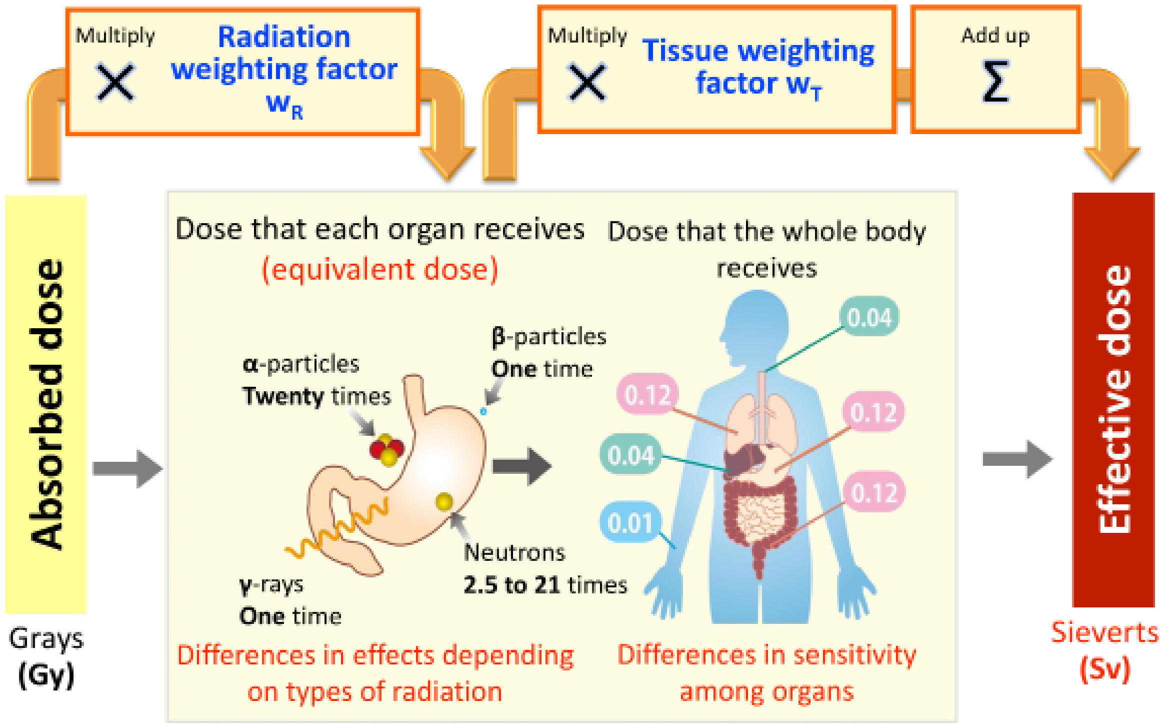
Units of Radiation

Conversion from Gray to Sievert



To calculate the effective dose that expresses the effects of radiation exposure on the whole body, it is necessary to first determine the absorbed doses of individual tissues and organs exposed. The equivalent dose (expressed in sieverts) is obtained by multiplying the absorbed doses of individual tissues and organs by their respective radiation weighting factors (W_R) for taking into account the types of radiation. The value of the radiation weighting factor is larger for the types of radiation having larger effects on the human body (α (alpha)-particles: 20; β (beta)-particles and γ-rays: 1).

Once the equivalent doses for individual tissues and organs exposed to radiation are determined, they are then multiplied by the respective tissue weighting factors (W_T) for taking into account differences in sensitivity among organs, and the products are summed. The tissue weighting factors are for weighting the radiation sensitivity of individual tissues and organs. Any organ or tissue where radiation is likely to induce fatal cancer is given a higher factor.

The tissue weighting factors summate to 1. Thus, the effective dose can be considered as the weighted average of the equivalent doses of all organs and tissues. Effective doses can be calculated similarly for both internal and external exposures.
(Related to p.38 of Vol. 1, “Various Factors”)

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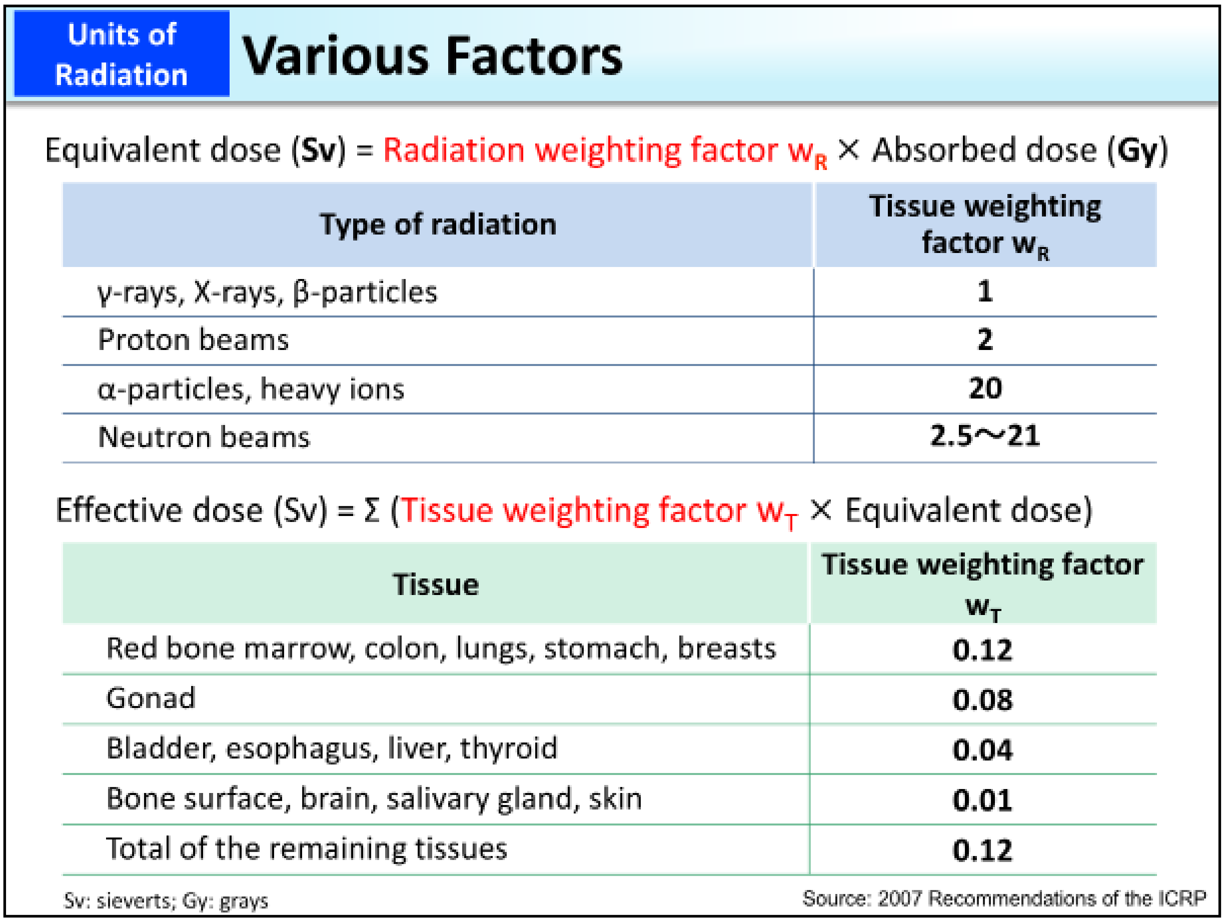


Units of Radiation

Various Factors

Equivalent dose (**Sv**) = Radiation weighting factor w_R × Absorbed dose (**Gy**)

Type of radiation	Tissue weighting factor w_R
γ-rays, X-rays, β-particles	**1**
Proton beams	**2**
α-particles, heavy ions	**20**
Neutron beams	**2.5～21**

Effective dose (Sv) = Σ (Tissue weighting factor w_T × Equivalent dose)

Tissue	Tissue weighting factor w_T
Red bone marrow, colon, lungs, stomach, breasts	**0.12**
Gonad	**0.08**
Bladder, esophagus, liver, thyroid	**0.04**
Bone surface, brain, salivary gland, skin	**0.01**
Total of the remaining tissues	**0.12**

Sv: sieverts; Gy: grays

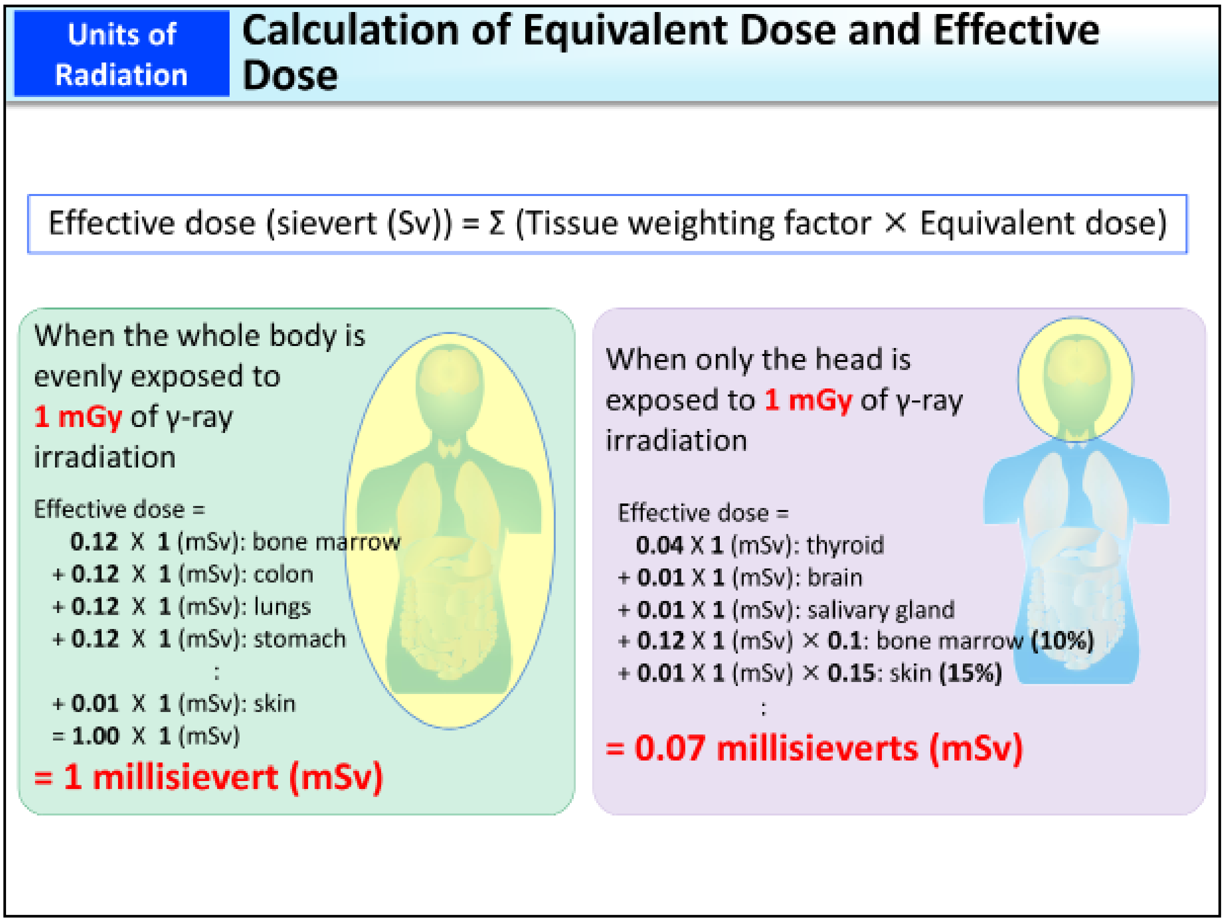
Source: 2007 Recommendations of the ICRP

Recommendations issued by the International Commission on Radiological Protection (ICRP) in 2007 presented new radiation weighting factors and tissue weighting factors. It is stated that α (alpha)-particles have 20 times larger effects on the human body than γ-rays and β (beta)-particles with the same absorbed doses. Neutron beams are also given high radiation weighting factors and are expected to have 2.5 to 21 times larger effects on the human body than γ-rays and β-particles depending on the energy quantities (p.37 of Vol. 1, "Conversion from Gray to Sievert").

A survey on the health effects of radiation on atomic bomb survivors revealed which organs and tissues are more prone to the cancer-causing effects of radiation (p.114 of Vol. 1, "Tissues and Organs Highly Sensitive to Radiation"). These tissues are assigned high tissue weighting factors.

Surveys on the health effects of radiation were also conducted on the children and grandchildren of atomic bomb survivors but no heritable effects of radiation were observed (p.109 of Vol. 1, "Chromosomal Aberrations among Children of Atomic Bomb Survivors"). Therefore, the ICRP lowered the tissue weighting factor for the gonads from 0.2 in the 1990 Recommendations to 0.08 in the 2007 Recommendations. In this way, the factors used in the calculation of effective doses are updated to accommodate new findings.

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



Units of Radiation

Calculation of Equivalent Dose and Effective Dose

Effective dose (sievert (Sv)) = Σ (Tissue weighting factor × Equivalent dose)

When the whole body is evenly exposed to **1 mGy** of γ-ray irradiation

Effective dose =
0.12 X **1** (mSv): bone marrow
+ **0.12** X **1** (mSv): colon
+ **0.12** X **1** (mSv): lungs
+ **0.12** X **1** (mSv): stomach
:
+ **0.01** X **1** (mSv): skin
= **1.00** X **1** (mSv)

= 1 millisievert (mSv)

When only the head is exposed to **1 mGy** of γ-ray irradiation

Effective dose =
0.04 X **1** (mSv): thyroid
+ **0.01** X **1** (mSv): brain
+ **0.01** X **1** (mSv): salivary gland
+ **0.12** X **1** (mSv) × **0.1**: bone marrow **(10%)**
+ **0.01** X **1** (mSv) × **0.15**: skin **(15%)**
:

= 0.07 millisieverts (mSv)

Methods for calculating an effective dose when the whole body is evenly exposed to 1 mGy of γ-ray irradiation and an effective dose when only the head is exposed to 1 mGy of γ-ray irradiation are compared.

Since the radiation weighting factor (W_R) for γ-rays is 1, the whole body being evenly exposed to 1 mGy means that the whole body is evenly exposed to 1 mSv (1 gray × 1 (W_R) = 1 millisievert). That is, equivalent doses are 1 mSv for all organs and tissues. To calculate effective doses, the equivalent doses for individual tissues are multiplied by their respective tissue weighting factors and the products are summed. Bone marrow, colon, lungs, stomach and breasts are given a high factor of 0.12 because these are organs with high risks of radiation-induced fatal cancer. The skin of the whole body is assigned a factor of 0.01. Thus, when the equivalent doses for all organs and tissues are multiplied by their respective tissue weighting factors and the products are summed, the result is an effective dose of 1 millisievert.

If only the head is exposed to 1 mGy in radiation inspection, the organs and tissues in the head, such as the thyroid, brain and salivary gland, are entirely exposed to radiation, so equivalent doses are 1 mSv for all these organs and tissues. For organs and tissues that are only partly present in the head, such as bone marrow and skin, equivalent doses are obtained by multiplying by the ratios of their areas exposed to radiation (bone marrow: 10%; skin: 15%). When their equivalent doses are multiplied by their respective tissue weighting factors and the products are summed, the result is an effective dose of 0.07 mSv.
(Related to p.36 of Vol. 1, “Relationship between Units”)

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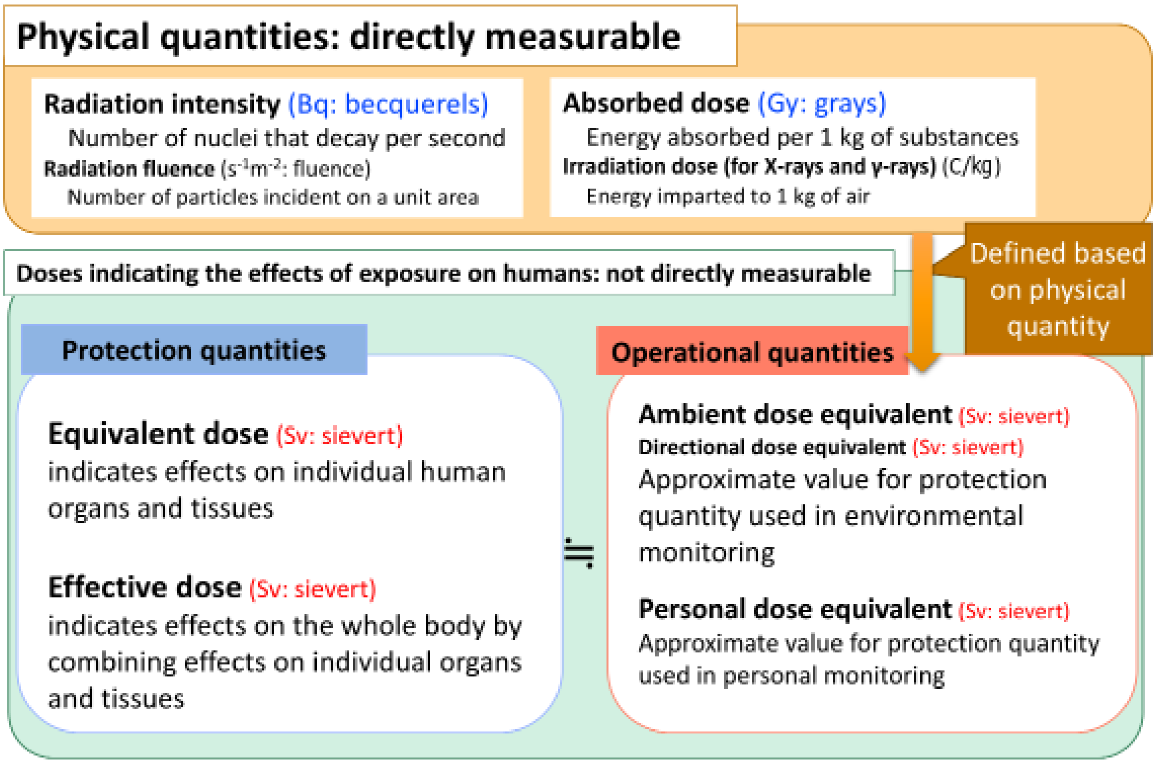
Units of Radiation

Concepts of Doses: Physical Quantities, Protection Quantities and Operational Quantities



Physical quantities: directly measurable

Radiation intensity (Bq: becquerels)
Number of nuclei that decay per second
Radiation fluence ($s^{-1}m^{-2}$: fluence)
Number of particles incident on a unit area

Absorbed dose (Gy: grays)
Energy absorbed per 1 kg of substances
Irradiation dose (for X-rays and γ-rays) (C/kg)
Energy imparted to 1 kg of air

Defined based on physical quantity

Doses indicating the effects of exposure on humans: not directly measurable

Protection quantities

Equivalent dose (Sv: sievert)
indicates effects on individual human organs and tissues

Effective dose (Sv: sievert)
indicates effects on the whole body by combining effects on individual organs and tissues

≒

Operational quantities

Ambient dose equivalent (Sv: sievert)
Directional dose equivalent (Sv: sievert)
Approximate value for protection quantity used in environmental monitoring

Personal dose equivalent (Sv: sievert)
Approximate value for protection quantity used in personal monitoring

To control radiation effects on the human body, it is necessary to take into account the effects of exposure on multiple parts of the body and the effects of previous exposures. The equivalent dose and the effective dose were invented for that purpose.

The equivalent dose is obtained by weighting effects on individual organs and tissues according to the types of radiation.

The effective dose is obtained by converting the effects on individual tissues to a value for the whole body. It is not the simple average of equivalent doses for individual organs but the result of weighting according to differences in sensitivity to radiation among organs.

A factor for weighting radiation effects on individual organs is called the tissue weighting factor.

Thus, protection quantities are calculated based on doses for organs and tissues in the human body. They are therefore different from physical quantities such as the radiation intensity (unit: becquerel) and absorbed dose (unit: gray) and cannot be measured directly with instruments. To indicate effects on the human body, operational quantities are defined.

Some survey meters use sieverts in their readings. They do not directly measure a protection quantity but show approximate values defined based on measured physical quantities, i.e., operational quantities. Operational quantities include the ambient dose equivalent used in environment monitoring and the personal dose equivalent used in personal monitoring (p.41 of Vol. 1, “Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses”).

To provide conservative (on the safe side) estimates of protection quantities, operational quantities are defined to assume slightly larger numerical values than the values of protection quantities in most cases.

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Units of Radiation

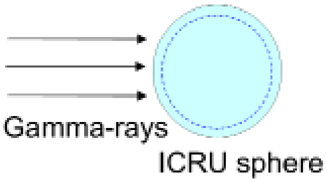
Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses

Dose equivalent = Absorbed dose at a reference point that meets certain requirements × Quality factor

To substitute for "effective doses" that cannot be actually measured, "operational quantities" that can be measured as conservative values or as nearly the same values as effective doses, such as an ambient dose equivalent and personal dose equivalent, are defined under certain conditions.

Ambient dose equivalent (1cm dose equivalent)

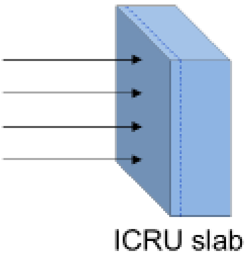
Dose equivalent is a dose that would be produced at a depth of 1 cm from the surface of an ICRU sphere, which is 30 cm in diameter and simulates human tissue, placed in a field where radiation is coming from one direction; Ambient dose equivalent is used in measurements of ambient doses using survey meters, etc.



Personal dose equivalent (1 cm dose equivalent)

Dose equivalent at a depth of 1 cm at a designated point on the human body; Since measurement is conducted using an instrument worn on the body, exposure from all directions is evaluated while a self-shielding effect is always at work.

⇒ Personal dose equivalents are always smaller than survey meter readings!



Operational quantities for approximating effective doses that cannot be actually measured (p.40 of Vol. 1, "Concepts of Doses: Physical Quantities, Protection Quantities and Operational Quantities") are defined, such as the ambient dose equivalent $H^*(d)$ (d is depth) for evaluating ambient doses in a work environment, etc., the personal dose equivalent $H_p(d)$ for evaluating personal exposure, and the directional dose equivalent $H'(d,\alpha)$ (α is the angle of incidence) as a quantity for use when there is a need to evaluate the depth and directions of incidence as well, as in the case of exposure of the lens of the eye to β-particles or soft X-rays.

Generally, both the ambient dose equivalent and the personal dose equivalent are also called 1 cm dose equivalents because a depth of 1 cm is used in the case of exposure to γ-rays.

However, while the ambient dose equivalent is measured using measuring instruments that are less affected by directivity, such as a stationary ionization chamber and a survey meter, the personal dose equivalent is measured using a small personal dosimeter worn on the trunk of the body, so incidence from the back is evaluated while a self-shielding effect is always at work. Therefore, in the case of exposures only from the front direction, such as exposures in laboratories, the ambient dose equivalent and the personal dose equivalent are equal, but in the case of exposures from all directions, personal dose equivalents are always smaller than the values measured with a survey meter, etc. Calculation of an effective dose for incidence from all directions is made under the condition of "rotational irradiation" in which the human body is rotated, and the calculated value will be exactly the same as the personal dose equivalent. In other words, the calculated value will generally be larger than the effective dose.

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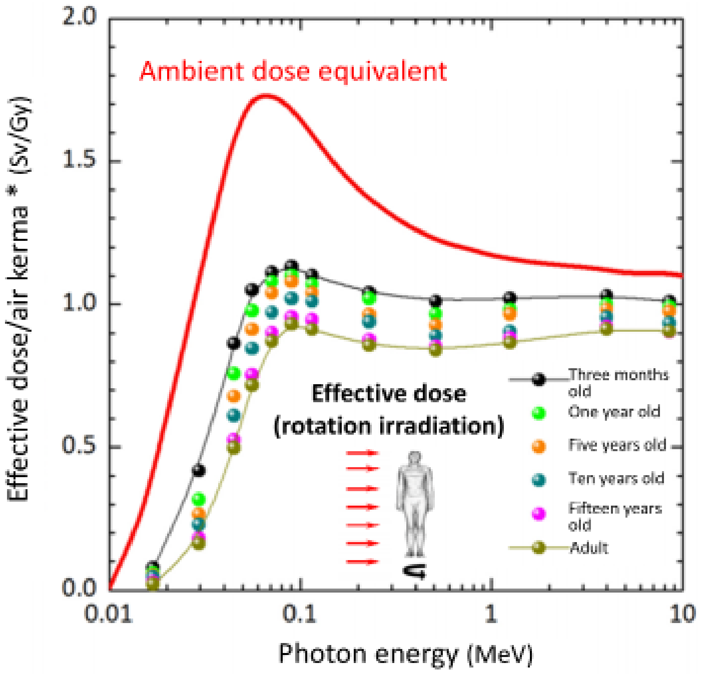
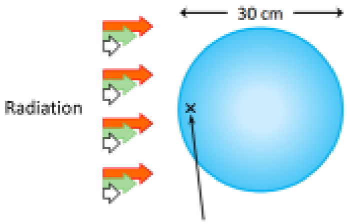
Units of Radiation

Difference between Values of Effective Dose and Dose Equivalent



* Air kerma is a unit of physical quantity.



The ambient dose equivalent measured with a survey meter is defined as the dose equivalent at a depth of 1 cm from the surface of an ICRU sphere that is 30 cm in diameter. The ambient dose equivalent is also called 1 cm dose equivalent.

Source: Partially revised material 1 for the 9th meeting of the Atomic Energy Commission of Japan in 2012 (a report by Akira Endo of JAEA)

The ambient dose equivalent measured with a survey meter is set to always indicate a larger value than the effective dose.

This is also the case for a personal dosimeter when measuring radiation incident only from the front. However, in a setting where a personal dosimeter is worn on the body and radiation sources are evenly distributed, measured value will be close to the value of “effective dose” because of the self-shielding effect of the human back, etc.

The graph above shows differences between effective dose (including the self-shielding effect of the back, etc. in the case of even irradiation by rotation) and ambient dose equivalent to the energy of incident γ-rays. While the degree of self-shielding slightly varies depending on differences in physique due to age, the value measured with a survey meter for Cs-137 γ-rays at 662 keV is shown to be about 30% larger than the effective dose for adults and the value measured with a personal dosimeter (personal dose equivalent). (Related to p.41 of Vol. 1, “Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses”)

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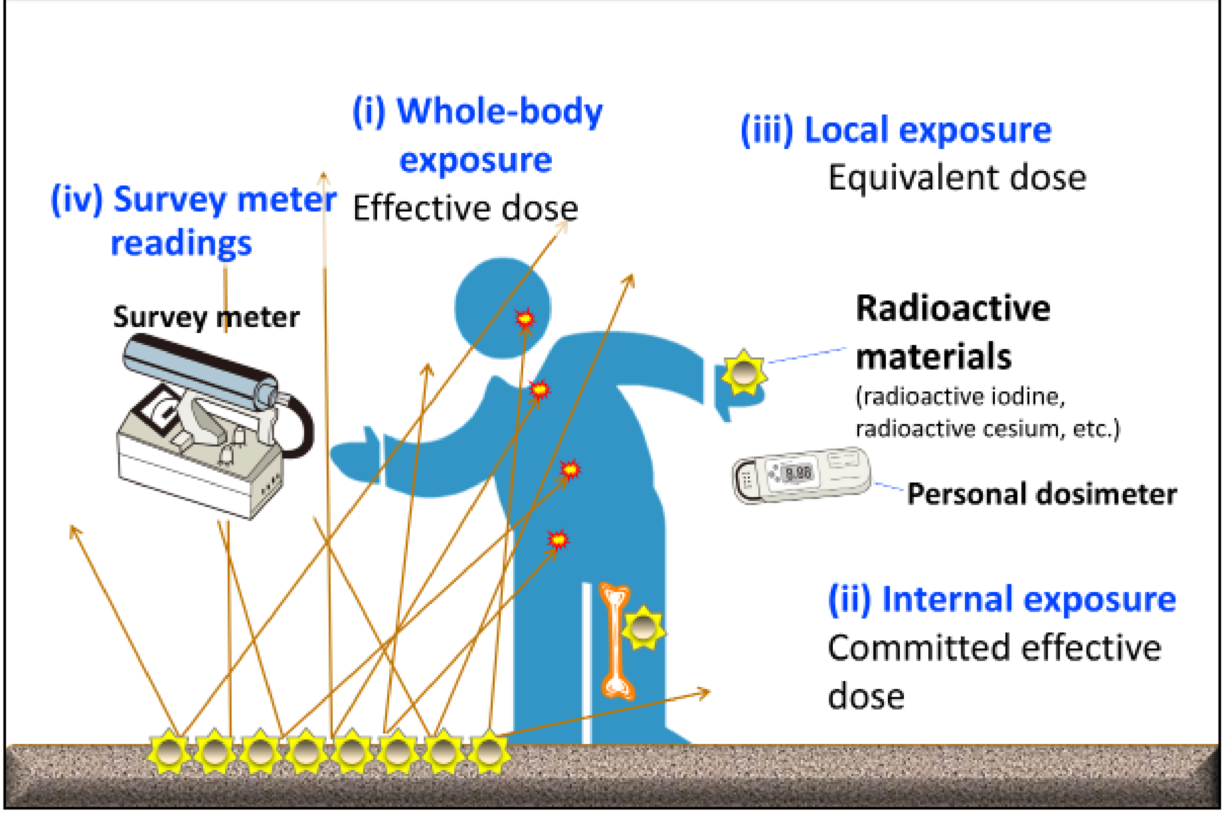
Units of Radiation

Doses in Units of Sieverts



(i) Whole-body exposure
Effective dose

(iii) Local exposure
Equivalent dose

(iv) Survey meter readings

Survey meter

Radioactive materials
(radioactive iodine, radioactive cesium, etc.)

Personal dosimeter

(ii) Internal exposure
Committed effective dose

Sievert is used as the unit for (i) radiation dose to the whole body (effective dose) (p.42 of Vol. 1, “Difference between Values of Effective Dose and Dose Equivalent”), (ii) radiation dose due to internal exposure (committed effective dose) (p.56 of Vol. 1, “Committed Effective Doses”), and (iii) dose from local exposure, in which exposure to radiation is limited to a certain location (equivalent dose). They are common in that they all take into account the risks of cancer and heritable effects on individuals or tissues exposed.

Sievert may also be used for (iv) the readings of survey meters. The relevant value shows a value converted to an ambient dose equivalent (p.44 of Vol. 1, “Various Measuring Instruments”).

Included in this reference material on March 31, 2013
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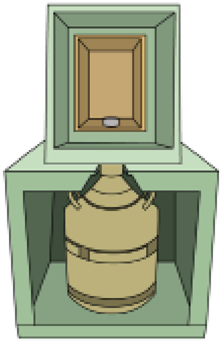
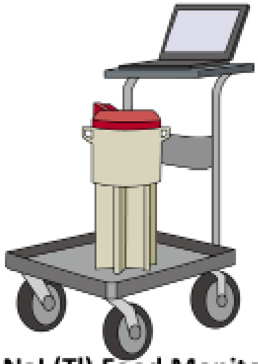
Dose Measurement and Calculation

Various Measuring Instruments



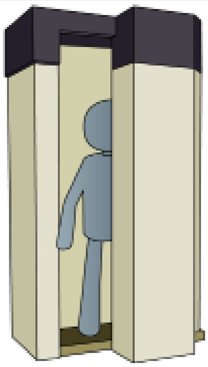
Ge Semiconductor Detector

Used to measure radioactivity in foods or soil; Effective in measuring low levels of radioactivity concentrations



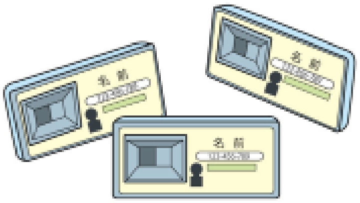
NaI (Tl) Food Monitor

Suitable for efficient radioactivity measurement of foods, etc.



Whole-body Counter

Assess accumulation of γ-ray nuclides in the body using numerous scintillation counters or the like



Integrating Personal Dosimeter

Worn on the trunk of the body for 1-3 months to measure cumulative exposure doses during that period

Electronic Personal Dosimeter

Equipped with a device to display dose rates or cumulative doses during a certain period of time and thus convenient for measuring and managing exposure doses of temporary visitors to radiation handling facilities

While radiation is not visible to the human eye, it is known to cause ionization and excitation (p.45 of Vol. 1, "Principles of Radiation Measurement"), and a variety of measuring instruments using these effects have been invented for different purposes and applications. The measuring instruments shown above all utilize the excitation effect.

To measure radioactivity concentrations in foods and soil, measuring instruments wherein a germanium detector (Ge detector) or a NaI (Tl) detector that can measure γ-ray spectra is installed in a lead shield are used. Ge detectors are excellent in γ-ray energy resolution and suitable for determining traces of radioactive materials. NaI (Tl) detectors are not as excellent as Ge detectors in terms of energy resolution but are easy to handle and have relatively high detection efficiency, so they are widely used in food inspection.

Also commercially available are whole-body counters that use numerous scintillation counters or Ge detectors worn on the body to assess accumulation of γ-ray nuclides in the body, as well as integrating personal dosimeters and electronic personal dosimeters for managing personal exposure. In particular, after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, a variety of electronic personal dosimeters have been invented to allow easy monitoring of information on exposure at certain time intervals.
(Related to p.60 of Vol. 1, "Instruments for Measuring Internal Exposure")

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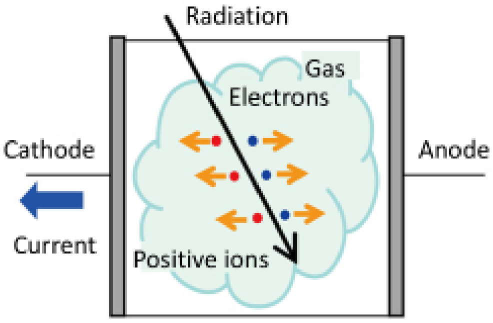
Updated on March 31, 2017

Dose Measurement and Calculation

Principles of Radiation Measurement

Measurements are carried out utilizing the interaction between radiation and substances.

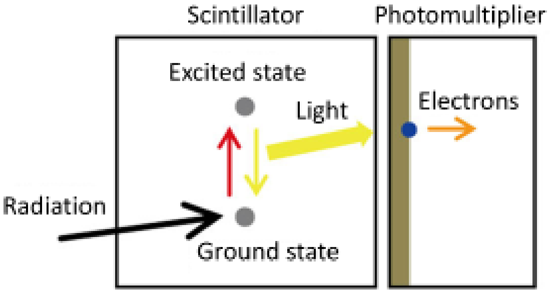
Ionization (with gas atoms)



- Detectors are filled with gases such as inert gases or air.
- When radiation passes through gas, molecules are ionized, creating positive ions and electrons.
- Positive ions and electrons are drawn toward the electrodes and are converted into electric signals for measurement.

GM counter survey meters, ionization chambers, etc.

Excitation



- When radiation passes through a scintillator, molecules are excited, but they return to their original state (ground state).
- Light emitted in the process is amplified and converted into a current for measurement.

NaI (Tl) scintillation survey meter, etc.

Radiation is known to interact with substances when passing through them. The amount of radiation can be measured utilizing the interaction between radiation and substances.

Geiger Muller (GM) counter survey meters and ionization chambers utilize the ionization between radiation and gas atoms. “Ionization effect” refers to the process in which radiation ejects electrons circling around nuclei in a substance. Detectors of GM counter survey meters and ionization chambers are filled with gases. When radiation passes inside a detector, it causes ionization of gas atoms, separating atoms into positive ions and electrons. Separated electrons and positive ions are attracted to the electrodes, causing a current to flow. This is converted into electric signals, which are then measured as the amount of radiation. As devices for radiation measurement by the use of ionization effect within a solid (a semiconductor) in the same manner, there are germanium semiconductor detectors and others. (Related to p.18 of Vol. 1, “Ionization of Radiation - Property of Ionizing Radiation”)

NaI (Tl) scintillation survey meters utilize excitation with substances. Radiation gives energy to electrons circling around nuclei, and when an electron jumps to an outer orbit, this phenomenon is called excitation. An atom in that state is unstable (excited), and when it returns to a stable state (ground state), it gives off energy in the form of light. This is called the excitation effect. A scintillator is a substance that emits light in response to incident radiation. Weak light emitted from a scintillator is amplified using a photomultiplier and is converted into an electric signal to measure radiation.

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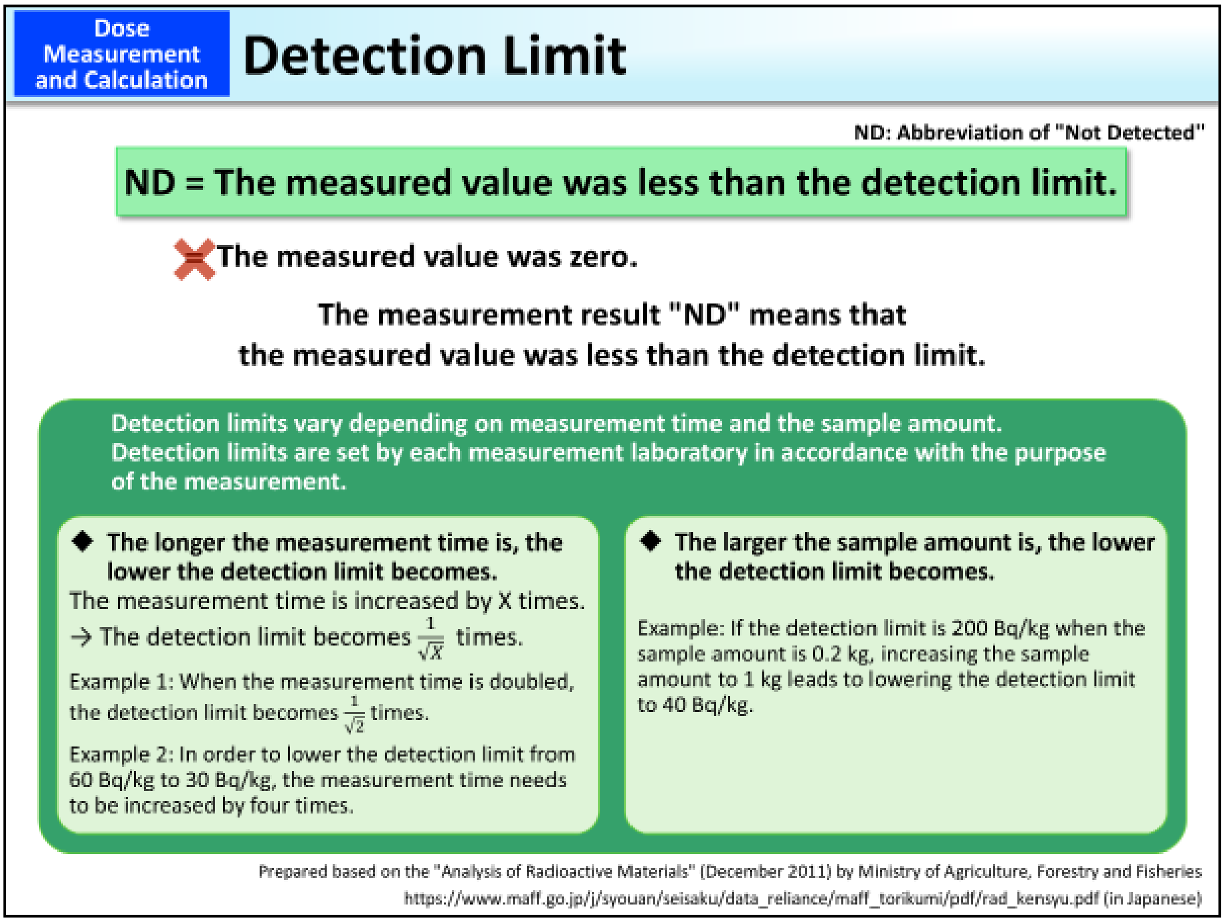

Dose Measurement and Calculation

Detection Limit

ND: Abbreviation of "Not Detected"

ND = The measured value was less than the detection limit.

✖ **The measured value was zero.**

**The measurement result "ND" means that
the measured value was less than the detection limit.**

**Detection limits vary depending on measurement time and the sample amount.
Detection limits are set by each measurement laboratory in accordance with the purpose of the measurement.**

- **The longer the measurement time is, the lower the detection limit becomes.**

The measurement time is increased by X times.
→ The detection limit becomes $\frac{1}{\sqrt{X}}$ times.

Example 1: When the measurement time is doubled, the detection limit becomes $\frac{1}{\sqrt{2}}$ times.

Example 2: In order to lower the detection limit from 60 Bq/kg to 30 Bq/kg, the measurement time needs to be increased by four times.

- **The larger the sample amount is, the lower the detection limit becomes.**

Example: If the detection limit is 200 Bq/kg when the sample amount is 0.2 kg, increasing the sample amount to 1 kg leads to lowering the detection limit to 40 Bq/kg.

Prepared based on the "Analysis of Radioactive Materials" (December 2011) by Ministry of Agriculture, Forestry and Fisheries
https://www.maff.go.jp/j/syouan/seisaku/data_reliance/maff_torikumi/pdf/rad_kensyu.pdf (in Japanese)

Results of the measurement of radioactivity or dose rates are sometimes indicated as “Not Detected (ND).”

This does not mean that there is no radioactive material but means that the measured concentration of radioactive materials is below the measurable detection limit.

Detection limits vary depending on the measurement time and the sample amount, and in general, the longer the measurement time is and the larger the sample amount is, the lower the detection limit becomes. When setting a detection limit lower, even a small amount of radioactive materials can be detected, but required time and cost are larger and this may lead to a decrease in the number of samples to be tested. Accordingly, detection limits are set by individual analytical laboratories in accordance with the purpose of the measurement.

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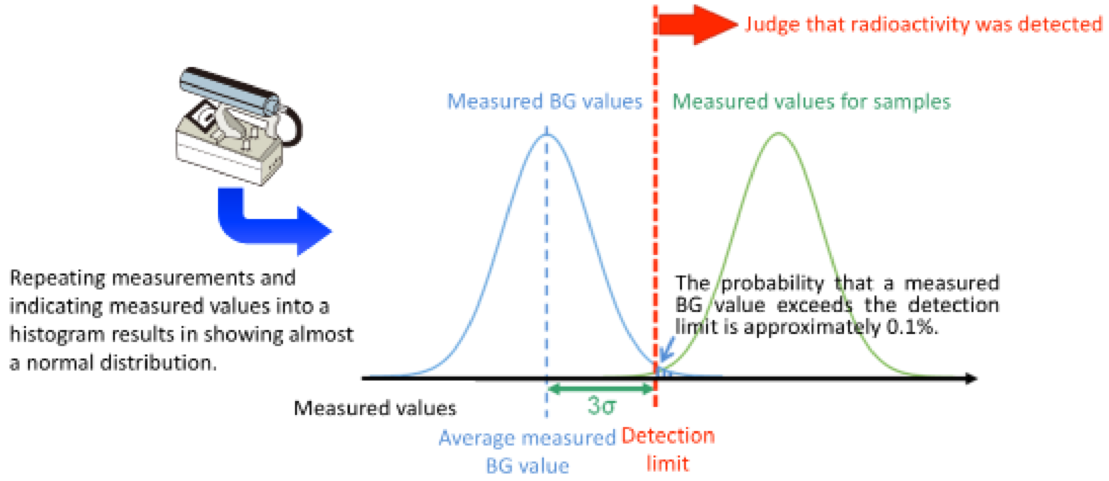
Dose Measurement and Calculation

Ideas on Detection Limits (3σ Method)

- Even a minor change in measurement conditions can influence measurement results and there is also background (BG) radioactivity derived not from samples themselves. Therefore, due consideration is required when setting a detection limit in order to assure statistical reliability.
- One of the representative ideas on detection limits is the 3σ method. Under the 3σ method, a detection limit is defined as a value obtained by adding three times sigma of the measured background values to their average. When a measurement result exceeds this value, it is judged that signals (radioactivity, a dose rate, etc.) from a sample are detected.



Repeating measurements and indicating measured values into a histogram results in showing almost a normal distribution.

The probability that a measured BG value exceeds the detection limit is approximately 0.1%.

When measuring background radioactivity or dose rates using a survey meter or other equipment, even a minor change in measurement conditions can influence measurement results. Therefore, it is necessary to repeat measurements in order to obtain reliable measurement results.

Indicating values obtained through repeated measurements into a histogram results in showing a normal distribution. The minimum amount of radioactivity that can be detected as a statistically significant value under the condition of fluctuating background dose rates is referred to as a detection limit (or lower limit).

Under the 3σ method, one of the representative ideas on detection limits, a detection limit is defined as a value obtained by adding three times sigma to the average of the measured background values. This is because when the measured value is larger than 3σ, the probability of BG measurements that exceed the detection limit by fluctuation is approximately 0.1%.

In addition to the 3σ method, there is the Currie method. Under this method, a lower detection limit is set in consideration of the fluctuation of sample measurements so as to reduce the probability of a “false negative,” where measurements close to but above the detection limit are judged as Not Detected (ND).

Reference

- “Practical handbook for γ-ray measurement,” authored by Gordon Gilmore and John D. Hemingway, translated into Japanese by Yonezawa Nakashiro, et al., NIKKAN KOGYO SHIMBUN, LTD. (2002)
- “Ideas on detection limits and minimum limits of determination,” by Uemoto Michihisa, Bunseki 2010 5, 216-221 (2010)

Included in this reference material on March 31, 2019
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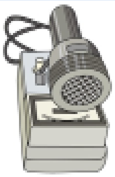
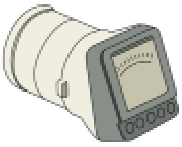
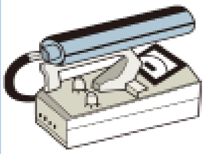
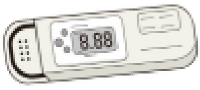
Dose Measurement and Calculation

Instruments for Measuring External Exposure

Type		Purpose	
GM counter survey meter (ionization)		Contamination detection	Has a thin entrance window and can detect β-particles efficiently; Suitable for detecting surface contamination
Ionization chamber survey meter (ionization)		γ-ray ambient dose rate	Accurate but unable to measure low dose rates like a scintillation type can
NaI (Tl) scintillation survey meter (excitation)		γ-ray ambient dose rate	Accurate and very sensitive; Suitable for measuring γ-ray ambient dose rates from the environment level up to around 10μSv/h
Personal dosimeter (light-stimulated luminescence dosimeter, luminescent glass dosimeter, electronic dosimeter, etc.) (excitation)		Personal dose Cumulative dose	Worn on the trunk of the body to measure personal dose equivalent of the relevant person's exposure while it is worn; A direct-reading type and types with alarm functions are also available.

Survey meters are either for inspecting body surface contamination or for measuring ambient dose rates. Geiger Muller (GM) tube-type survey meters are highly sensitive to β (beta)-particles and are thus suitable for inspecting body surface contamination. They are relatively affordable and useful in locating contamination and confirming the effects of decontamination.

Ionization chambers are most suited for measuring high-level ambient dose rates but cannot measure very low dose rates. Therefore, a scintillation type is most suited for measuring ambient dose rates in the general environment.

NaI (Tl) scintillation survey meters can also measure the radioactivity intensity, but measurement results vary depending on the level of radiation at the measuring location and the way of measurement. Since calibration at a facility with a radioactive source that serves as a reference is required before converting the measurement results into becquerels, expert assistance is required to implement the measurements.

Personal dosimeters provide cumulative exposure dose readings. An electronic direct-reading type allows a person to confirm the degree of exposure at certain time intervals or after every operation.

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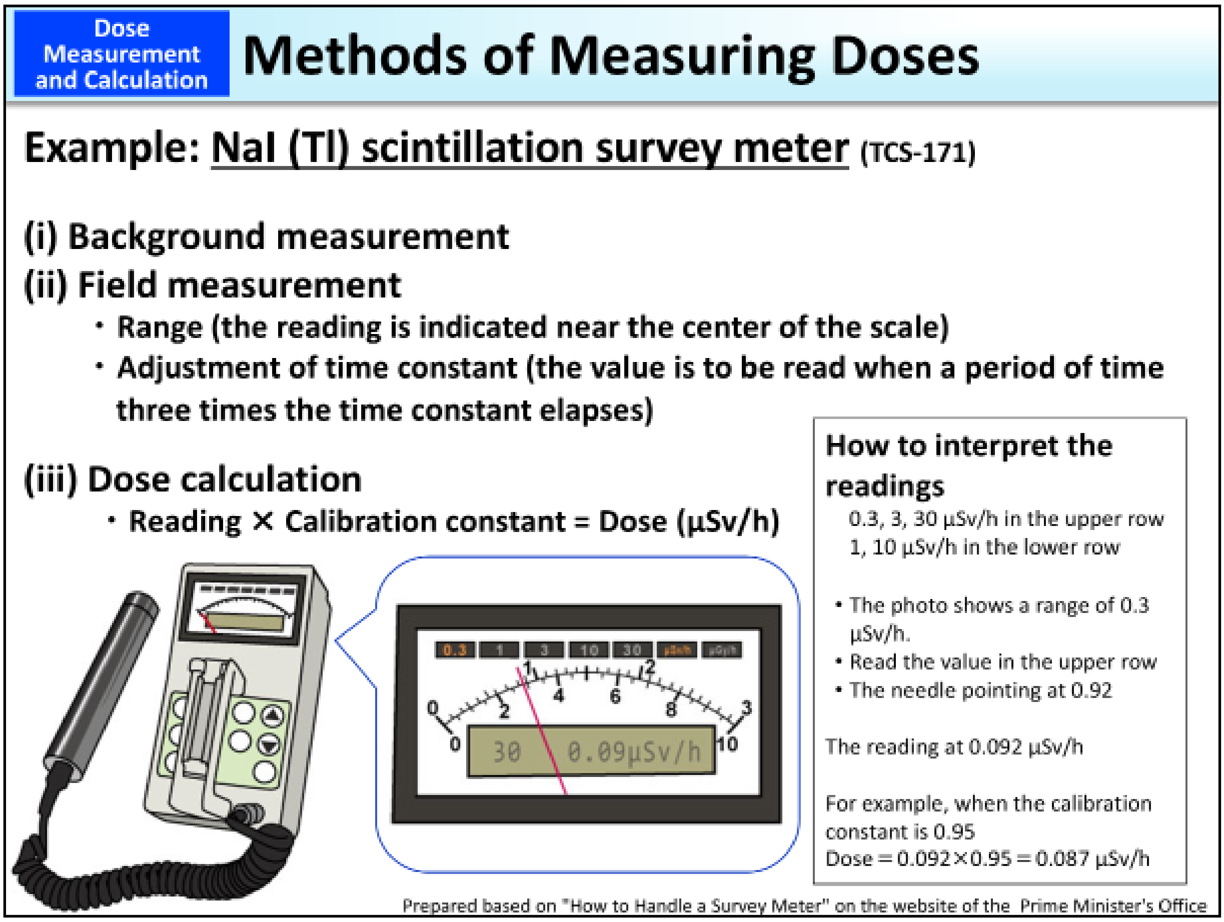


Dose Measurement and Calculation

Methods of Measuring Doses

Example: NaI (Tl) scintillation survey meter (TCS-171)

(i) Background measurement

(ii) Field measurement

- Range (the reading is indicated near the center of the scale)
- Adjustment of time constant (the value is to be read when a period of time three times the time constant elapses)

(iii) Dose calculation

- Reading × Calibration constant = Dose (μSv/h)

How to interpret the readings

0.3, 3, 30 μSv/h in the upper row
1, 10 μSv/h in the lower row

- The photo shows a range of 0.3 μSv/h.
- Read the value in the upper row
- The needle pointing at 0.92

The reading at 0.092 μSv/h

For example, when the calibration constant is 0.95
Dose = 0.092×0.95 = 0.087 μSv/h

Prepared based on "How to Handle a Survey Meter" on the website of the Prime Minister's Office

A method of measuring γ-ray ambient dose rate using a NaI scintillation survey meter is shown as an example of a method of measuring doses.

Before measurement, the device is checked for soundness (appearance, power supply, high voltage) and then background is measured (set a range at 0.3μSv/h and a time constant at 30 sec). Normally, the background value is around 0.1μSv/h.

Field measurements are normally carried out at a height of about 1 m above the ground. The counting range is adjusted so that the meter readings come near the center of the scale. The time constant is adjusted according to the purpose of measurement. For measurements in a rough, wide range or of high doses, the time constant is lowered. To make accurate measurements or to measure low doses, the time constant is increased. After a period of time about three times the time constant has elapsed since the start of a field measurement, the average of the readings is read (for example, the value is read after the lapse of 90 seconds when the time constant is 30 sec.).

The dose equivalent rate (μSv/h) can be obtained by multiplying the reading by the calibration constant that is preset for each measurement condition.

When using measuring instruments, precautions should be taken such as checking whether they operate properly before use, handling them carefully because they are precision instruments, covering measuring instruments with polyethylene sheets during rain or when making measurements in highly contaminated areas, etc.

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

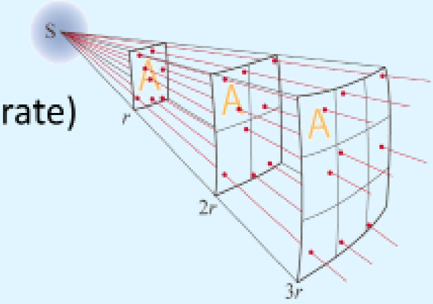
Dose Measurement and Calculation

Characteristics of External Exposure Doses

1) **Distance**: Dose rates are inversely proportional to the distance squared.

$$I = \frac{k}{r^2}$$

I : Radiation intensity (dose rate)
r : Distance
k : Constant



2) **Time**: Doses are proportional to the time of exposure provided the dose rates are the same.
(Total) dose (microsieverts) =
Dose rate (microsieverts/h) × Time

The intensity of radiation (dose rate) is strong (large) when the source of radiation (radiation source) is close, and it gets weaker (smaller) as the distance increases, even if the amount of radioactive materials remains the same. When the radioactive materials are located only in one place (point source), the dose rate becomes smaller in inverse proportion to the distance squared. Dose rates also decrease due to atmospheric influence, etc.

When radioactive materials are evenly distributed on a broad plain surface, the formula to express the relationship between the distance and the dose rate is rather complicated, but as in the case of a point source, the higher it is from the ground surface, the lower the dose rate is. However, radioactive materials are not evenly distributed in reality and a plain surface is not necessarily smooth, and also owing to attenuation of radiation in the air or other reasons, the dose rate does not always match the value obtained from the relational expression.

Calculation of external exposure doses is based not on the radioactivity intensity (becquerels) but on the amount of radiation (grays or sieverts) the human body is exposed to.

If the dose rate is constant, the total exposure dose can be calculated by multiplying the dose rate by the time of exposure to radiation.

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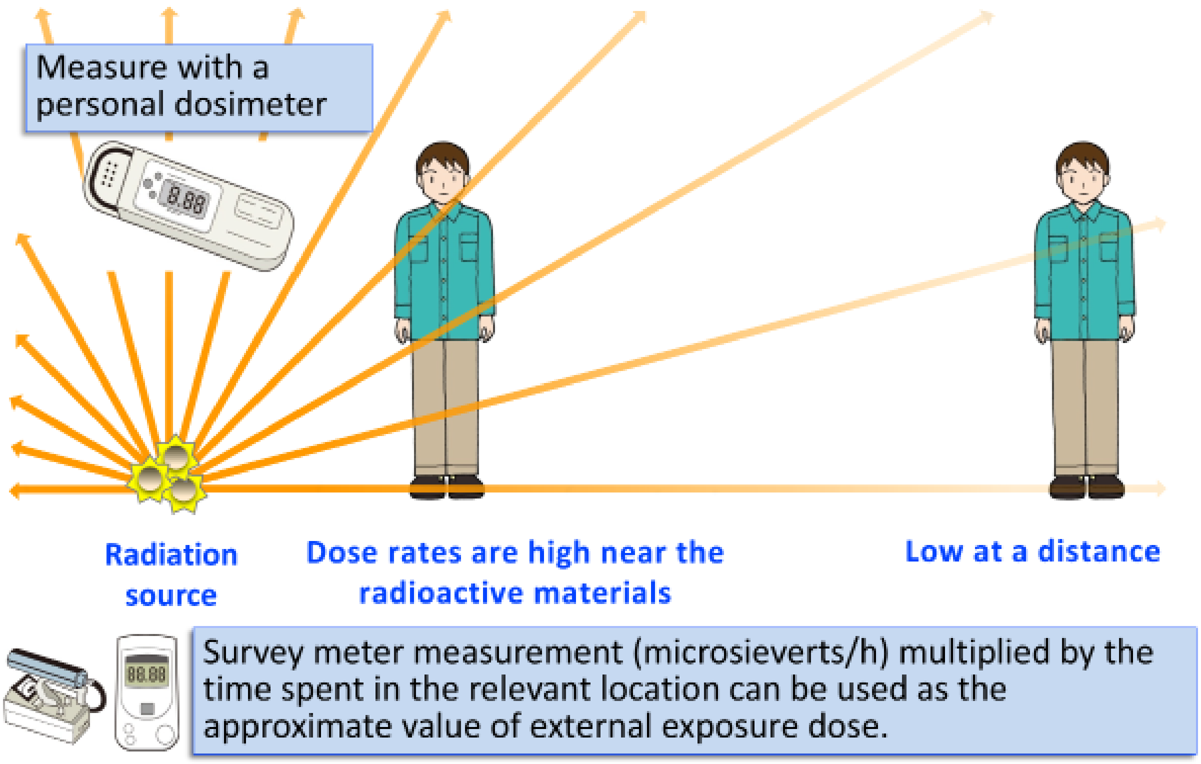
Dose Measurement and Calculation

External Exposure (Measurement)



Measure with a personal dosimeter

Radiation source

Dose rates are high near the radioactive materials

Low at a distance

Survey meter measurement (microsieverts/h) multiplied by the time spent in the relevant location can be used as the approximate value of external exposure dose.

One of the means to measure doses due to external exposure is to wear a personal dosimeter on the body. Personal dosimeters can measure cumulative amounts of radiation exposure for a certain period of time, and provide dose rate readings.

Another means is to measure radiation dose rates in a workplace with a survey meter to estimate the level of exposure supposing that a person stays in that place. Since α (alpha)-particles and β (beta)-particles from outside the body do not reach into the body (p.22 of Vol. 1, “Penetrating Power and Range of Effects on the Human Body”), γ-rays are measured to obtain doses due to external exposure. Many recent instruments provide readings in microsieverts per hour (μSv/h), so such readings are multiplied by the time a person spent in a certain location to roughly calculate his/her external exposure dose. However, these measurements must be made with an instrument, such as a NaI (Tl) scintillation survey meter, that has proper performance and is well calibrated.

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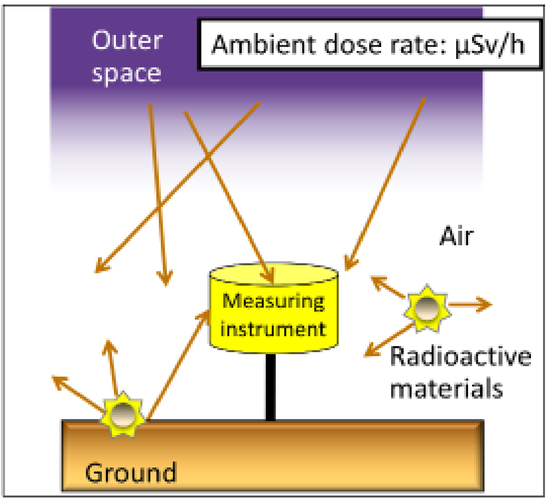
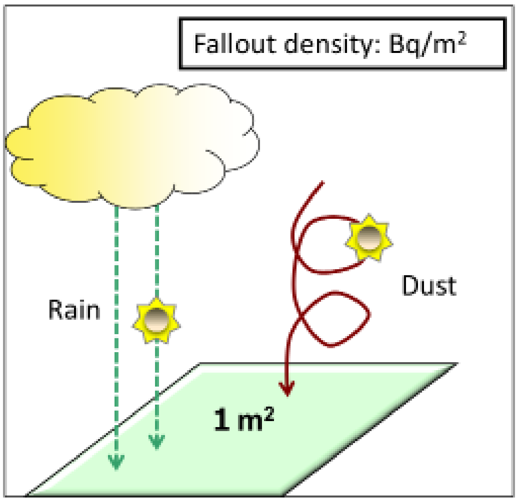
Measurement of Environmental Radiation and Radioactivity

- **Ambient dose rate** shows measured amount of γ-rays in the air.
  Indicated in microsieverts per hour (μSv/h)
- **Fallout density** is the amount of radioactive materials that have deposited (or descended) per unit area in a certain period of time.
  e.g., becquerels per squared meter (Bq/m²)





The ambient dose rate is obtained by measuring γ-ray doses in the air, and is indicated in microsieverts per hour. γ-rays from radioactive materials suspended in the air and γ-rays from radioactive materials fallen on the ground are both detected. The measured value is not limited to the amount of radiation derived from accidents. Major natural radiation is that from the ground and cosmic rays.

Normally, a measuring instrument is placed at a height of about 1 m from the ground, because most important internal organs are located at this height in the case of an adult. There are cases where a measurement instrument is placed at a height of 50 cm from the ground in places where mainly children spend time, such as schools and kindergartens.

The amount of radioactivity in fallout is expressed as the amount of radioactive materials fallen per unit area. Generally, such amount is expressed as a numerical value per day or month for each kind of radioactive material.

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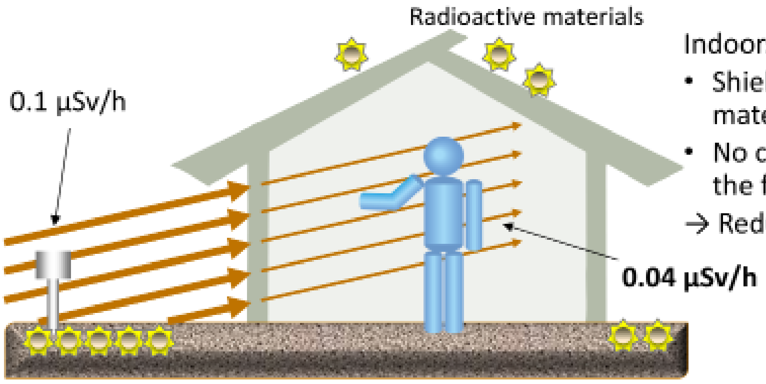
Dose Measurement and Calculation

Shielding and Reduction Coefficient



Indoors
- Shielding by building materials
- No contamination under the floor

→ Reduced dose rate

Location	Reduction coefficient*
Wooden house (one or two stories)	0.4
Block or brick house (one or two stories)	0.2
The first and second floors of a building (three or four stories) with each floor 450-900m² wide	0.05
Upper floors of a building with each floor 900m² or wider	0.01

* The ratio of doses in a building when assuming that a dose outdoors at a sufficient distance from the building is 1

Source: Prepared based on the "Disaster Prevention Countermeasures for Nuclear Facilities, etc." (June 1980 (partly revised in August 2010)), Nuclear Safety Commission

In the absence of an appropriate survey meter for measuring ambient dose rates (p.48 of Vol. 1, "Instruments for Measuring External Exposure"), calculations can be made based on the ambient dose rates that the government or local municipalities issued. For the amount of exposure outdoors, measurement results obtained near the relevant building are used. To calculate doses indoors, the indoor ambient dose rate is estimated by multiplying the value of nearby outdoor dose rate by a reduction coefficient.

Reduction coefficients, which take into consideration the effect of shielding by the building and the fact that there is no contamination under the floor, vary depending on the types of buildings and whether radioactive materials are suspended or deposited. When radioactive materials are deposited on soil or a building, in the case of a wooden house, for example, radiation from outside is blocked and the total amount of radiation indoors is reduced to around 40% of the initial amount outdoors. Houses made of blocks, bricks or reinforced concrete have higher shielding effects and radiation levels inside are lower than in wooden houses.

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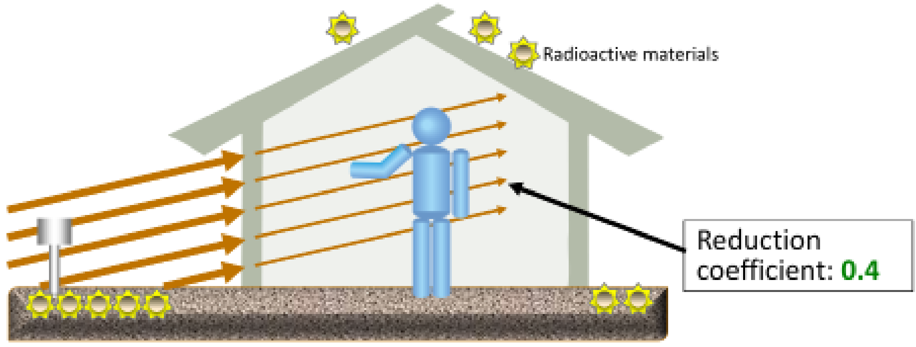
Updated on March 31, 2019

Additional Exposure Doses after an Accident (Example of Calculation)

It is important to subtract values in normal times.

Dose rate (increase due to an accident: µSv/h)
Actual measurement - Value in normal times
= Exposure rate at the time of the accident



Exposure rate at the time of the accident
× Number of hours spent outdoors in a day
+
Exposure rate at the time of the accident × 0.4
× Number of hours spent indoors in a day

Daily exposure dose

× 365 days = Annual additional exposure dose

The ambient dose rate measured with a survey meter includes γ-rays from natural environment. To calculate the amount of radiation released due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS alone, the values measured before the accident (background values) must be subtracted from the currently measured ambient dose rates to ascertain the increase caused by the accident. The values before the accident are available on the website, "Environmental Radioactivity and Radiation in Japan" (https://www.kankyo-hoshano.go.jp/data/database/, in Japanese).

The value obtained by multiplying the increased outdoor and indoor dose rates by the time spent indoors and outdoors is an approximate increase in exposure dose compared with normal times (additional exposure dose).

The calculation example for obtaining a daily additional exposure dose after the accident is made under the assumption that a person stays outdoors for eight hours and stays in a typical Japanese house with a reduction coefficient of 0.4 for 16 hours. Furthermore, an annual additional exposure dose is estimated by multiplying the daily additional exposure dose by 365, the number of days in a year.

The value of 0.23 µSv/h, which was adopted as the reference value in designating Intensive Contamination Survey Areas where mainly municipalities conduct decontamination after the accident, is derived from the annual additional exposure dose of 1 mSv (hourly exposure dose of 0.19 µSv, which becomes 1 mSv in annualized terms under the same assumption on the safe side as applied in the above calculation example, plus the exposure dose due to natural radiation of 0.04 µSv).

This calculation example is a simplified estimation method provided under the conservative assumption in the response to the accident at TEPCO's Fukushima Daiichi NPS. Therefore, it is considered that the actual external exposure dose of an individual in real life may be lower than the calculation result.

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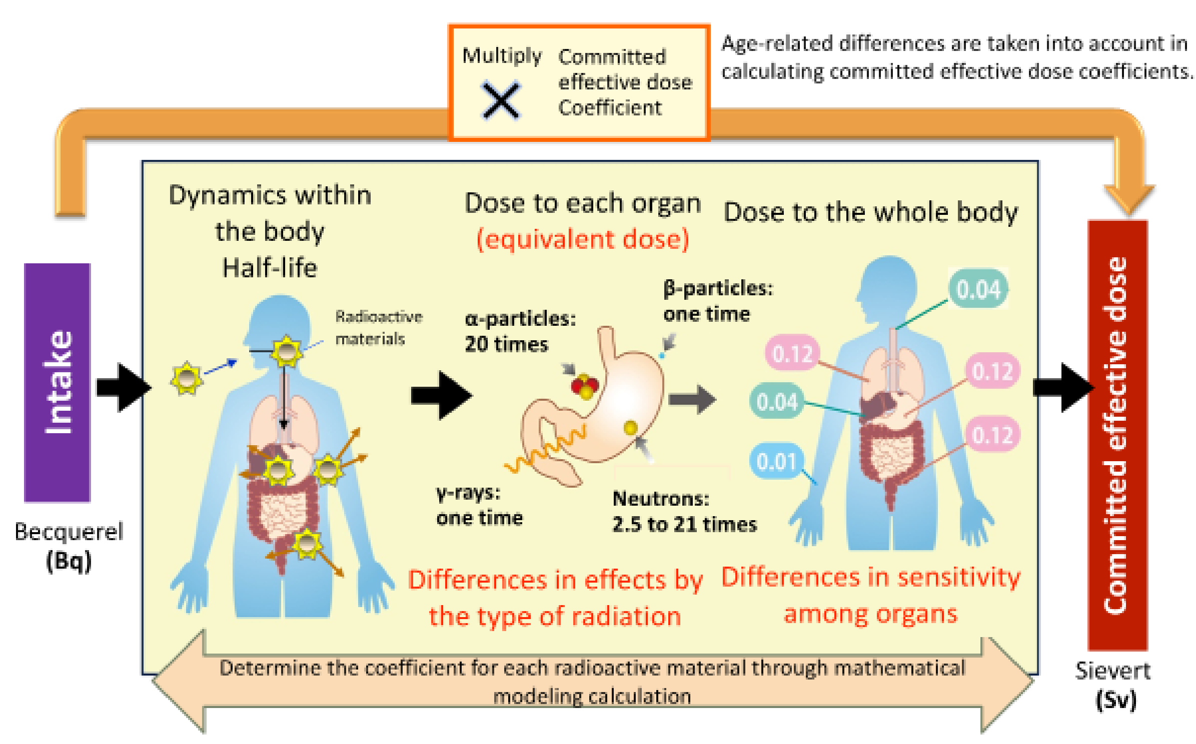
Dose Measurement and Calculation

Calculation of Internal Exposure Doses



Multiply × Committed effective dose Coefficient

Age-related differences are taken into account in calculating committed effective dose coefficients.

Intake

Becquerel (Bq)

Dynamics within the body Half-life

Dose to each organ (equivalent dose)

Dose to the whole body

Differences in effects by the type of radiation

Differences in sensitivity among organs

Committed effective dose

Sievert (Sv)

Determine the coefficient for each radioactive material through mathematical modeling calculation

Methods of obtaining effective doses due to internal exposure are essentially the same as for external exposure. However, how to calculate absorbed doses for respective organs and tissues is different.

The part of the body where radioactive materials accumulate varies by their types. Even the same type of radioactive material differs in the behavior within the body, such as metabolism and accumulation, depending on whether they enter the body via the respiratory organs through inhalation or via the digestive tract together with foods and drinks. Moreover, how long radioactive materials will remain in the body varies depending on whether the person is an adult, a child, or an infant.

Mathematical model calculation is performed for each of these different conditions to determine the relationship between the intake of radioactive materials and the absorbed dose of each organ and tissue. Then, differences in sensitivity by types of radiation and among different organs are taken into account in the same manner as for calculation of external exposure doses. An internal exposure dose calculated in this way is called a committed effective dose (in sieverts) (p.56 of Vol. 1, "Committed Effective Doses").

Specifically, internal exposure doses can be obtained by multiplying intake (in becquerels) by a committed effective dose coefficient. Committed effective dose coefficients are defined in detail for each type of radionuclide and age group (p.57 of Vol. 1, "Conversion Factors to Effective Doses").

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

Dose Measurement and Calculation

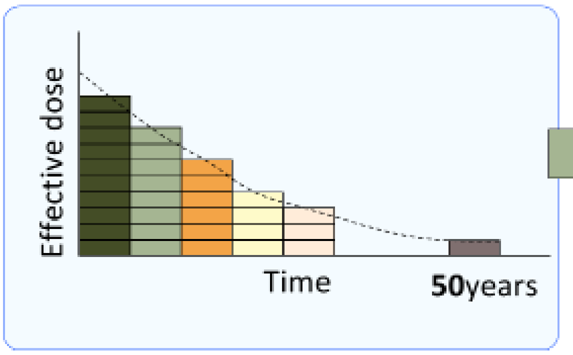
Committed Effective Doses

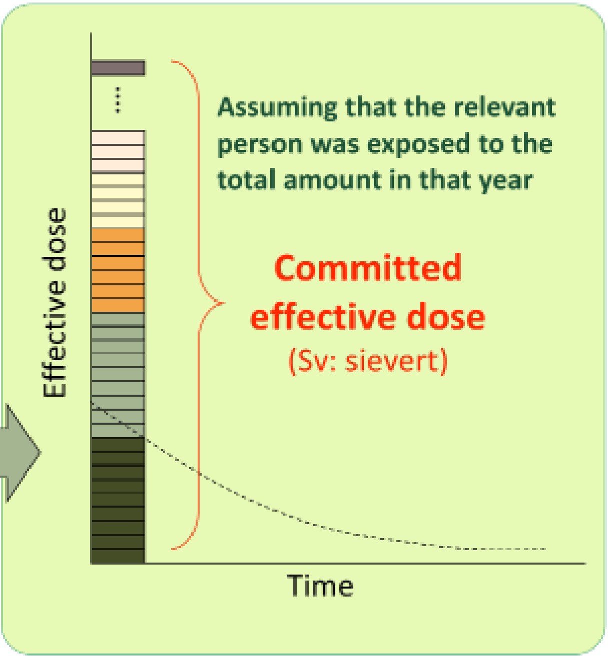
Exposure dose estimating how much radiation a person will be exposed to in lifetime from a single intake of radioactive materials

Calculation of internal exposure

Integrating future doses

- Public (adult): 50 years after intake
- Children: up to age 70 after intake





Radioactive materials remain in the body for a certain period of time after being taken into the body. In the meantime, the body will be continuously exposed to radiation. Thus, the total amount of radiation that a person will be exposed to into the future is calculated as dose due to internal exposure based on a single intake of radioactive materials. This is called a committed dose (in sieverts).

Any radioactive materials taken into the body will decrease over time. One contributing factor is the decay of the radioactive materials. Another is excretion as urine and feces. The rate of excretion from the body varies according to the types of elements, their chemical forms, and the age of the person. With these differences taken into account, the cumulative amount of radiation that the human body will receive in a lifetime from radioactive materials is assumed as the amount received in the year of the intake, and a committed dose is calculated.

In particular, the lifetime cumulative dose based on effective dose is called “committed effective dose.” The lifetime here is 50 years for adults, and for children it is the number of years up to reaching age 70. In the case of radioactive cesium, which is discharged out of the body at a fast rate (Cesium-134 and Cesium-137 have effective half-lives of 64 days and 70 days, respectively) (p.31 of Vol. 1, “Radioactive Materials Derived from Nuclear Accidents”), most of the committed dose is considered to be received within 2 to 3 years after its intake.

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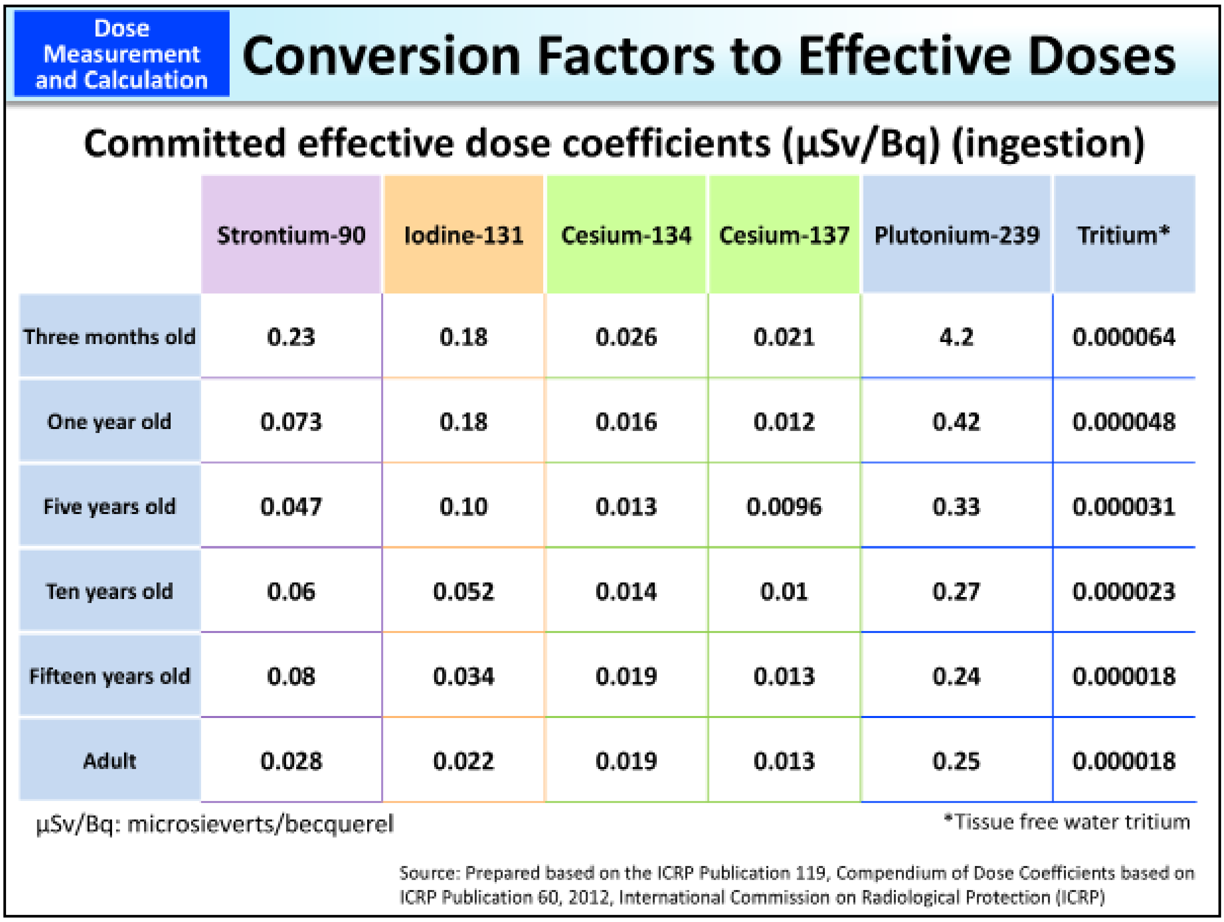

Dose Measurement and Calculation

Conversion Factors to Effective Doses

Committed effective dose coefficients (μSv/Bq) (ingestion)

	Strontium-90	Iodine-131	Cesium-134	Cesium-137	Plutonium-239	Tritium*
Three months old	0.23	0.18	0.026	0.021	4.2	0.000064
One year old	0.073	0.18	0.016	0.012	0.42	0.000048
Five years old	0.047	0.10	0.013	0.0096	0.33	0.000031
Ten years old	0.06	0.052	0.014	0.01	0.27	0.000023
Fifteen years old	0.08	0.034	0.019	0.013	0.24	0.000018
Adult	0.028	0.022	0.019	0.013	0.25	0.000018

μSv/Bq: microsieverts/becquerel

*Tissue free water tritium

Source: Prepared based on the ICRP Publication 119, Compendium of Dose Coefficients based on ICRP Publication 60, 2012, International Commission on Radiological Protection (ICRP)

For dose assessment for internal exposure, doses are calculated by estimating an intake for each nuclide and chemical form and multiplying estimated intakes by dose coefficients. Dose coefficients are committed equivalent doses or committed effective doses for an intake of 1 Bq and a specific value has been given for each nuclide, chemical form, intake route (ingestion or inhalation), and for each age group by the ICRP.

The commitment period, i.e., the period during which doses are accumulated, is 50 years for adults and the number of years up to reaching age 70 after intake for children.

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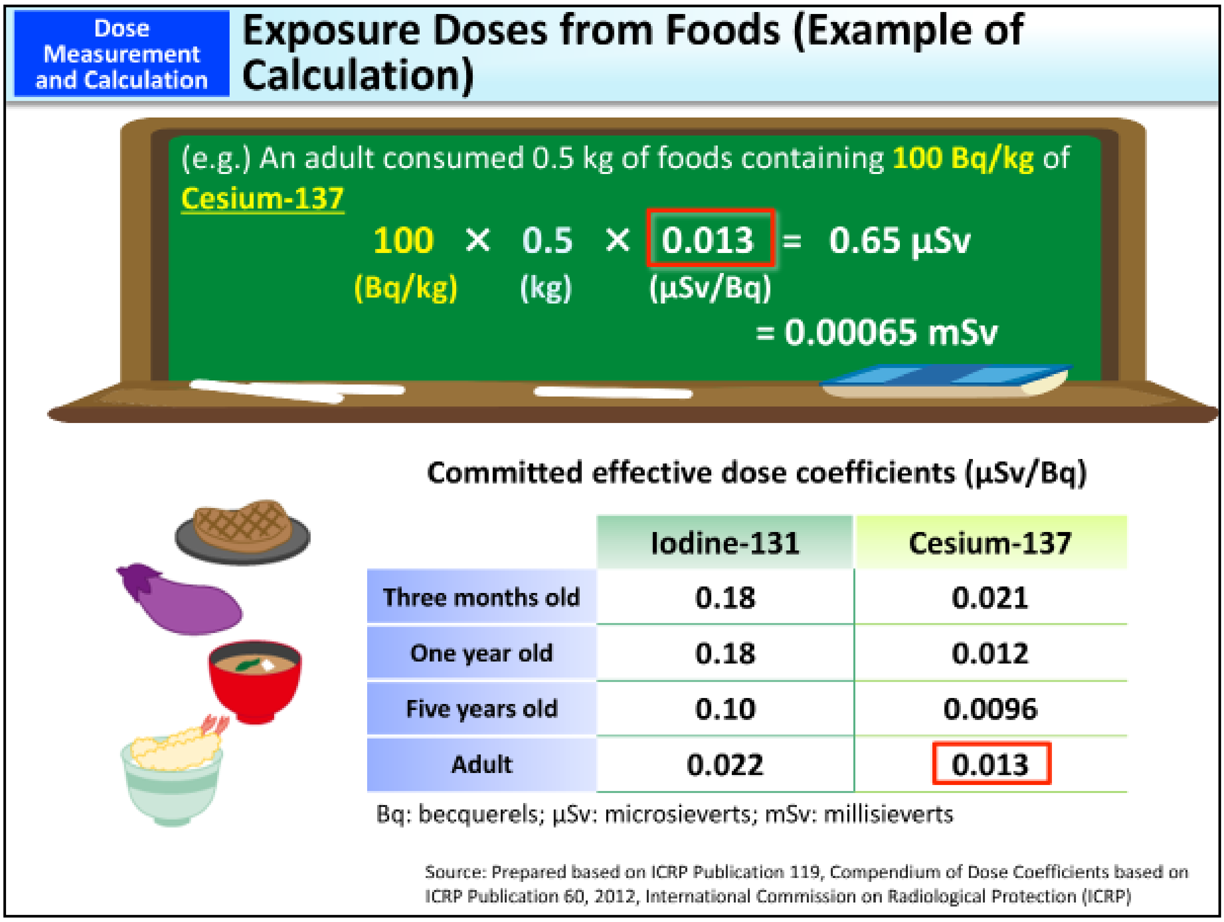

Dose Measurement and Calculation

Exposure Doses from Foods (Example of Calculation)

(e.g.) An adult consumed 0.5 kg of foods containing **100 Bq/kg** of **Cesium-137**

$$\underset{(Bq/kg)}{100} \times \underset{(kg)}{0.5} \times \underset{(\mu Sv/Bq)}{\boxed{0.013}} = 0.65\ \mu Sv$$

$$= 0.00065\ mSv$$

Committed effective dose coefficients (μSv/Bq)

	Iodine-131	Cesium-137
Three months old	0.18	0.021
One year old	0.18	0.012
Five years old	0.10	0.0096
Adult	0.022	0.013

Bq: becquerels; μSv: microsieverts; mSv: millisieverts

Source: Prepared based on ICRP Publication 119, Compendium of Dose Coefficients based on ICRP Publication 60, 2012, International Commission on Radiological Protection (ICRP)

For example, the dose that an adult who consumed foods containing Cesium-137 will receive is calculated here.

Suppose the person has consumed 0.5 kg of foods containing 100 Bq of Cesium-137 per 1 kg.

The amount of Cesium-137 actually consumed is 50 Bq. This value is multiplied by an effective dose coefficient to calculate committed effective dose (p.56 of Vol. 1, “Committed Effective Doses”).

Committed effective dose coefficients are defined in detail for each type of radioactive material, each intake route (inhalation or ingestion), and each age group (p.57 of Vol. 1, “Conversion Factors to Effective Doses”).

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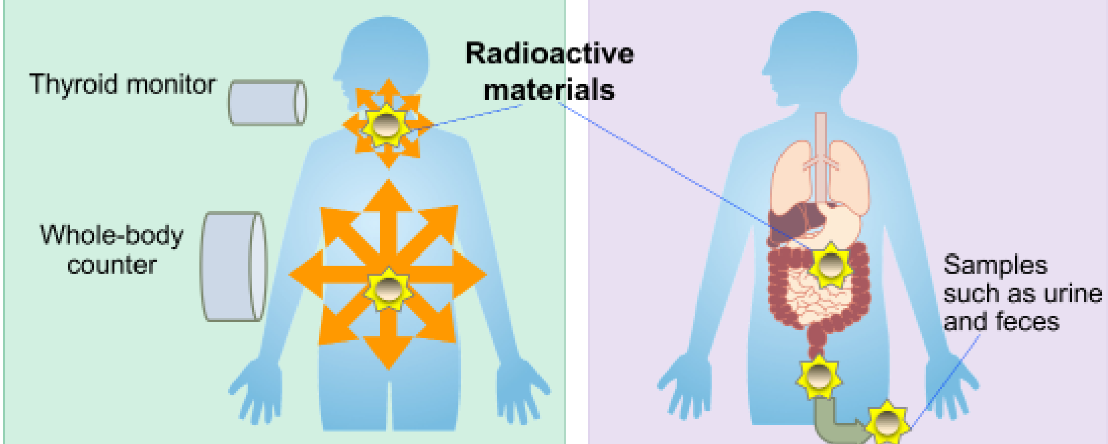
Dose Measurement and Calculation

Measuring Methods for Estimating the Intake of Radioactivity



Direct counting

- Measure radiation from radioactive materials in the body.
- Subjects for direct counting need to set aside time for measurement.
- Materials that emit γ-rays are mainly measured.
- The measuring time is short.
- The accuracy of dose assessment is high.

Bioassay

- Measure radioactive materials contained in excretion.
- Submit samples (urine, feces, etc.).
- All radioactive materials can be measured.
- It takes time to conduct chemical analysis.
- The margin of error in dose assessment results is large.

Direct counting methods that directly measure γ-rays coming from within the body or bioassay methods that measure the amount of radioactive materials in samples such as urine and feces are used to estimate the intake of radioactive materials, which is required for calculating internal exposure doses.

In direct counting, the longer the measuring time, the more accurate values can be obtained. However, external measuring instruments also measure radiation from the environment while measuring radiation from the human body. Therefore, if measurements are carried out in locations at high ambient dose rates, sufficient shielding against environmental radiation is required. These instruments cannot measure radioactive materials that do not emit γ-rays or X-rays.

Bioassays can measure all kinds of radioactive materials but cannot provide accurate numerical values based on a single sampling. Therefore, it is necessary to collect samples for several days (urine, feces, etc.). Given that the amounts of radioactive materials excreted varies depending on individuals, their health conditions and amounts of food consumption, the margin of error is considered to be larger than that by direct counting.

Based on the results obtained using these methods, intake scenario (i.e., such as date of intake, acute or chronic intake, chemical form or particulate size, route of intake etc.) is taken into consideration and mathematical models (p.55 of Vol. 1, “Calculation of Internal Exposure Doses”) are used to calculate the percentages of radioactive materials remaining in the body or excreting into the samples measured to determine the intake of radionuclides. In both methods, if an exposure scenario is not certain, calculation results will have a larger margin of error.

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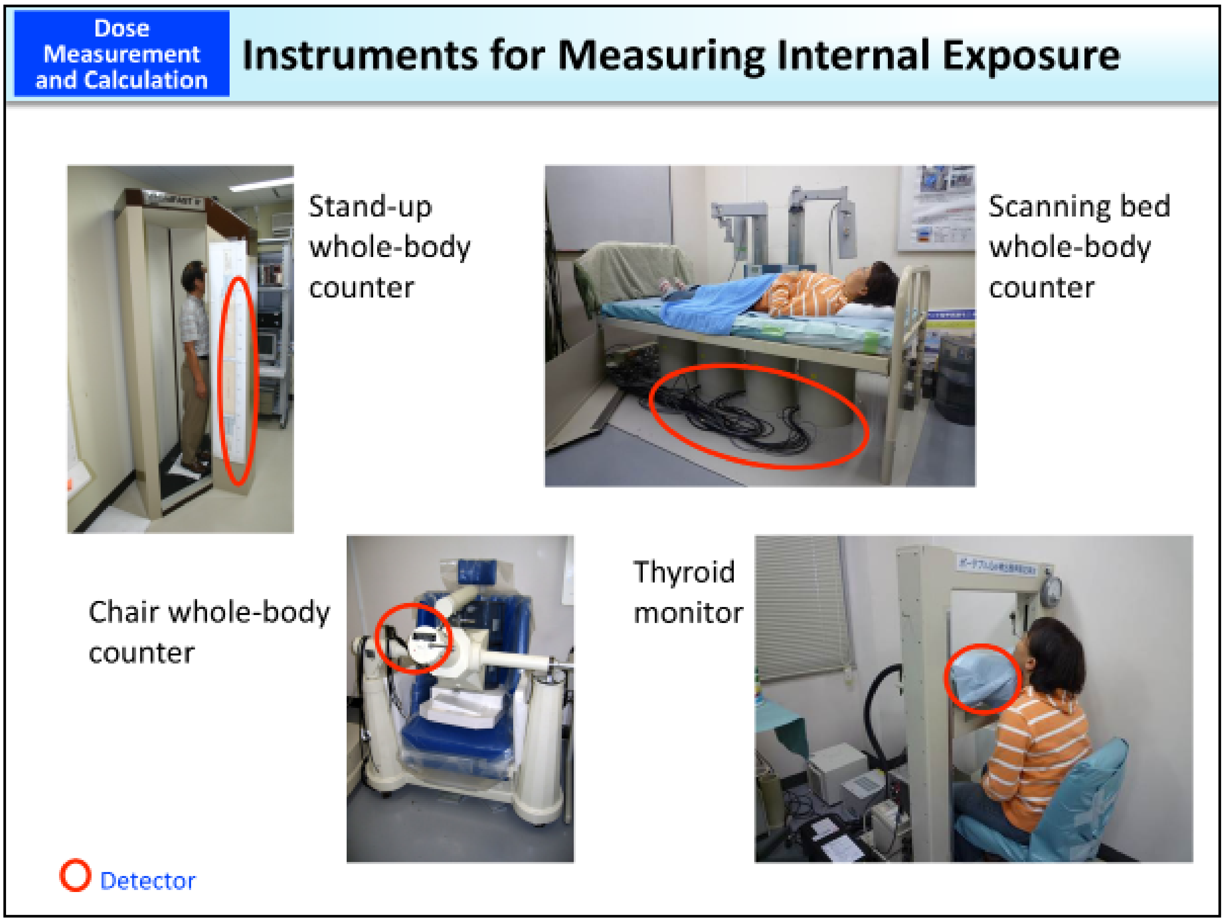

Dose Measurement and Calculation

Instruments for Measuring Internal Exposure

Stand-up whole-body counter

Scanning bed whole-body counter

Chair whole-body counter

Thyroid monitor

○ Detector

An instrument for measuring γ-rays emitted from the whole body, called a whole-body counter, is used to directly measure internal radioactivity. Whole-body counters have several types, including a stand-up type, bed type, and chair type.

Since radioactive cesium is distributed throughout the body, a whole-body counter is used to measure its amount within the body. If internal exposure by radioactive iodine is suspected, a thyroid monitor is used, as iodine accumulates in the thyroid (p.127 of Vol. 1, “Thyroid”). A radiation detector is applied to the part of the neck where the thyroid gland is situated to measure γ-rays emitted from there.

The time required for measurement is 1 to 5 minutes for simplified whole-body counters, 10 to 30 minutes for precision whole-body counters, and 2 to 5 minutes for thyroid monitors. (Related to p.172 of Vol. 2, “Internal Exposure Measurement Using a Whole-body Counter”)

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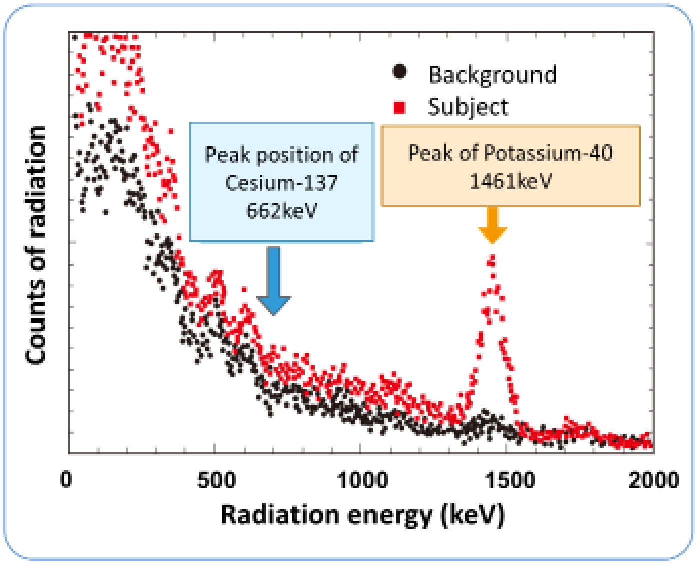
Dose Measurement and Calculation

Data on Internal Exposure Measured by Direct Counting

Whole-body counter



Measure radiation emitted from within the body ⇒ Measure internal radioactivity for each radioactive material

The amount of potassium in the body is around 2 g per 1 kg of body weight, and approx. 0.01% of that amount is radioactive potassium (Potassium-40)

keV: kilo electron volts

Radioactivity of each nuclide can be quantitatively assessed by measuring radiation emitted from within the body using a whole-body counter.

The black round dots in the graph represent values measured while no one is on the bed (background state). When the subject is on the bed, radiation peaks appear, as indicated by the red square dots. The energy of γ-rays is unique for each radioisotope. For example, radioactive potassium, K-40, emits γ-rays with energy of 1,461 keV. Therefore, if such amount of energy is detected, this reveals the existence of K-40 within the body. The gamma-ray energy of Cesium-137 is 662 keV.

While potassium is an element essential to life, approx. 0.01% of all potassium is radioactive. Radioactive potassium is mainly contained in water in cells and is present in muscles but is seldom present in fat cells that contain little water (p.8 of Vol. 1, “Naturally Occurring or Artificial”).

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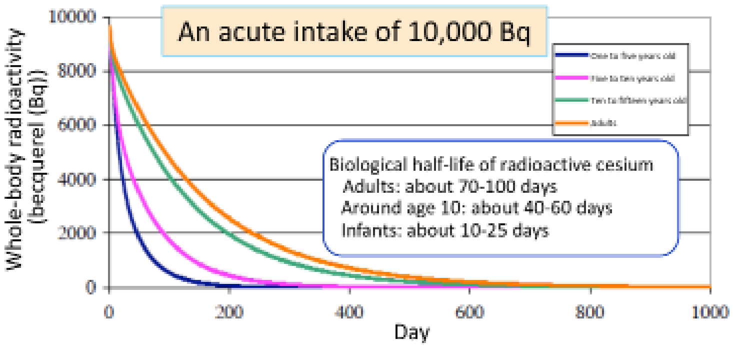
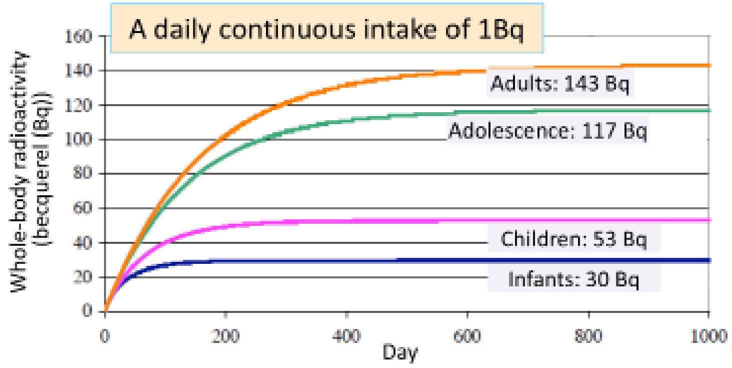
Dose Measurement and Calculation

Radioactivity in the Body and Dose Assessment



The younger a person is, the faster the metabolism.
↓
Estimation of initial exposure
- will be effective for no longer than around a year even for adults.
- will be effective for up to around half a year for children.



The younger a person is, the smaller the amount of radioactive materials remaining in the body.
↓
In estimating additional exposure through ingestion,
- significant values are unlikely to be obtained in children.
- it is more reasonable to examine adults in order to detect trace intake.

Source: Prepared based on a material released for the Japan Society of Radiation Safety Management Symposium in Miyazaki (June 29, 2012)

Whole-body counters (WBCs) can measure the radioactivity content in a body on the day of measurement. Similar to other radiation measuring devices, WBCs have a detection limit depending on their performance and counting time.

Given that radioactive cesium has a biological half-life of 70-100 days for adults (p.11 of Vol. 1, “Half-lives and Radioactive Decay”), around one year after the accident would be the time limit for estimation of the initial body burden (in the case of a single intake event at the beginning). As shown in the upper figure, the radioactivity of cesium incorporated into the body decreases in around a year to nearly zero, namely the level before the intake. Subsequent whole-body counting is performed for the purpose of estimating chronic exposure, mainly from foods (p.61 of Vol. 1, “Data on Internal Exposure Measured by Direct Counting”).

In contrast, whole-body counting for children is likely to yield values lower than the detection limit because trace amounts of the initial intake can be observed for a period of about half a year, and the residual radioactivity accumulated in the body by chronic intake is also minimal in children. In such cases, it would be more reasonable to examine adults and estimate their internal doses in terms of understanding the internal exposure situation in details, taking into account the fact that the committed effective dose coefficients are similar for both children and adults, despite the notable difference in their metabolism rates.

In order to estimate the committed effective dose from the measurement result for the radioactivity in the body, it is necessary to use an appropriate intake scenario and an appropriate model aligned with the exposure circumstances, such as acute or chronic intake, inhalation or ingestion as a dominant route of intake, the time when the intake started, and so on.

Regarding radionuclides with short effective half-lives, such as I-131, the radioactivity in the body diminishes rapidly, making it difficult to detect such radionuclides as time progresses. Additionally, pure beta-emitters lacking γ-ray emission, such as Sr-90, also cannot be detected by a whole-body counter (WBC).

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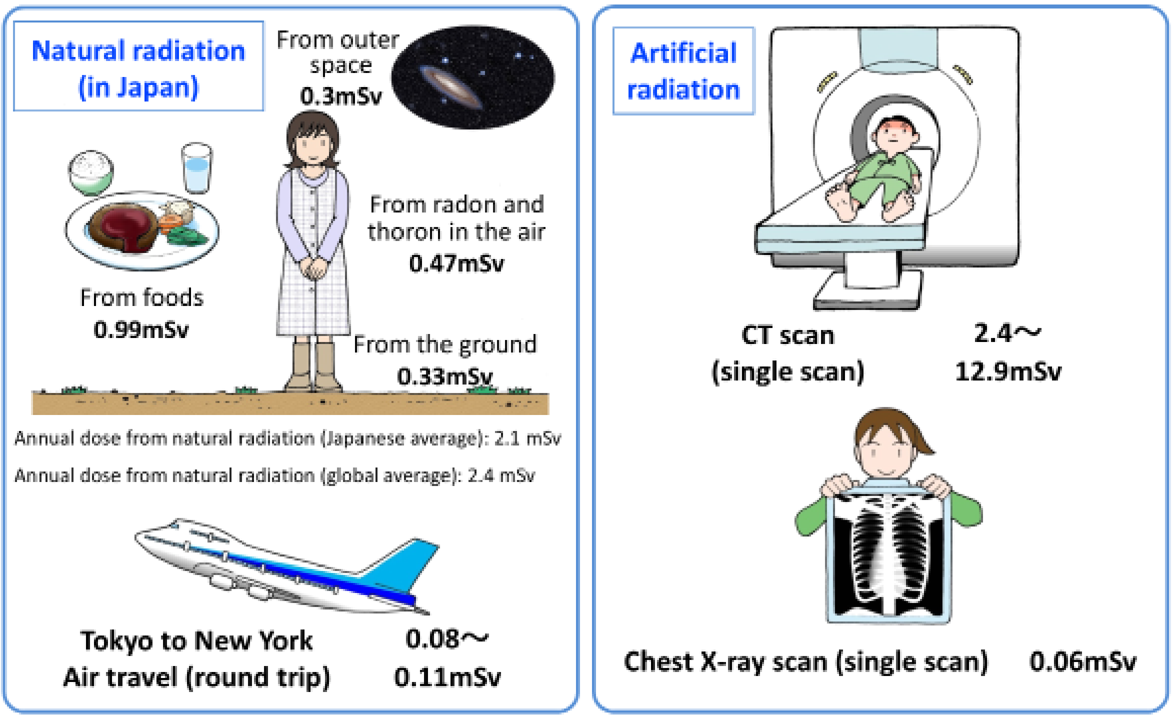
Radiation around Us

Exposure Dose from Natural and Artificial Radiation



mSv: millisieverts

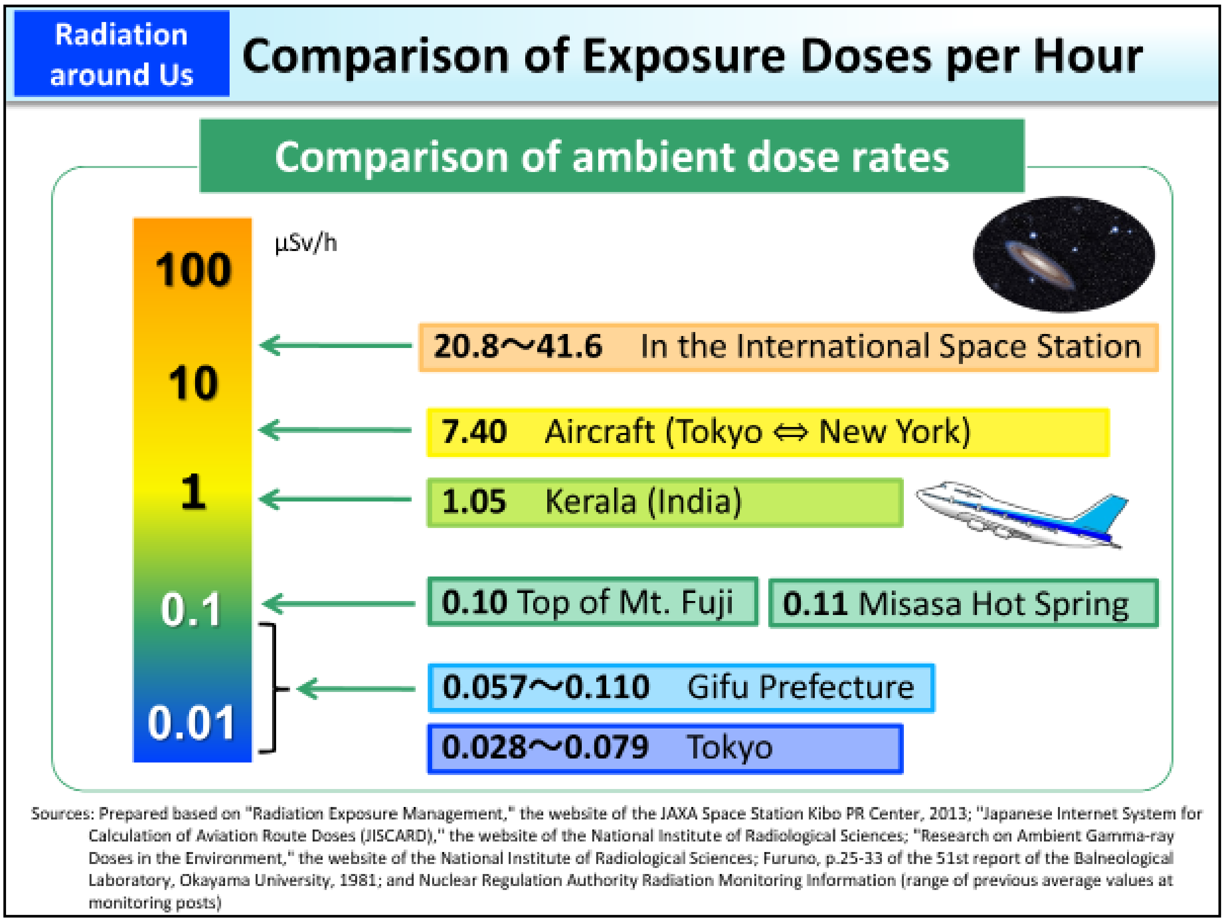
Sources: Prepared based on the 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report; "Environmental Radiation in Daily Life (Calculation of National Doses), ver. 3" (2020), Nuclear Safety Research Association; and ICRP (International Commission on Radiological Protection) 103, etc.

Radiation exists around us and we are exposed to it in our daily lives without realizing. It is impossible to completely avoid radiation exposure in our daily lives.

External exposure to natural radiation from outer space and the ground, and internal exposure to naturally occurring radioactive materials, such as those in foods and radon in the air, amount to a global average of 2.4 mSv and a Japanese average of 2.1 mSv annually (p.65 of Vol. 1, "Comparison of Exposure Doses per Year").

The percentage of medical exposure from radiological examinations is known to be high in Japan. The annual average medical exposure in Japan is estimated to be 2.6 mSv. This is considered due to the fact that an environment to ensure easy access to healthcare has been developed under the universal health insurance system and that CT scans, which involve high-dose exposure per examination, are quite common and upper gastro intestinal (UGI) examination is generally utilized for stomach cancer screening in Japan. In 2015, the diagnostic reference levels for medical exposure were established (revised in 2020), and efforts for optimizing medical exposure are now being made (p.76 of Vol. 1, "Radiation Doses from Medical Diagnosis").

Included in this reference material on March 31, 2013
Updated on March 31, 2022



Radiation around Us

Comparison of Exposure Doses per Hour

Comparison of ambient dose rates

20.8〜41.6 In the International Space Station

7.40 Aircraft (Tokyo ⇔ New York)

1.05 Kerala (India)

0.10 Top of Mt. Fuji

0.11 Misasa Hot Spring

0.057〜0.110 Gifu Prefecture

0.028〜0.079 Tokyo

Sources: Prepared based on "Radiation Exposure Management," the website of the JAXA Space Station Kibo PR Center, 2013; "Japanese Internet System for Calculation of Aviation Route Doses (JISCARD)," the website of the National Institute of Radiological Sciences; "Research on Ambient Gamma-ray Doses in the Environment," the website of the National Institute of Radiological Sciences; Furuno, p.25-33 of the 51st report of the Balneological Laboratory, Okayama University, 1981; and Nuclear Regulation Authority Radiation Monitoring Information (range of previous average values at monitoring posts)

In outer space and aircraft, ambient dose rates are higher because of cosmic rays from galaxies and the Sun. Ambient dose rates are also high at high altitudes such as the top of Mt. Fuji, compared to low altitudes, because the influence of cosmic rays is stronger. At low altitudes, cosmic rays (radiation) interact with oxygen and nitrogen atoms in the atmosphere and thereby lose energy, resulting in reduced amounts of radiation reaching the ground. Accordingly, ambient dose rates become lower.

Ambient dose rates in most living spaces are in the range of 0.01 to 1 µSv/h, but there are areas where the level of natural radiation is high because soil there contains large amounts of radioactive materials, such as radium and thorium. Such areas are called high natural radiation areas (p.67 of Vol. 1, “Ground Radiation (World)”).

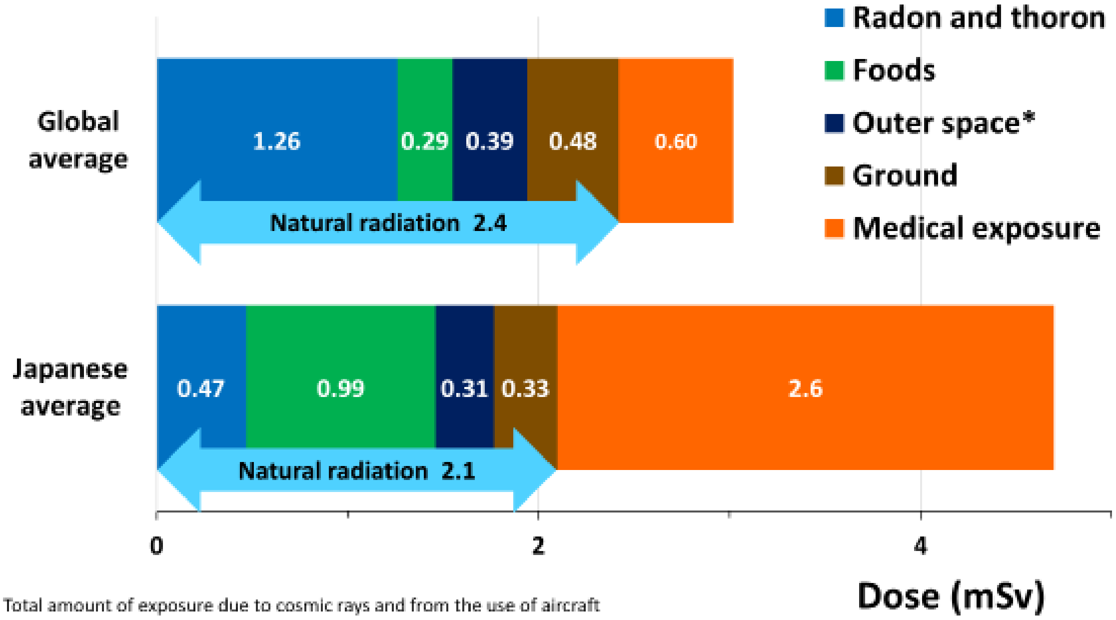
While there is no high natural radiation area in Japan, ambient dose rates are slightly higher in places where soil contains a lot of radium, such as Misasa Onsen Hot Springs, which is famous for radon hot springs (p.68 of Vol. 1, “Ground Radiation (Japan)”).

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

Radiation around Us

Comparison of Exposure Doses per Year

Exposure in daily life (annual)



* Total amount of exposure due to cosmic rays and from the use of aircraft

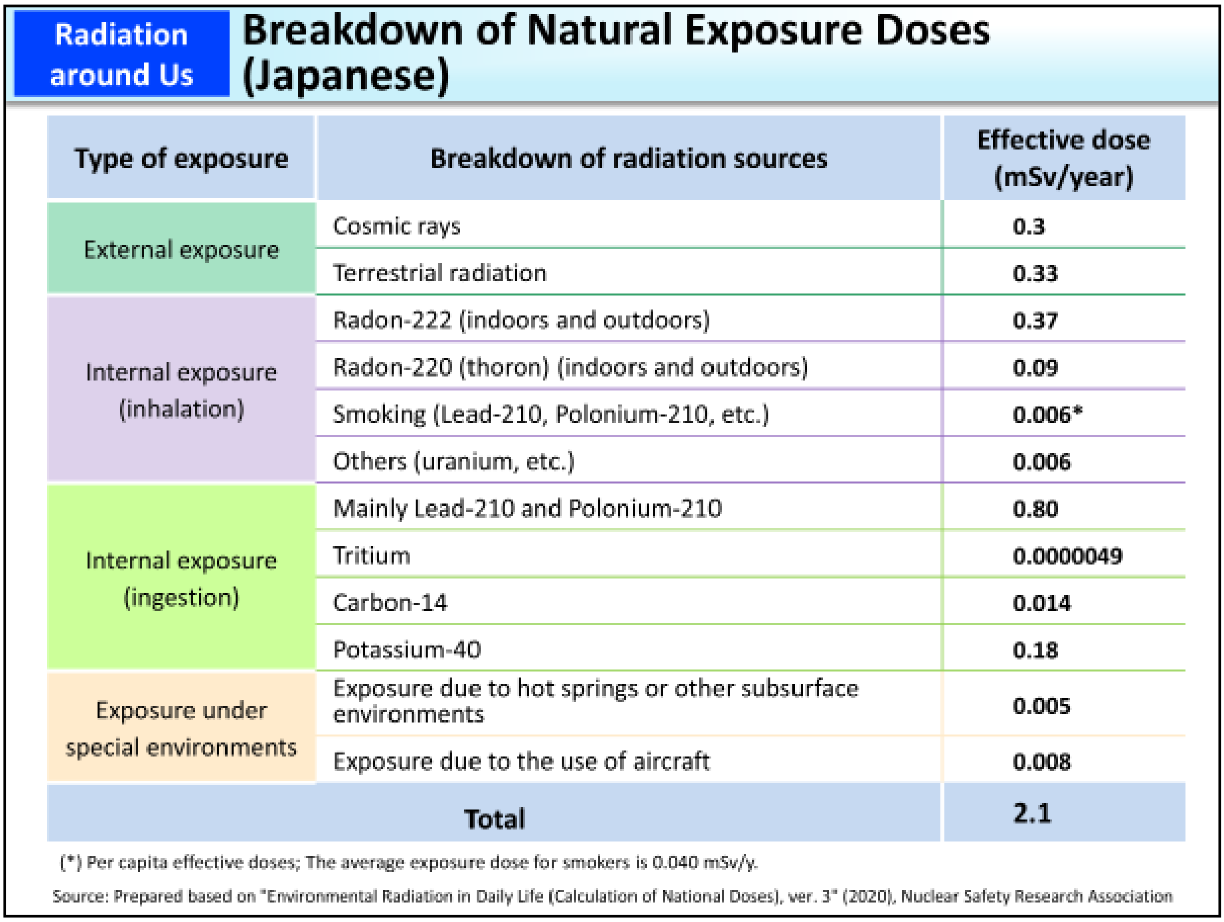
Sources: Prepared based on the 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report; and "Environmental Radiation in Daily Life (Calculation of National Doses), ver. 3" (2020), Nuclear Safety Research Association

In November 2020, the Nuclear Safety Research Association of Japan published “Environmental Radiation in Daily Life (Calculation of the National Doses) ver. 3” and announced Japan’s national doses therein. The survey shows that the annual average dose of Japanese people is 4.7 mSv, of which 2.1 mSv are estimated to be caused by exposure to natural radiation.

Comparison with the global average shows that Japanese people’s exposures to Radon-222 and Radon-220 (thoron) are relatively low while exposures from foods are relatively high. The Japanese people’s exposure due to Lead-210 and Polonium-210 in foods amounts to 0.80 mSv, which is high compared to the global average, probably due to Japanese people’s high consumption of fish and seafood (p.66 of Vol. 1, “Breakdown of Natural Exposure Doses (Japanese)”). Incidentally, analyses of Lead-210 and Polonium-210 in foods have rarely been conducted so often in foreign countries as in Japan and this is considered to be one of the factors of higher exposures to Lead-210 and Polonium-210 among Japanese compared with the global average.

The annual average medical exposure in Japan is estimated to be 2.6 mSv. As a result of the estimation based on the latest information, it was found that the annual average decreased significantly from 3.87 mSv stated in “Environmental Radiation in Daily Life (Calculation of the National Doses) ver. 2,” which was published in 2011. While exposure doses from radiological examinations vary widely among individuals, Japanese people’s exposure doses are known to be significantly high on average. In particular, the widespread use of CT scans is a major contributing factor. As criteria for determining the appropriateness of medical exposure, it is recommended to use the diagnostic reference levels. The diagnostic reference levels have also been published in Japan (p.76 of Vol. 1, “Radiation Doses from Medical Diagnosis”).

Included in this reference material on March 31, 2013
Updated on March 31, 2022



Radiation around Us

Breakdown of Natural Exposure Doses (Japanese)

Type of exposure	Breakdown of radiation sources	Effective dose (mSv/year)
External exposure	Cosmic rays	0.3
	Terrestrial radiation	0.33
Internal exposure (inhalation)	Radon-222 (indoors and outdoors)	0.37
	Radon-220 (thoron) (indoors and outdoors)	0.09
	Smoking (Lead-210, Polonium-210, etc.)	0.006*
	Others (uranium, etc.)	0.006
Internal exposure (ingestion)	Mainly Lead-210 and Polonium-210	0.80
	Tritium	0.0000049
	Carbon-14	0.014
	Potassium-40	0.18
Exposure under special environments	Exposure due to hot springs or other subsurface environments	0.005
	Exposure due to the use of aircraft	0.008
Total		2.1

(*) Per capita effective doses; The average exposure dose for smokers is 0.040 mSv/y.

Source: Prepared based on "Environmental Radiation in Daily Life (Calculation of National Doses), ver. 3" (2020), Nuclear Safety Research Association

This table shows that the intake of Lead-210 and Polonium-210 through ingestion accounts for a significant portion of Japanese people's internal exposures. Lead-210 and Polonium-210 are created when Radon-222 in the air goes through the following process. They are deposited on the ground or settled in rivers and oceans and are taken into the human body through foods.

Radon-222 (half-life of approx. 3.8 days) → Polonium-218 (half-life of approx. 3 minutes) → Lead-214 (half-life of approx. 27 minutes) → Bismuth-214 (half-life of approx. 20 minutes) → Polonium-214 (half-life of approx. 1.6×10^{-4} sec.) → Lead-210 (half-life of approx. 22 years) → Bismuth-210 (half-life of approx. 5 days) → Polonium-210 (half-life of approx. 138 days)

One reason why Japanese people's exposure doses from foods are higher compared to Western countries is that their diets contain lots of fish, which is abundant in Polonium-210. This accounts for Japanese people's large effective doses. Incidentally, analyses of Lead-210 and Polonium-210 in foods have rarely been conducted so often in foreign countries as in Japan and this is considered to be one of the factors of higher exposures to Lead-210 and Polonium-210 among the Japanese population when compared to the global average.

On the other hand, exposure to Radon is smaller among Japanese people, and this is considered to be due to the fact that the concentrations of Uranium-238, which generates Radon-222 through decay, are generally low in soil in Japan and that traditional Japanese houses are well ventilated and Radon-222 that seeps indoors from the ground is quickly diffused outside.

Internal exposure to Radon-222 and Radon-220 (thoron) through inhalation will be explained in “Internal Exposure to Radon and Thoron through Inhalation” on p.71 of Vol. 1.

Tritium has smaller effects on the human body compared with other nuclides, and the exposure doses due to natural tritium are relatively small (p.57 of Vol. 1, “Conversion Factors to Effective Doses”).

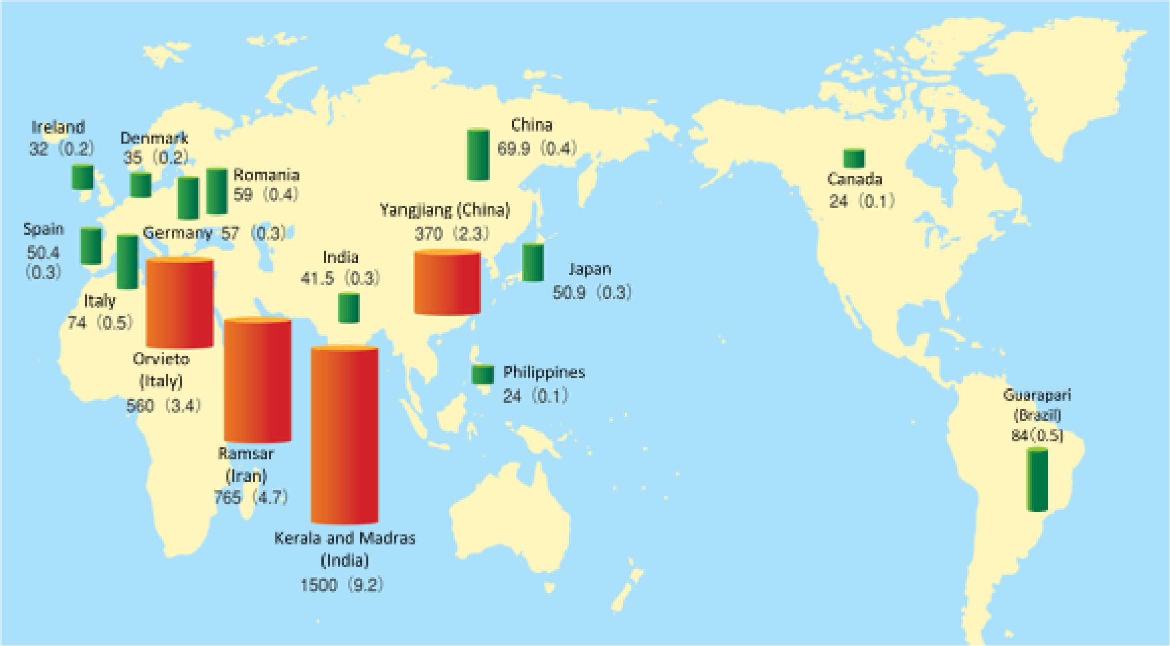
Included in this reference material on March 31, 2013
Updated on March 31, 2023

Radiation around Us

Ground Radiation (World)

Nanograys/h (mSv/y)

0.7 Sv/gray is used in conversion to effective doses.



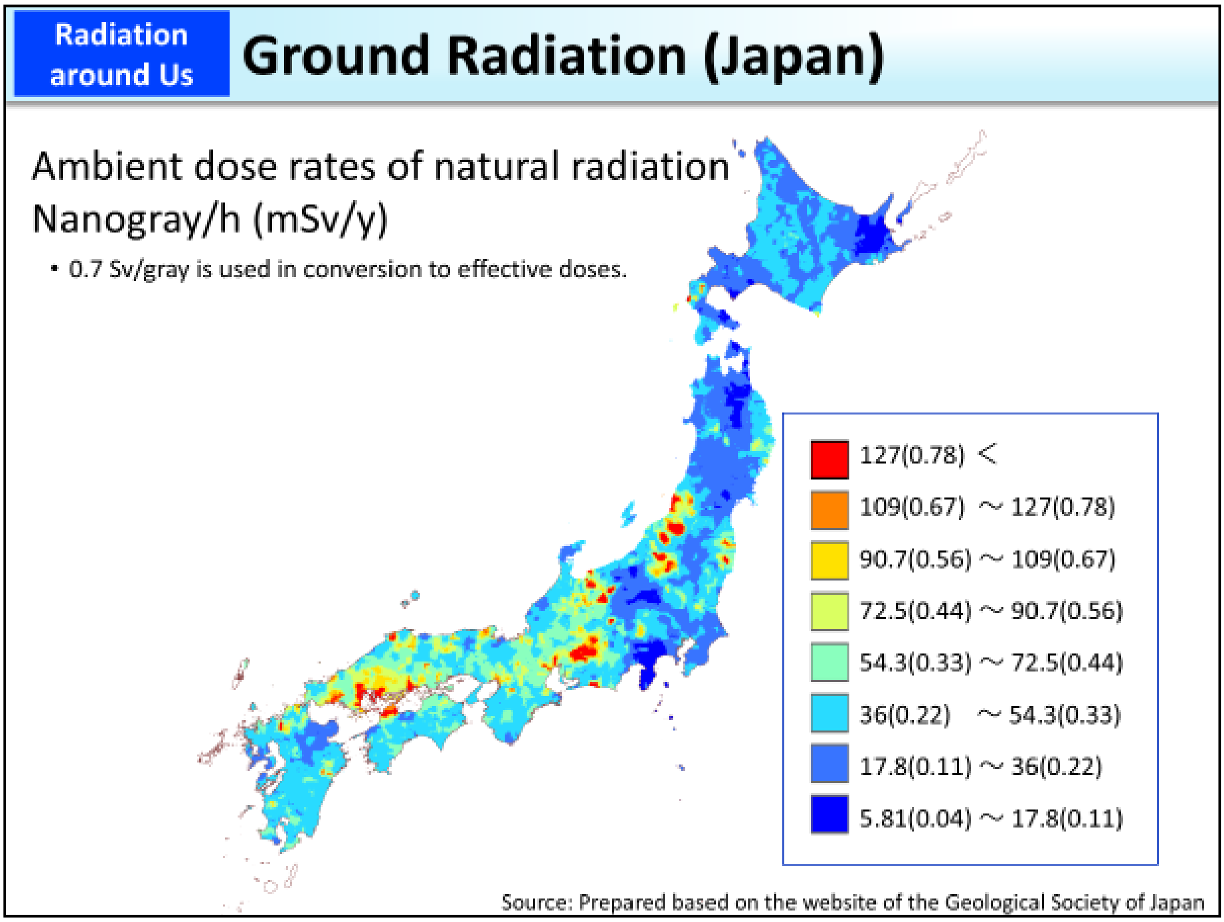
Sources: Prepared based on the 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report; and "Environmental Radiation in Daily Life (Calculation of National Doses), ver. 3" (2020), Nuclear Safety Research Association

There are regions around the world where natural radiation is 7 to 30 times higher than in Japan, such as Yangjiang in China, Kerala in India, and Ramsar in Iran. The high levels of natural radiation in these regions are due to the fact that soil there is rich in radioactive materials such as radium, thorium and uranium.

It has been reported that in Guarapari in Brazil, which was previously well-known as a high natural radiation area, ambient dose rates have reduced as a result of asphalt paving for urbanization.

Based on epidemiological studies in China and India, no significant increases in cancer deaths and incidence rates have been reported so far in these regions (p.124 of Vol. 1, “Effects of Long-Term Low-Dose Exposure”). In Ramsar, analysis on cancer risks is underway.

Included in this reference material on March 31, 2013
Updated on March 31, 2022



Radiation around Us

Ground Radiation (Japan)

Ambient dose rates of natural radiation
Nanogray/h (mSv/y)

- 0.7 Sv/gray is used in conversion to effective doses.

🟥 127(0.78) <
🟧 109(0.67) ~ 127(0.78)
🟨 90.7(0.56) ~ 109(0.67)
🟩 72.5(0.44) ~ 90.7(0.56)
🟩 54.3(0.33) ~ 72.5(0.44)
🟦 36(0.22) ~ 54.3(0.33)
🟦 17.8(0.11) ~ 36(0.22)
🟦 5.81(0.04) ~ 17.8(0.11)

Source: Prepared based on the website of the Geological Society of Japan

In Japan, like everywhere else, the amount of ground radiation varies from area to area. Comparison of ambient dose rates among different prefectures shows that there is a difference of 0.4 mSv per year between Gifu, where the ambient dose rates are highest, and Kanagawa, where the values are lowest.

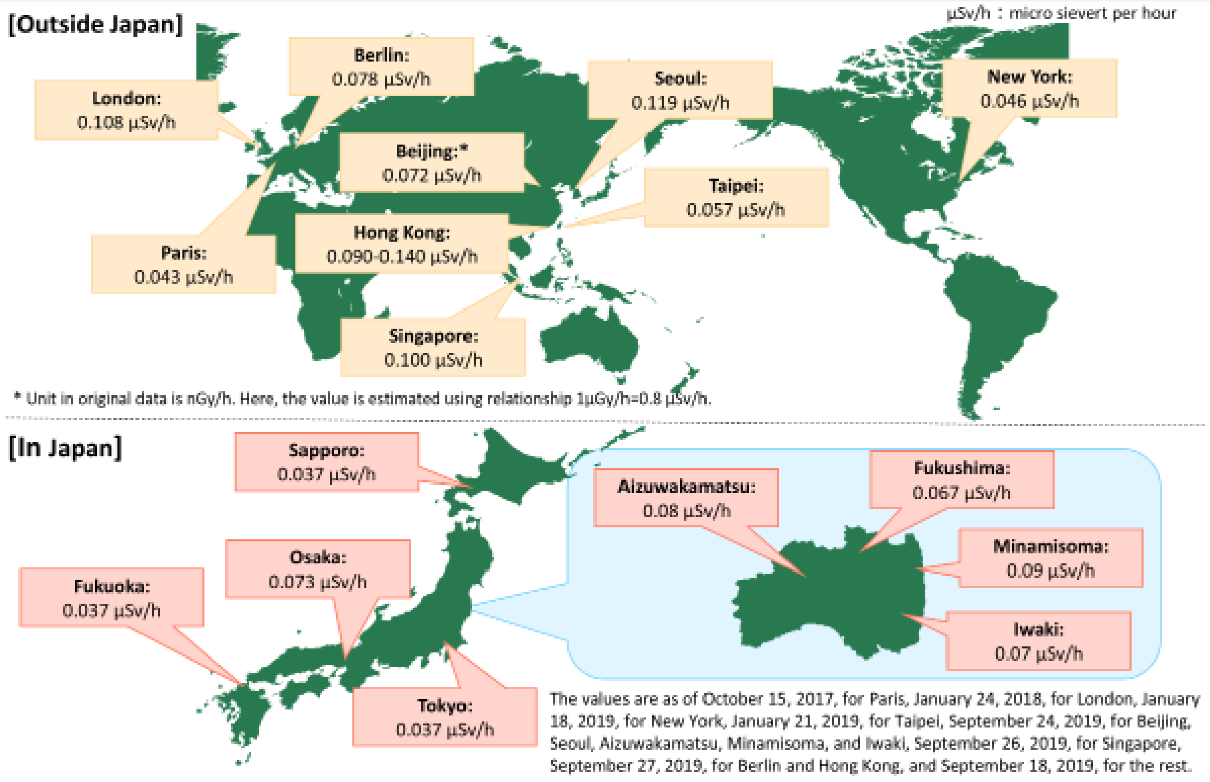
In the Kanto Plain, where a fewer types of radionuclides are contained in the ground, the amount of radiation from the ground is generally less. In western Japan, where granite is directly exposed to the ground in many places, the amount of radiation from the ground tends to be about 1.5 times higher than in eastern Japan because granite is relatively rich in radionuclides such as uranium, thorium and potassium.
(Related to p.8 of Vol. 1, “Naturally Occurring or Artificial”)

Included in this reference material on March 31, 2013
Updated on March 31, 2022

Radiation around Us

Results of the Measurements of Ambient Dose Rates in Major Cities

μSv/h : micro sievert per hour



* Unit in original data is nGy/h. Here, the value is estimated using relationship 1μGy/h=0.8 μSv/h.

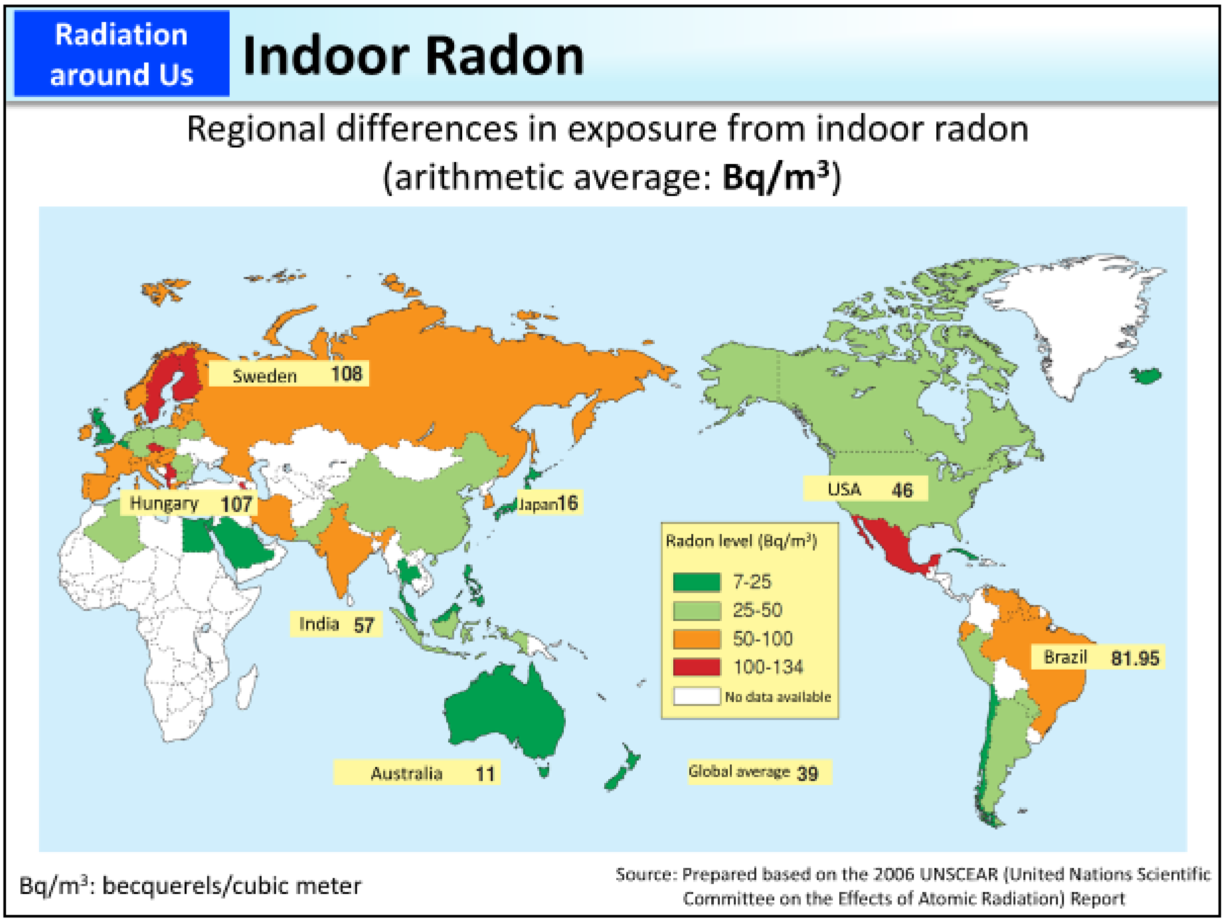
The values are as of October 15, 2017, for Paris, January 24, 2018, for London, January 18, 2019, for New York, January 21, 2019, for Taipei, September 24, 2019, for Beijing, Seoul, Aizuwakamatsu, Minamisoma, and Iwaki, September 26, 2019, for Singapore, September 27, 2019, for Berlin and Hong Kong, and September 18, 2019, for the rest.

Source: Prepared based on data by the Japan National Tourism Organization (https://www.japan.travel/es/news/post-2011-3-11-general-information/; as of December 2023)

These figures show the results of the measurements of ambient dose rates at major cities in and outside Japan. Radiation doses shown in the figures are mostly from 0.03 μSv/h to 0.14 μSv/h, which reveals that radiation doses vary by region. This is mainly because radiation doses from the earth differ due to differences in soil and rocks in respective regions.

Ambient dose rates in four cities in Fukushima Prefecture decreased significantly over time after Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident and have become almost the same as those in other major cities in and outside Japan.

Included in this reference material on March 31, 2019
Updated on March 31, 2024



Radiation around Us

Indoor Radon

Regional differences in exposure from indoor radon
(arithmetic average: **Bq/m^3**)

Bq/m^3: becquerels/cubic meter

Source: Prepared based on the 2006 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report

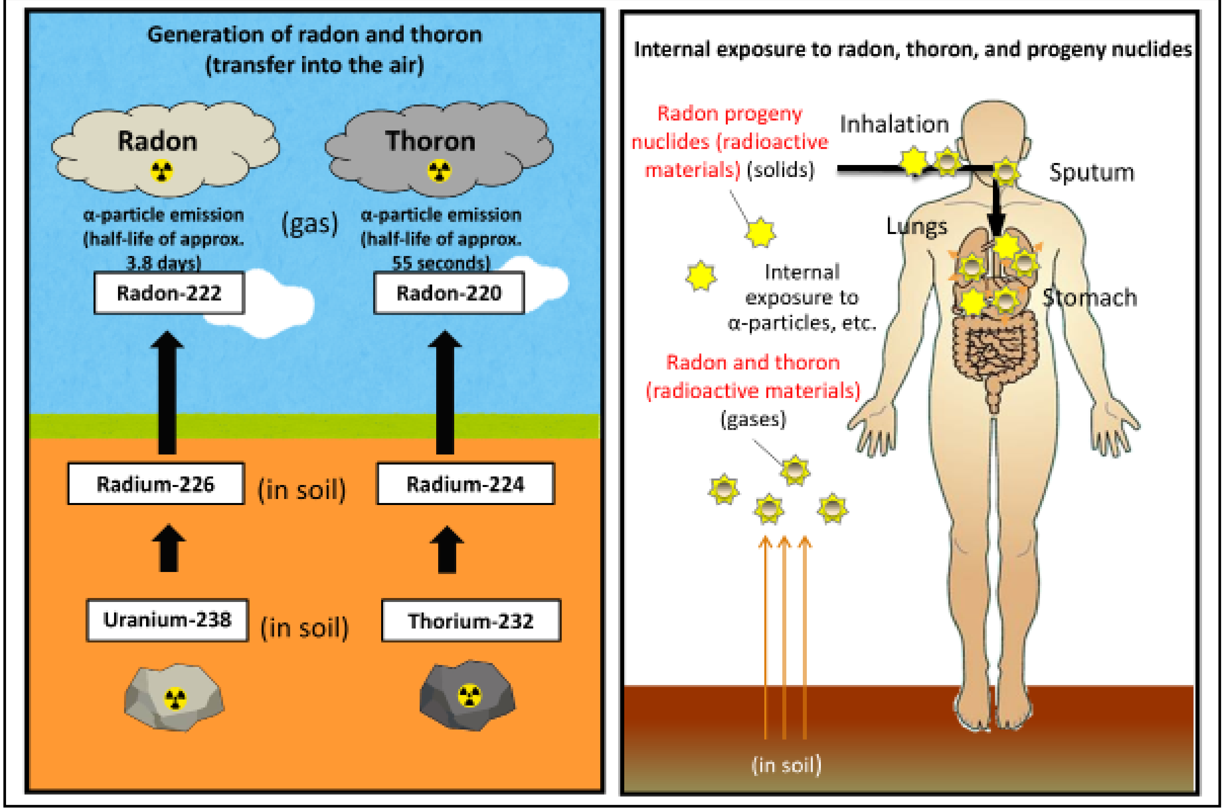
Radon is a radioactive noble gas produced by the alpha-decay of radium, which is universally present under the ground. Since radon is a gas, it is emitted from the ground and seeps into houses (p.71 of Vol. 1, “Internal Exposure to Radon and Thoron through Inhalation”).

In areas where people live in masonry houses, such as Europe, indoor radon concentrations are high and exposure doses tend to be high as a result.

The global average of indoor radon concentrations is 39 Bq/m^3, while Japan has an average value of 16 Bq/m^3. There are also large regional differences in internal exposure doses from indoor radon.

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

Internal Exposure to Radon and Thoron through Inhalation



Radon (Radon-222) and thoron (Radon-220) are gaseous radioactive materials produced through radioactive decay of a radium ore. They enter the human body through inhalation. Radon results from decay of Radium-226 produced in a decay chain (uranium series) that starts from uranium, and thoron results from decay of Radium-224 produced in a decay chain (thorium series) that starts from Thorium-232. Radon has a half-life of approx. 3.8 days and thoron has a half-life of approx. 55 seconds.

Radon and its progeny nuclides are the largest contributors of natural radiation exposure.

Because radon and thoron diffuse into the air from the ground, building materials, etc. (p.72 of Vol. 1, “Generation of Radon Gas from Solid Radium”), people inhale radon and thoron in their lives on a daily basis. Inhaled radon reaches the lungs and emits α (alpha)-particles, causing internal exposure of the lungs. Radon inhaled into the body further decays into progeny nuclides, which then migrate from the lungs and the esophagus to the digestive organs together with sputum, causing further internal exposure.

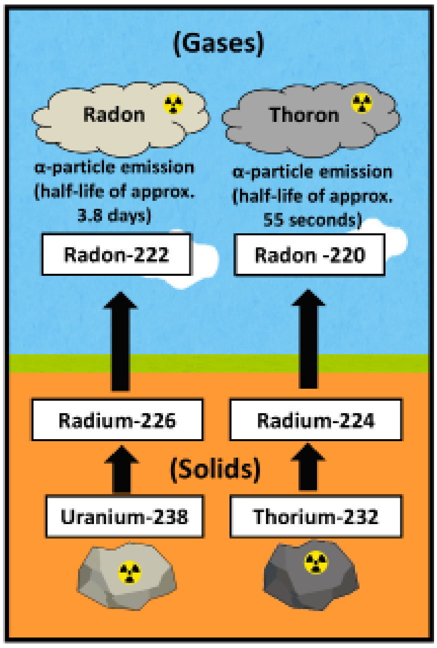
Radon contributes less to internal exposure than its progeny nuclides. This is because radon, being a gas, is easily exhaled, while radon daughter nuclides, i.e., radioactive Polonium-218 and Lead-214 that is created through decay of the former, are solids and therefore not easily expelled out of the body once inhaled as they adhere to the alveoli and the bronchial wall surface.

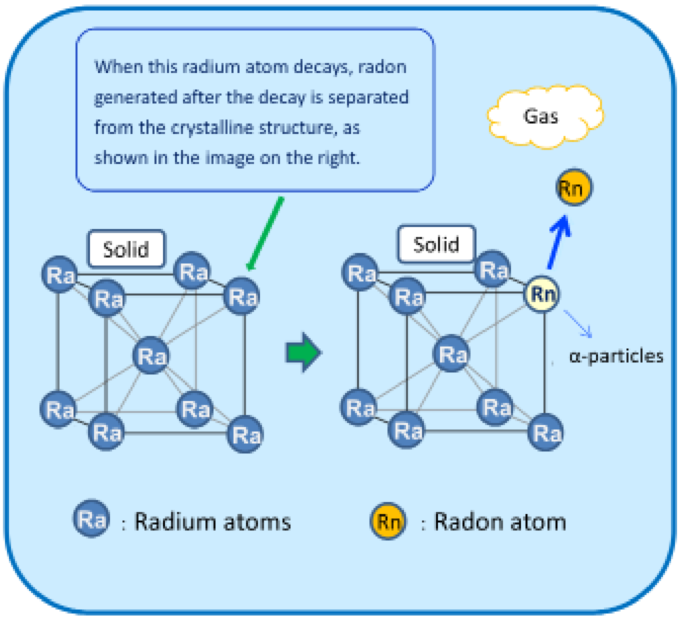
Included in this reference material on March 31, 2015
Updated on March 31, 2021

Radiation around Us

Generation of Radon Gas from Solid Radium

It may seem strange that solid radium directly turns into radon gas.
This is caused by radioactive decay that causes atoms to change.



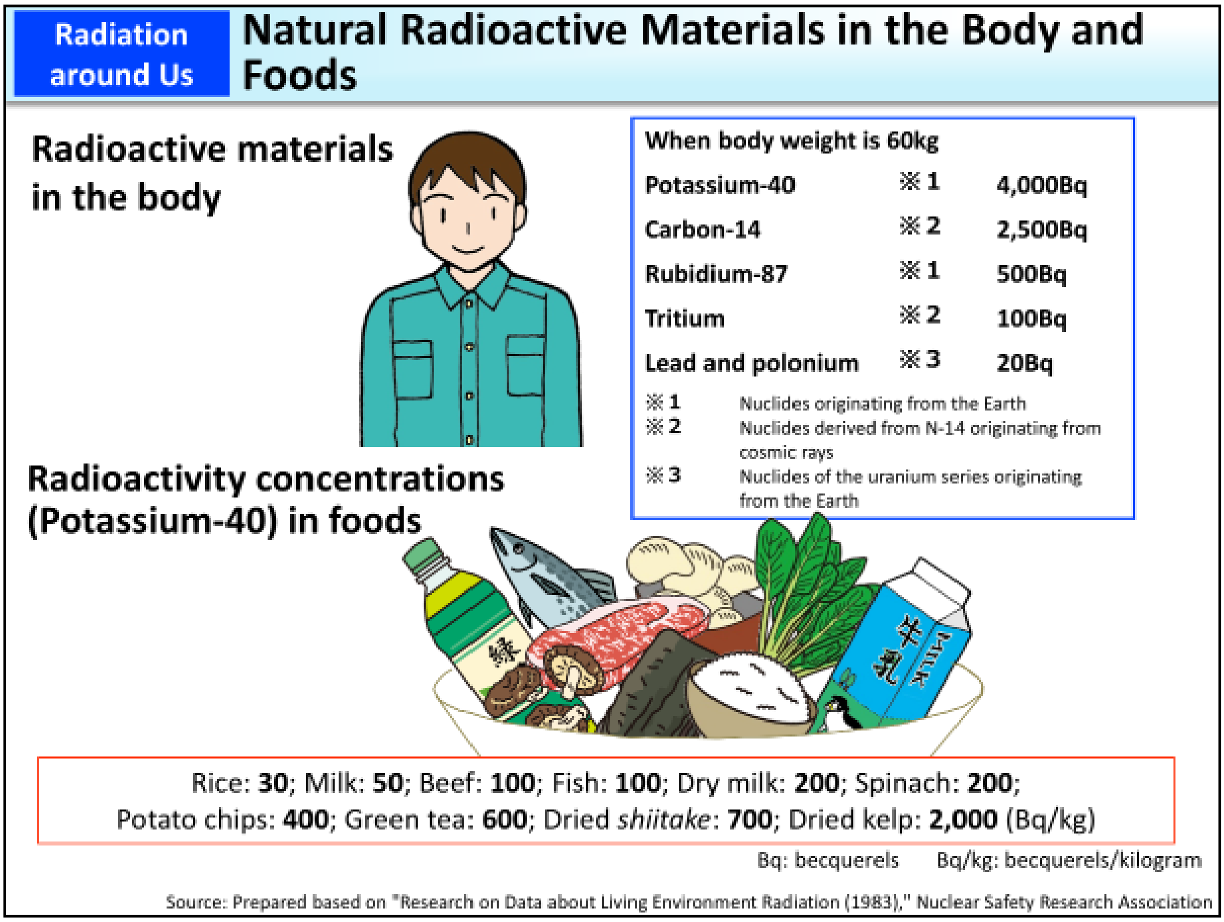

When this radium atom decays, radon generated after the decay is separated from the crystalline structure, as shown in the image on the right.

Radium, a radioactive material, is present in a crystal structure called body-centered cubic at room temperature and normal pressure, as shown in the right image.

When radium decays, it emits α (alpha)-particles and turns into radon.

Radon is a chemically stable element, like helium and neon. Being chemically stable or being an inert element means that it stably exists as radon without reacting with other elements to form compounds. Radon has a melting point of approx. -71°C and a boiling point of approx. -62°C and is therefore in a gas form under normal conditions. When radium atoms making up the crystal structure decay into radon atoms, they leave the crystal structure (because the force binding them as a crystal is lost) and come to exist in a gas form. Since radon is an inert gas, it emanates from the ground into the air without reacting with any underground substances.

Included in this reference material on March 31, 2016



Radiation around Us

Natural Radioactive Materials in the Body and Foods

Radioactive materials in the body

When body weight is 60kg

Potassium-40	※1	4,000Bq
Carbon-14	※2	2,500Bq
Rubidium-87	※1	500Bq
Tritium	※2	100Bq
Lead and polonium	※3	20Bq

※1 Nuclides originating from the Earth
※2 Nuclides derived from N-14 originating from cosmic rays
※3 Nuclides of the uranium series originating from the Earth

Radioactivity concentrations (Potassium-40) in foods

Rice: **30**; Milk: **50**; Beef: **100**; Fish: **100**; Dry milk: **200**; Spinach: **200**; Potato chips: **400**; Green tea: **600**; Dried *shiitake*: **700**; Dried kelp: **2,000** (Bq/kg)

Bq: becquerels Bq/kg: becquerels/kilogram

Source: Prepared based on "Research on Data about Living Environment Radiation (1983)," Nuclear Safety Research Association

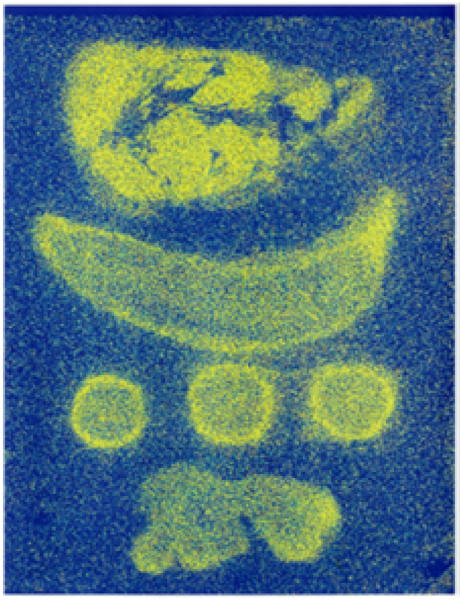
Potassium is an element necessary for life and is contained in most foods. Because 0.01% of potassium is radioactive, most foods contain radioactive potassium. Radioactive potassium emits β (beta)-particles and γ-rays, causing internal exposure from food intake (p.74 of Vol. 1, "Visualized Radiation"). The internal potassium concentration is held constant, so exposure doses from potassium in foods depend on individuals' physiques and are considered unaffected by diet (p.8 of Vol. 1, "Naturally Occurring or Artificial").

The values for dry foods in the list are those analyzed in their product states, which include the effects of concentration increases due to drying. For example, if the weight decreases to one-tenth through drying, concentration increases by ten times.

Included in this reference material on March 31, 2013
Updated on February 28, 2018

Radiation around Us

Visualized Radiation



Radiographs of pork meat, banana (cut vertically and horizontally), and ginger

Radiation from foods

- Mostly β-particles from Potassium-40
- The natural abundance ratio of Potassium-40* is **0.012%**.
- Potassium-40 has a half-life of **1.26 × $\mathbf{10^9}$** years.

*Percentage of Potassium-40 relative to the total amount of potassium found in nature

Source: Applied Physics Vol.67, No.6, 1998

Potassium-40 contained in foods emits β (beta)-particles and γ-rays.

The distribution of potassium can be found by using an imaging plate[1] and detecting β-particles from Potassium-40.

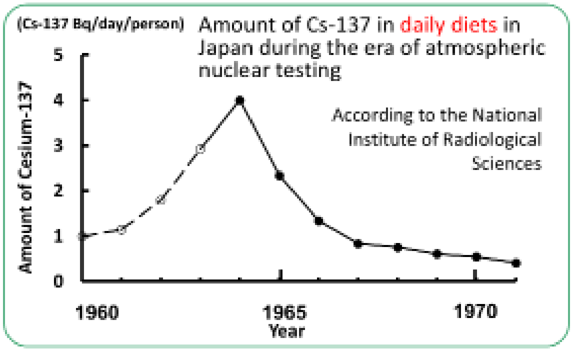
The above image was obtained by placing pieces of pork meat, banana and ginger on an imaging plate and exposing for 25 days while blocking shielding external radiation. The protein part of the pork meat, the peel of the banana, and the buds of the ginger contain relatively large amounts of potassium. It can be seen that the fat portion of the pork meat contains little potassium.

1. An imaging plate is a support medium, such as a plastic sheet, coated with a fluorescent substance that reacts to radiation. By placing a sample containing radioactive materials on a plate for a defined period of time, two-dimensional distribution of radioactivity in the sample can be examined.

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

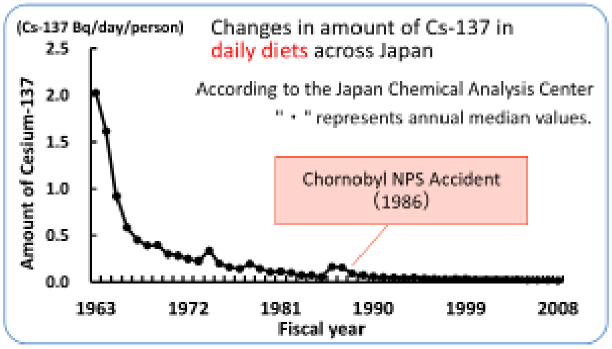
Radiation around Us

Changes in Cesium-137 Concentrations in Foods over Time since before the Accident



Amount of Cs-137 in daily diets in Japan during the era of atmospheric nuclear testing

According to the National Institute of Radiological Sciences



Changes in amount of Cs-137 in daily diets across Japan

According to the Japan Chemical Analysis Center

" • " represents annual median values.

*The two studies differ in sampling time and location.

- If an adult keeps consuming the typical diet of the 1960s for a year, internal radiation dose due to Cesium-137 is:

$$\underset{(\text{Bq/day})}{4.0} \times \underset{(\text{day/year})}{365} \times \underset{(\mu\text{Sv/Bq})}{0.013} = 19\ \mu\text{Sv/y}$$

$$= \underline{0.019\ \mu\text{Sv/y}}$$

- (Japanese average)
  Annual internal exposure dose due to natural radiation in foods is:
  0.99 mSv/y

Source: Prepared based on the "Environmental Radiation in Daily Life (Calculation of National Doses), ver. 3" (2020), Nuclear Safety Research Association

Atmospheric nuclear tests were carried out around the world from 1945 to 1980. As a result, large amounts of artificial radionuclides were released into the air and fell to Japan as well (p.78 of Vol. 1, "Effects of Radioactive Fallout due to Atmospheric Nuclear Testing"). Radioactivity in daily diets has been measured across Japan in order to find out what effects the artificial radionuclides would have on health.

Meals people actually consume are used as samples to measure radioactivity in daily diets, and this practice is useful in estimating and evaluating internal exposure doses from meals.

The amount of Cesium-137 in daily diets was highest around 1963, the year when nuclear testing, particularly in the atmosphere, was banned. It dropped sharply afterwards, and in 1975, it reduced to about a tenth of the peak amount. While there was a slight increase in 1986 because of the Chornobyl NPS Accident, the amount went down slowly until the 2000s.

If an adult were to keep consuming a typical diet of the 1960s, which had the highest level of Cesium-137, Japanese people's internal exposure dose due to Cesium-137 would be as follows:

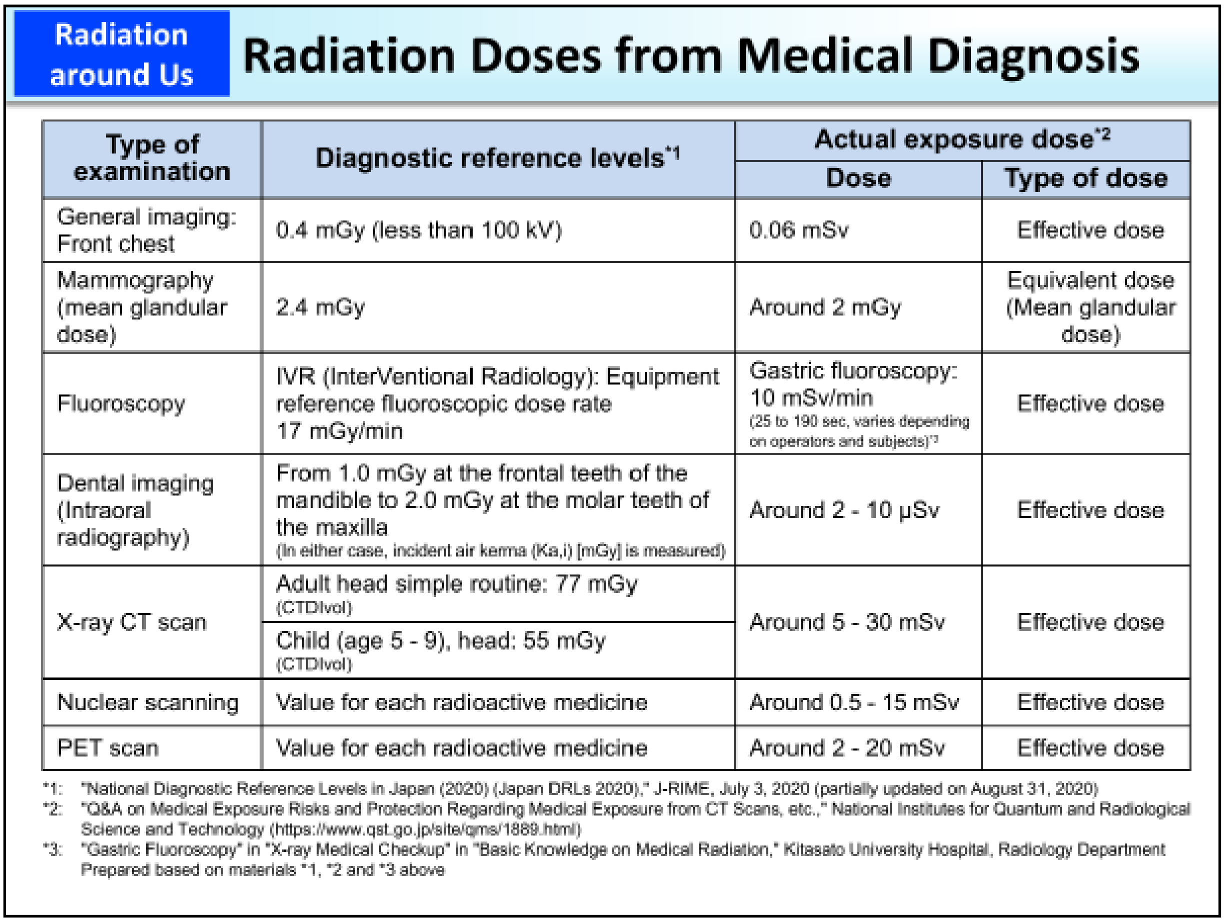
4.0 (Bq/day) × 365 (day/year) × 0.013 (μSv/Bq)=19 μSv/y =0.019 mSv/y

This value is about 2% of Japanese people's internal exposure dose (0.99 mSv/y) due to natural radiation in foods.

Because the above two studies differ in the location where samples (daily diets) were taken and the number of samples, there is a difference in their numerical values.

(The black dots in the graph (right) showing changes in amount of Cesium-137 in daily diets over time across Japan represent annual median values.)

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



Radiation around Us

Radiation Doses from Medical Diagnosis

Type of examination	Diagnostic reference levels[*1]	Actual exposure dose[*2]	
		Dose	Type of dose
General imaging: Front chest	0.4 mGy (less than 100 kV)	0.06 mSv	Effective dose
Mammography (mean glandular dose)	2.4 mGy	Around 2 mGy	Equivalent dose (Mean glandular dose)
Fluoroscopy	IVR (InterVentional Radiology): Equipment reference fluoroscopic dose rate 17 mGy/min	Gastric fluoroscopy: 10 mSv/min (25 to 190 sec, varies depending on operators and subjects)[*3]	Effective dose
Dental imaging (Intraoral radiography)	From 1.0 mGy at the frontal teeth of the mandible to 2.0 mGy at the molar teeth of the maxilla (In either case, incident air kerma (Ka,i) [mGy] is measured)	Around 2 - 10 μSv	Effective dose
X-ray CT scan	Adult head simple routine: 77 mGy (CTDIvol)	Around 5 - 30 mSv	Effective dose
	Child (age 5 - 9), head: 55 mGy (CTDIvol)		
Nuclear scanning	Value for each radioactive medicine	Around 0.5 - 15 mSv	Effective dose
PET scan	Value for each radioactive medicine	Around 2 - 20 mSv	Effective dose

[*1] "National Diagnostic Reference Levels in Japan (2020) (Japan DRLs 2020)," J-RIME, July 3, 2020 (partially updated on August 31, 2020)

[*2] "Q&A on Medical Exposure Risks and Protection Regarding Medical Exposure from CT Scans, etc.," National Institutes for Quantum and Radiological Science and Technology (https://www.qst.go.jp/site/qms/1889.html)

[*3] "Gastric Fluoroscopy" in "X-ray Medical Checkup" in "Basic Knowledge on Medical Radiation," Kitasato University Hospital, Radiology Department

Prepared based on materials *1, *2 and *3 above

Exposure doses from radiological examinations vary by the types of examinations. Some examinations, such as dental imaging, only involve very slight, local exposure, while some other examinations, such as X-ray CT scans and nuclear scanning, involve relatively high exposure doses. Even with the same type of examination, doses could vary widely depending on the medical institution. It is therefore recommended to use the diagnostic reference levels as criteria for determining whether radiation doses from medical diagnosis are appropriate or not. If the average radiation dose of a medical institution greatly deviates from the diagnostic reference levels, the International Commission on Radiological Protection (ICRP) recommends that irradiation conditions for the examination be reconsidered.

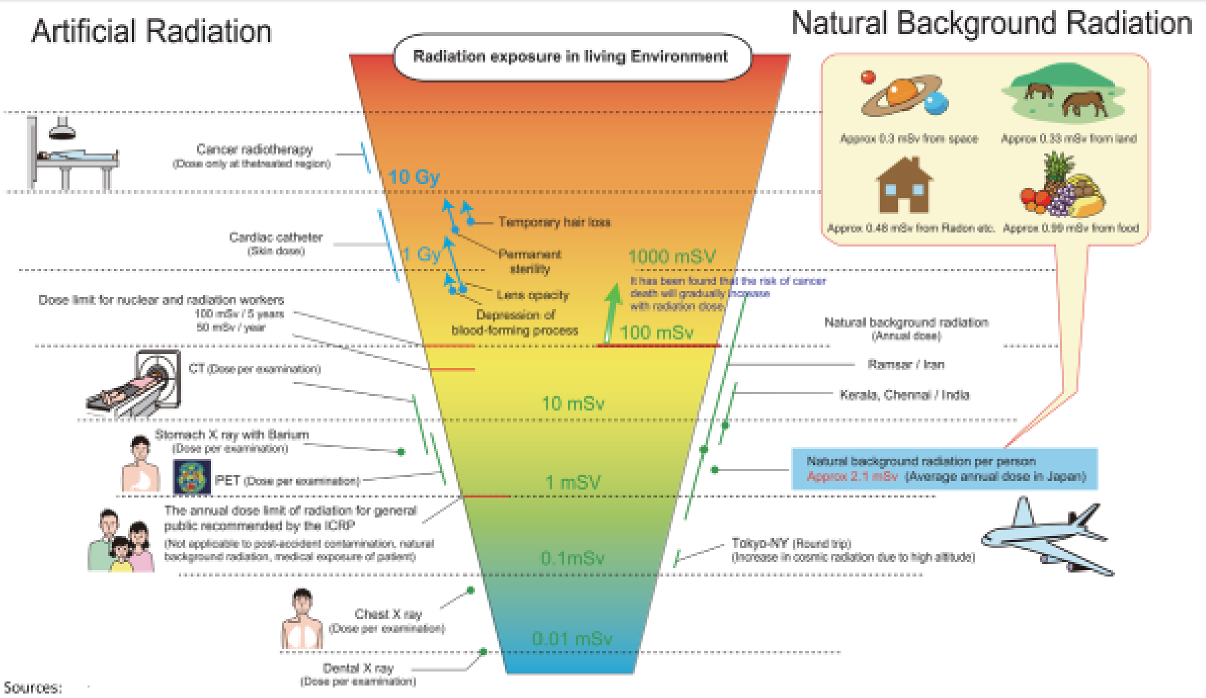
Some countries are already using the diagnostic reference levels. In Japan, the Japan Association of Radiological Technologists issued a medical exposure guideline (reduction targets) in 2000, in which they compiled values equivalent to the diagnostic reference levels. It was updated in 2006 as the 2006 medical exposure guideline. The Japan Network for Research and Information on Medical Exposures (J-RIME)[1] established Japan's first diagnostic reference levels based on the results of surveys conducted by participating organizations. For the latest diagnostic reference levels, the "National Diagnostic Reference Levels in Japan (2020) (Japan DRLs 2020)" was published on July 3, 2020 (partially updated on August 31, 2020).

1. The Japan Network for Research and Information on Medical Exposures (J-RIME) started in 2010 as a base for establishing a medical exposure protection system that matches Japan's circumstances, by gathering expert opinions through cooperation from academic societies and associations, and collecting and sharing domestic and international research information on medical exposures. J-RIME's activities include collecting data on medical exposure, such as exposure doses from radiation therapy and risk assessment, to get a picture of medical exposures in Japan, and building an appropriate protection system for medical exposure in Japan while taking international trends into account.

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Radiation around Us

Comparison of Exposure Doses (Simplified Chart)



Sources:
- The 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report
- The 2007 ICRP (International Commission on Radiological Protection) Report
- The exposure guideline of the Japan Association of Radiological Technologists
- "Environmental Radiation in Daily Life (Calculation of the National Doses)," new edition

Prepared by the National Institute of Radiological Sciences, National Institutes for Quantum Science and Technology, based on the sources above (May 2021)

mSv: millisieverts

Comparison of radiation doses in daily life shows that doses from one single event and annual doses are mostly on the order of millisieverts, except for special cases such as radiation therapy (p.76 of Vol. 1, "Radiation Doses from Medical Diagnosis").

Exposure doses found to have health effects on people are considered to be at levels exceeding 100 millisieverts.

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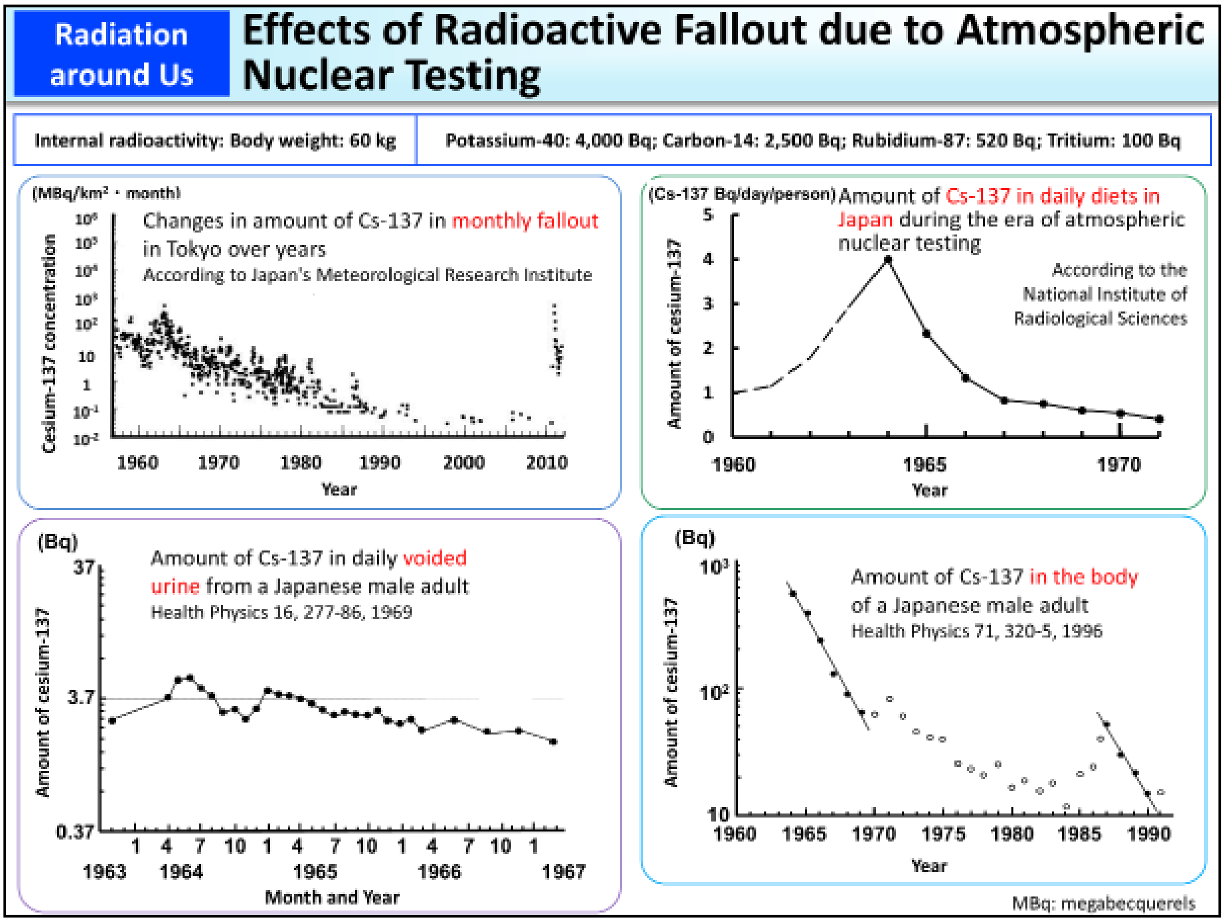

Radiation around Us

Effects of Radioactive Fallout due to Atmospheric Nuclear Testing

Internal radioactivity: Body weight: 60 kg	Potassium-40: 4,000 Bq; Carbon-14: 2,500 Bq; Rubidium-87: 520 Bq; Tritium: 100 Bq

Changes in amount of Cs-137 in monthly fallout in Tokyo over years

According to Japan's Meteorological Research Institute

Amount of Cs-137 in daily diets in Japan during the era of atmospheric nuclear testing

According to the National Institute of Radiological Sciences

Amount of Cs-137 in daily voided urine from a Japanese male adult

Health Physics 16, 277-86, 1969

Amount of Cs-137 in the body of a Japanese male adult

Health Physics 71, 320-5, 1996

MBq: megabecquerels

Large amounts of artificial radionuclides were released into the environment in the era during which atmospheric nuclear testing was frequently conducted. These artificial radionuclides were spread all around the world as they were carried by air currents, and gradually fell onto the surface of the Earth from the atmosphere. Such radioactive falling matter is called fallout. The amount of fallout was highest in 1963, just before the ban of atmospheric nuclear testing, and has been decreasing since then.

Because there is a time lag between contamination of foods with cesium and their consumption, the amount of radioactive cesium in daily diets was highest in 1964, then dropped sharply by 1967, and has been decreasing relatively slowly since then.

Like the amount of cesium in daily diets, the amounts of Cesium-137 in urine and the body were also highest in 1964. An increase in the amount of cesium in the body was also found among Japanese people as a result of the influence of the Chornobyl NPS Accident.

As a result of atmospheric nuclear testing during the aforementioned era, plutonium and Strontium-90, etc. were released into the environment, in addition to radioactive cesium. These radionuclides still exist in soil, albeit only slightly.

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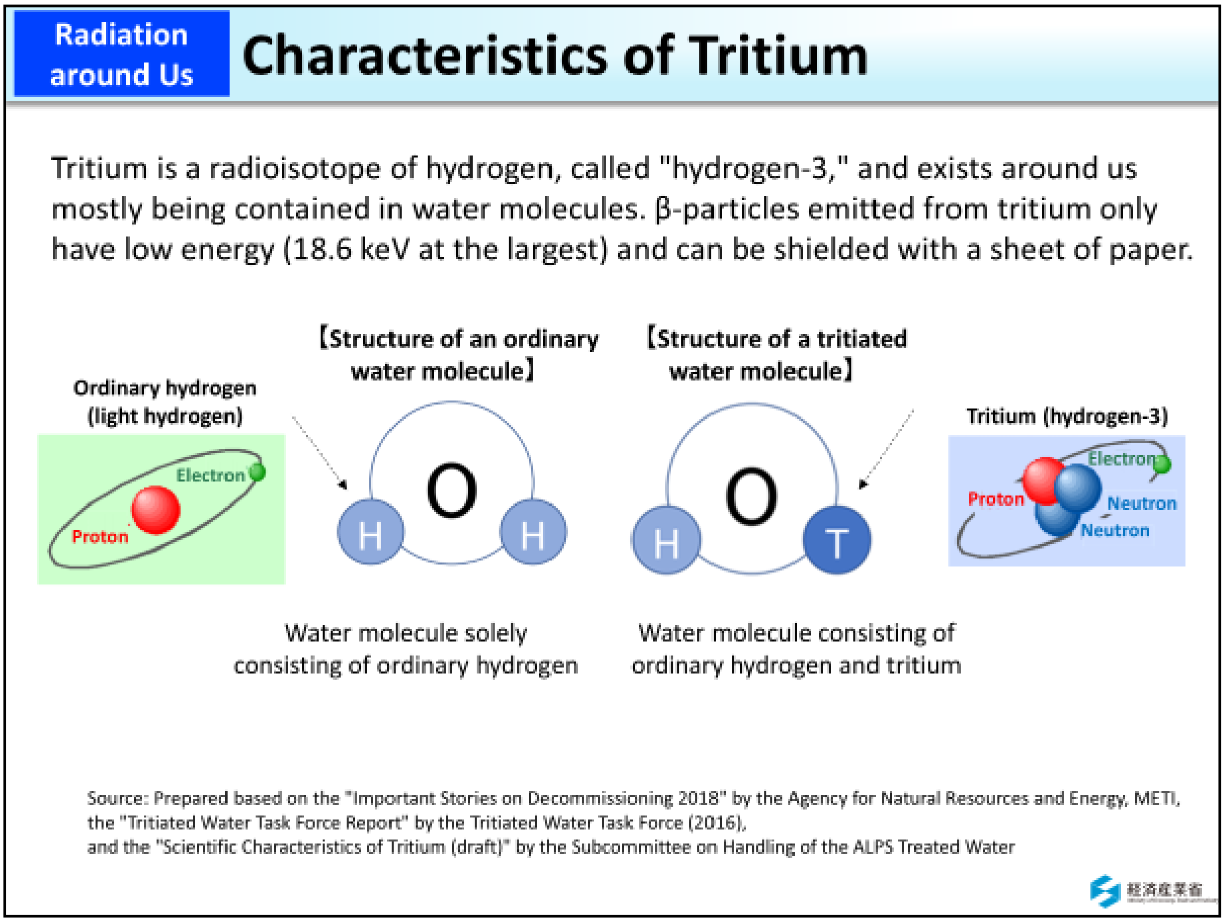

Radiation around Us

Characteristics of Tritium

Tritium is a radioisotope of hydrogen, called "hydrogen-3," and exists around us mostly being contained in water molecules. β-particles emitted from tritium only have low energy (18.6 keV at the largest) and can be shielded with a sheet of paper.

Water molecule solely consisting of ordinary hydrogen

Water molecule consisting of ordinary hydrogen and tritium

Source: Prepared based on the "Important Stories on Decommissioning 2018" by the Agency for Natural Resources and Energy, METI, the "Tritiated Water Task Force Report" by the Tritiated Water Task Force (2016), and the "Scientific Characteristics of Tritium (draft)" by the Subcommittee on Handling of the ALPS Treated Water

The water processed with the multi-nuclide removal equipment, also called the Advanced Liquid Processing System (ALPS), or other equipment, at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, still contains tritium, which is a radioactive material.

Tritium is a radioisotope of hydrogen, called "hydrogen-3." As tritium combines with oxygen to form water molecules just as ordinary hydrogen does, it exists around us contained in water molecules, and is also found in water vapor in the air, rainwater, seawater, and tap water. It is difficult to remove tritium by ALPS as it exists as part of water molecules. Tritium is generated in nature by cosmic rays in addition to being artificially generated through operations of nuclear power plants.

Tritium emits β (beta)-particles, a type of radiation, but β-particles emitted from tritium have low energy and can be shielded with a sheet of paper. Therefore, external exposure to tritium is unlikely to exert any influence on the human body. A biological half-life for water containing tritium is ten days, and even if it is ingested, it will be eliminated from the body promptly and will not accumulate in any specific organs (p.31 of Vol. 1, "Radioactive Materials Derived from Nuclear Accidents"). The committed effective dose coefficient when orally ingesting tritium is 0.000018 μSv/Bq, a smaller value compared with other radionuclides (p.57 of Vol. 1, "Conversion Factors to Effective Doses").

[Reference materials]
Basic knowledge on tritium:
- Contaminated water management in Fukushima: Top priority on safety and security; Measure (ii) What is "tritium"?
  https://www.enecho.meti.go.jp/about/special/johoteikyo/osensuitaisaku02.html (in Japanese)

Influence of tritium on the human body:
- Top priority on safety and security; Measure (iii) Explanation of tritium and radiation exposure
  https://www.enecho.meti.go.jp/about/special/johoteikyo/osensuitaisaku03.html (in Japanese)

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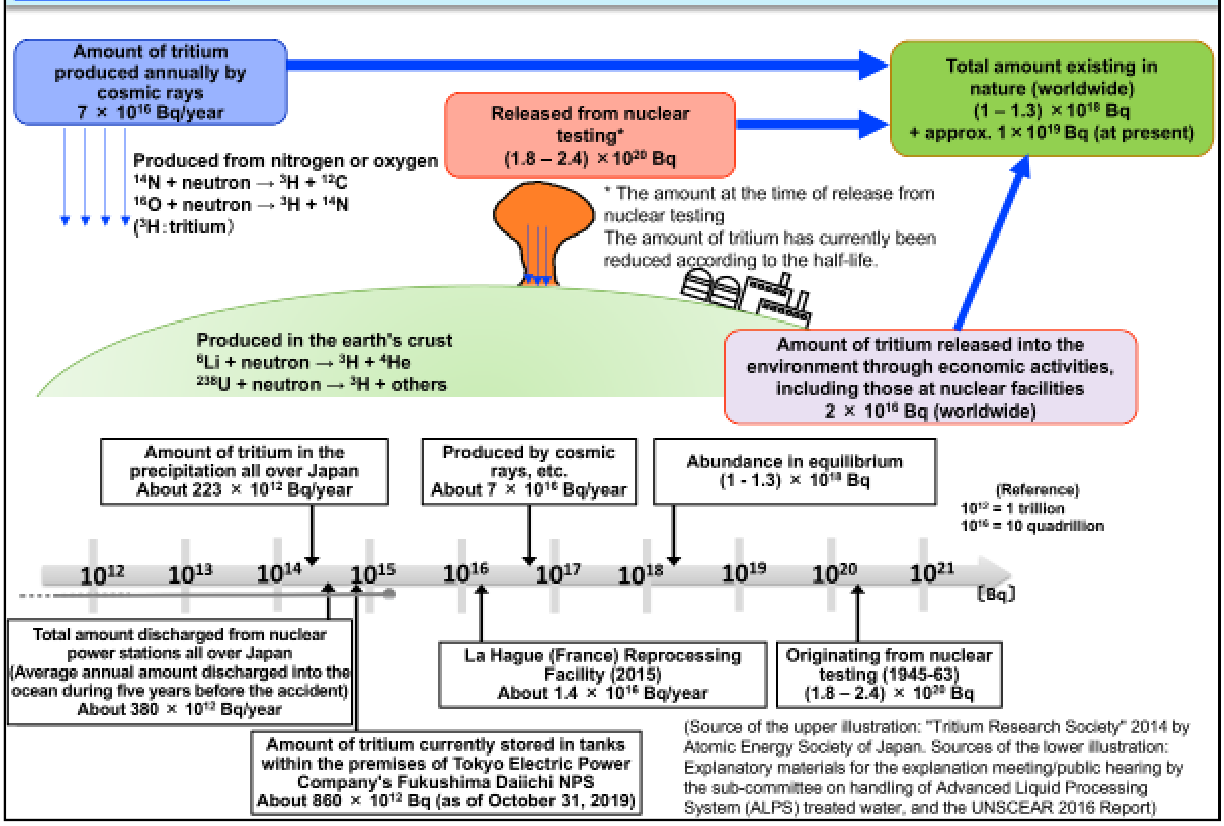
Radiation around Us

Amount of Tritium Existing in the Environment



(Source of the upper illustration: "Tritium Research Society" 2014 by Atomic Energy Society of Japan. Sources of the lower illustration: Explanatory materials for the explanation meeting/public hearing by the sub-committee on handling of Advanced Liquid Processing System (ALPS) treated water, and the UNSCEAR 2016 Report)

Tritium (^{3}H) is a radioisotope of hydrogen (with a half-life of about 12.3 years) and emits weak radiation (β-particles) (p.79 of Vol. 1, "Characteristics of Tritium").

In nature, about seventy quadrillion (7 × 10^{16}) Bq of tritium is produced annually by cosmic rays, etc. on earth. In the past nuclear testing (1945 to 1963), tritium of 1.8 to 2.4 × 10^{20} Bq was released. In addition, tritium is discharged daily from facilities such as nuclear power stations around the world and the annual amount of tritium released from nuclear power stations around the world is 2 × 10^{16} Bq. Before the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident, the annual amount of tritium released from nuclear power stations all over Japan was 380 × 10^{12} Bq (which is the average annual amount discharged into the ocean during the five years before the accident). Abundance in equilibrium (abundance when generation and disintegration[1] stay in equilibrium) in the environment is estimated to be 1 to 1.3 × 10^{18} Bq, and the current abundance of tritium derived from nuclear testing and released from nuclear facilities, etc. is estimated to be 1 × 10^{19} Bq. The released tritium exists mostly as hydrogen that makes up water molecules and it is also contained in water vapor in the atmosphere, rainwater, sea water and tap water. The annual amount of tritium contained in the precipitation in Japan is estimated to be about 223 × 10^{12} Bq.

1. The phenomenon wherein a radionuclide emits radiation and transforms into a different nuclide (p.10 of Vol. 1, "Parent and Daughter Nuclides"). Tritium transforms into helium through disintegration.

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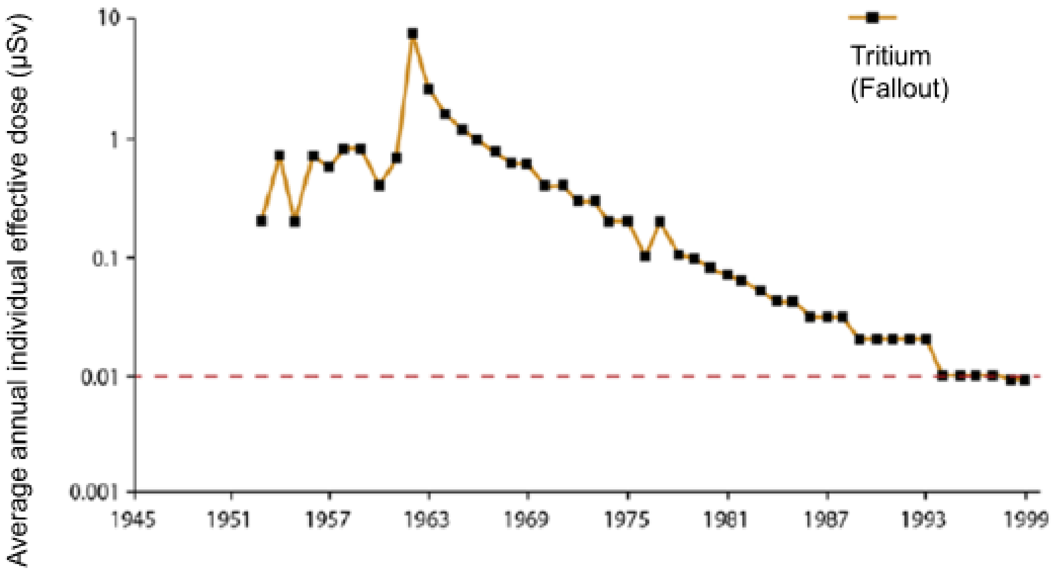
Radiation around Us

Changes in Tritium in Radioactive Fallout over Time



Source: UNSCEAR 2016 Report, Annex C-Biological effects of selected internal emitters-Tritium

During the period from 1950 to 1963, nuclear weapon tests were conducted and caused a large amount of radioactive fallout across the globe. As a result, the average annual individual doses from tritium increased with the peak value of 7.2 μSv in 1962. After that, the amount of tritium decreased with the half-life, which resulted in little effect on the individual dose. In 1999, it became 0.01 μSv, which was about one-seven hundredth of the peak value.

In the nuclear testing, not only tritium but also cesium, plutonium and strontium were released into the environment.

According to the 2016 report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the epidemiological studies conducted so far have not confirmed any tritium-specific risk about the effects of public exposure to tritium. Additionally, from the fact that the incidence of childhood leukemia has not increased since the early 1960s when nuclear tests were frequently conducted, it is considered that there is a low possibility that the health risk by exposure to tritium is underestimated.
(Related page: p.78 of Vol. 1, "Effects of Radioactive Fallout due to Atmospheric Nuclear Testing")

Included in this reference material on March 31, 2021

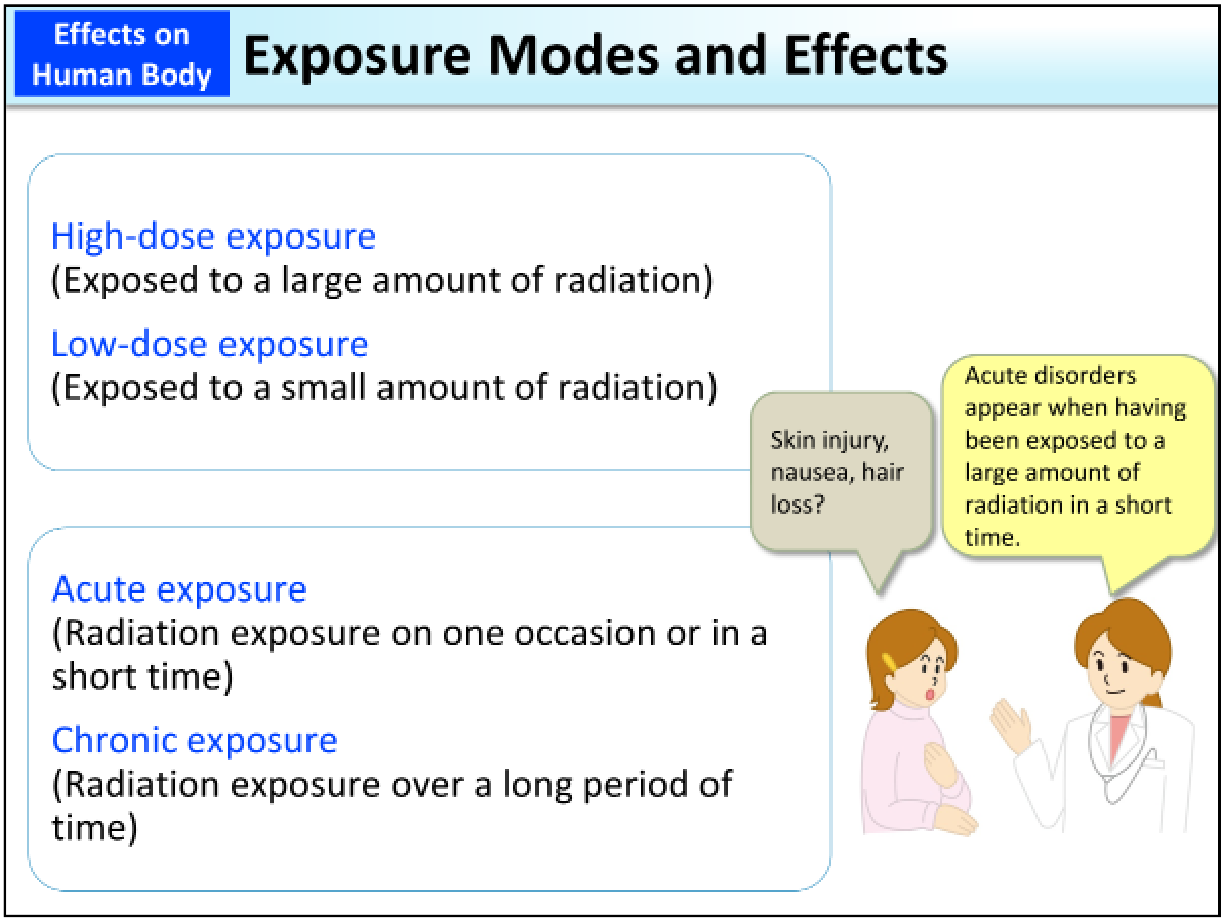
Chapter 3

Health Effects of Radiation

Chapter 3 explains radiation effects on the human body and mechanism of generating effects.

You can understand the health effects of radiation based on scientific grounds, including data on the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, atomic bomb survivors, and the Chornobyl NPS Accident.

You can also understand the relation between types of exposure (affected body parts, exposure dose and period) and health effects and psychological effects due to worries over radiation.



Effects on Human Body

Exposure Modes and Effects

High-dose exposure
(Exposed to a large amount of radiation)

Low-dose exposure
(Exposed to a small amount of radiation)

Acute exposure
(Radiation exposure on one occasion or in a short time)

Chronic exposure
(Radiation exposure over a long period of time)

Skin injury, nausea, hair loss?

Acute disorders appear when having been exposed to a large amount of radiation in a short time.

Physical effects of radiation depend on the amount of exposure, not on whether a person is ever exposed to radiation.

Whether any significant effects appear in the human body due to having been exposed to radiation depends on whether it is internal exposure or external exposure, whole-body exposure or local exposure, or which part was exposed in the case of local exposure, the amount of radiation, or the duration of exposure.

Types and levels of radiation effects on the human body can be ascertained more accurately when there is more information available.

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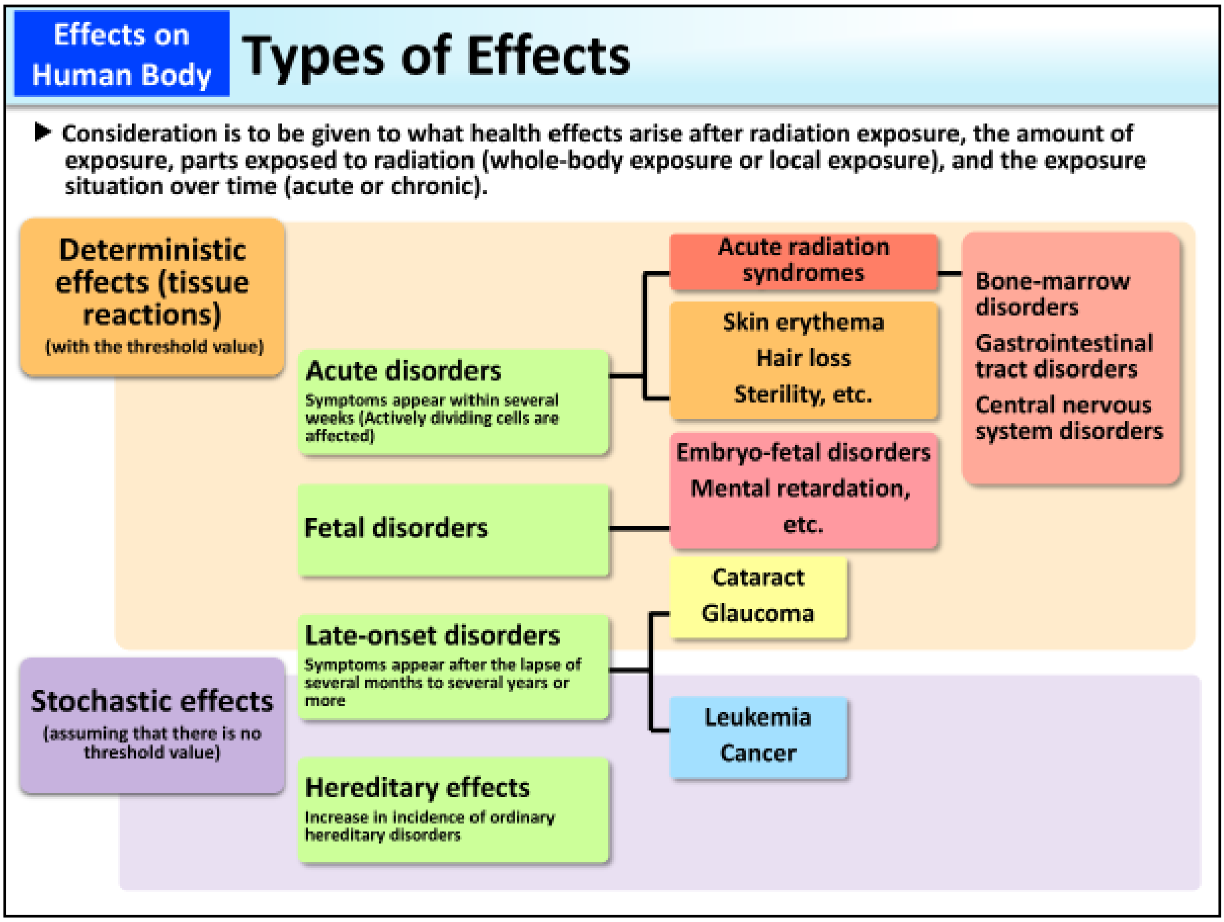

Effects on Human Body

Types of Effects

▶ Consideration is to be given to what health effects arise after radiation exposure, the amount of exposure, parts exposed to radiation (whole-body exposure or local exposure), and the exposure situation over time (acute or chronic).

Deterministic effects (tissue reactions)
(with the threshold value)

Acute disorders
Symptoms appear within several weeks (Actively dividing cells are affected)

Acute radiation syndromes

Bone-marrow disorders
Gastrointestinal tract disorders
Central nervous system disorders

Skin erythema
Hair loss
Sterility, etc.

Fetal disorders

Embryo-fetal disorders
Mental retardation, etc.

Late-onset disorders
Symptoms appear after the lapse of several months to several years or more

Cataract
Glaucoma

Leukemia
Cancer

Stochastic effects
(assuming that there is no threshold value)

Hereditary effects
Increase in incidence of ordinary hereditary disorders

When considering health effects of radiation on human body, one method is to separately consider stochastic effects and deterministic effects (tissue reactions). The above figure compiles these two effects.

Deterministic effects (tissue reactions) do not appear unless having been exposed to radiation exceeding a certain level. Most of the deterministic effects are categorized into acute disorders whose symptoms appear within several weeks after exposure.

Stochastic effects are effects whose incidence cannot be completely denied even with low-dose exposure. Exposure doses are managed on the safe side in general under the assumption that there is no threshold value.

However, it has not been confirmed that hereditary disorders due to radiation exposure appear among human beings at the same frequencies as estimated from the results of tests on laboratory animals.

(Related to p.85 of Vol. 1, “Classification of Radiation Effects,” and p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects”)

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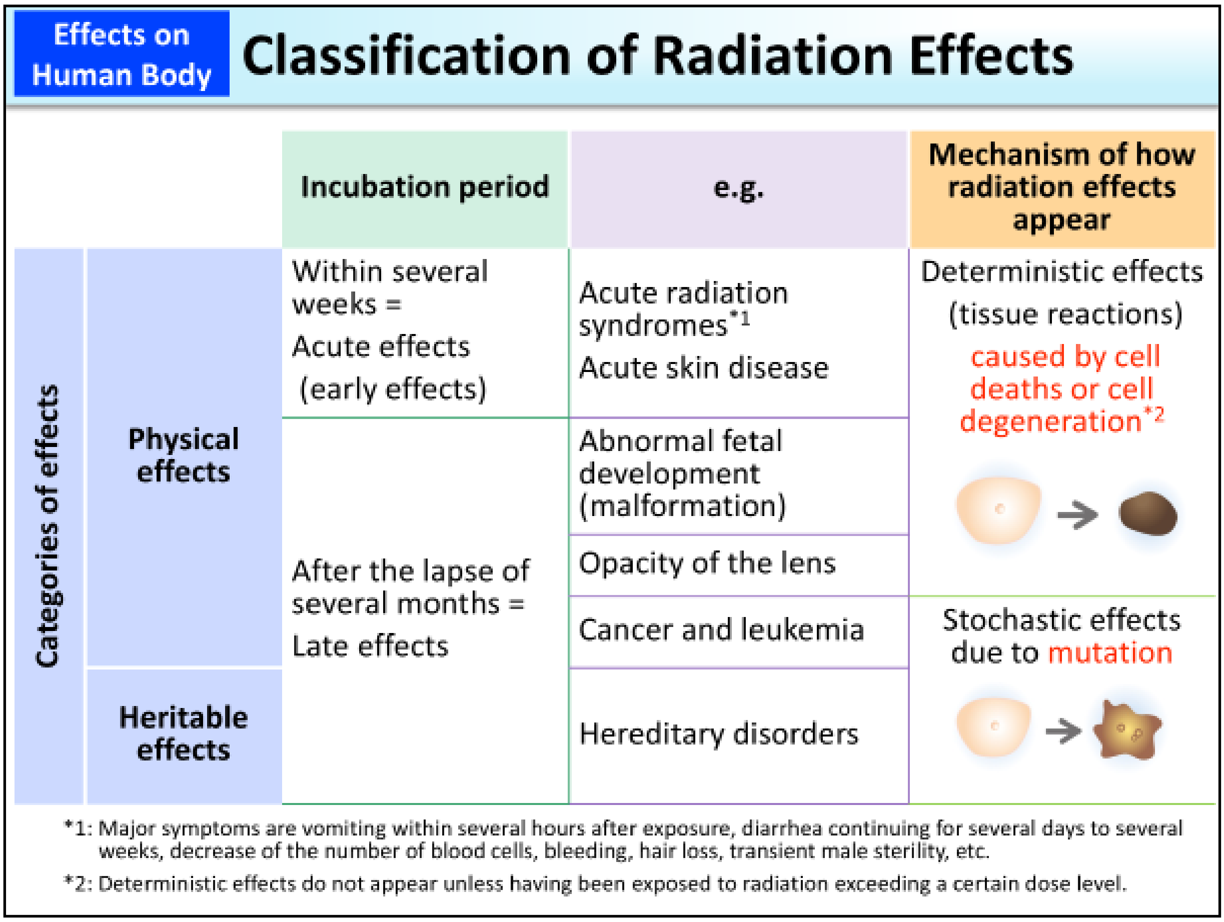

Effects on Human Body

Classification of Radiation Effects

		Incubation period	e.g.	Mechanism of how radiation effects appear
Categories of effects	Physical effects	Within several weeks = Acute effects (early effects)	Acute radiation syndromes*1 Acute skin disease	Deterministic effects (tissue reactions) caused by cell deaths or cell degeneration*2
		After the lapse of several months = Late effects	Abnormal fetal development (malformation)	
			Opacity of the lens	
			Cancer and leukemia	Stochastic effects due to mutation
	Heritable effects		Hereditary disorders	

*1: Major symptoms are vomiting within several hours after exposure, diarrhea continuing for several days to several weeks, decrease of the number of blood cells, bleeding, hair loss, transient male sterility, etc.

*2: Deterministic effects do not appear unless having been exposed to radiation exceeding a certain dose level.

Radiation effects are classified into physical effects appearing in a person exposed to radiation and heritable effects appearing in his/her children or grandchildren.

Radiation effects may also be classified depending on the length of time until any symptom appears after exposure. That is, there are acute effects (early effects) that appear relatively early after exposure and late effects that appear after the lapse of several months.

Another classification is based on the difference in mechanisms of how radiation effects appear, i.e., deterministic effects (tissue reactions) and stochastic effects.

Deterministic effects (tissue reactions) are symptoms caused by deaths or degeneration of a number of cells constituting organs and tissues. For example, after exposure to a relatively large amount of radiation, a skin injury or a decrease of the number of blood cells due to deterioration of hemopoietic capacity may occur within several weeks (acute radiation syndrome). Exposure to a large amount of radiation during pregnancy may cause some effects on the fetus and radiation exposure to the eyes may induce cataracts after a while.

On the other hand, stochastic effects are caused by mutation of cell genes, such as cancer and heritable effects. Radiation may damage DNA, which may result in genetic mutation (p.88 of Vol. 1, “Damage and Repair of DNA”). Each mutation is unlikely to lead to diseases, but theoretically, the possibility of causing cancer or heritable effects cannot be completely denied. Therefore, in relation to cancer or heritable effects, exposure doses are managed on the safe side under the assumption that there is no threshold dose.
(Related to p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects,” and p.108 of Vol. 1, “Risks of Heritable Effects for Human Beings”)

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Effects on Human Body

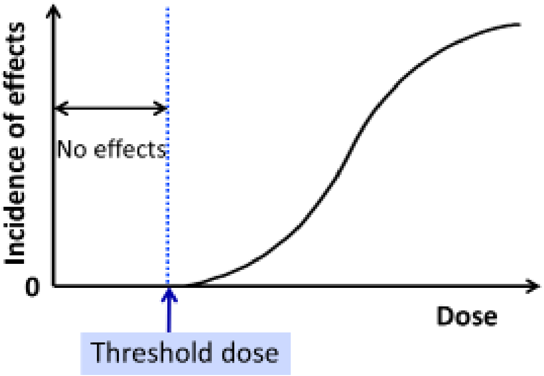
Deterministic Effects (Tissue Reactions) and Stochastic Effects

Deterministic effects (tissue reactions)

(Hair loss, cataract, skin injury, etc.)

A dose level, at which specific symptoms appear in 1 % of the population exposed to the same dose of radiation, is defined as the threshold dose.

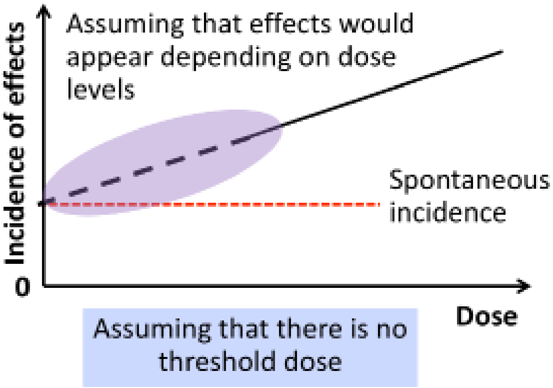
(2007 Recommendations of the International Commission on Radiological Protection (ICRP))



Stochastic effects

(Cancer, leukemia, hereditary effects, etc.)

Effects of radiation exposure under certain doses are not clear because effects of other cancer-promoting factors such as smoking and drinking habits are too large. However, the ICRP specifies the standards for radiological protection for such low-dose exposures, assuming that they may have some effects as well.



One of the characteristics of the deterministic effects (tissue reactions) is the existence of the threshold dose, which means that exposure to radiation under this level causes no effects but exposure to radiation above this level causes effects. Radiation exposure above the threshold dose causes deaths or degeneration of a large number of cells at one time and the incidence rate increases sharply.

On the other hand, in radiological protection, it is assumed that there is no threshold dose for stochastic effects. Under this assumption, the possibility that radiation exposure even at extremely low doses may exert some effects can never be eliminated. It is difficult to epidemiologically detect stochastic effects due to radiation exposure at low doses below the range of 100 to 200 mSv, but the ICRP specifies the standards for radiological protection for low-dose exposures, assuming that effects would appear depending on dose levels (linear dose-response relationship) (p.165 of Vol. 1, “Biological Aspect”).

When assessing cancer risks due to low-dose exposures, results of the epidemiological studies of atomic bomb survivors in Hiroshima and Nagasaki have mainly been used. It is known that cancer risks increase almost linearly as exposure doses increase above approx. 100 mSv (p.117 of Vol. 1, “Relationship between Solid Cancer Deaths and Doses”). However, it is not clear whether risks also increase linearly in the case of radiation exposure at doses below 100 mSv (p.166 of Vol. 1, “Disputes over the LNT Model”). Additionally, it is shown that risks increase quadratically in tandem with doses above approximately 1,000 mSv (p.118 of Vol. 1, “Dose-response Relationship of Radiation-induced Leukemia”). The WHO and UNSCEAR assess risks by applying the linear-quadratic dose response model.

Furthermore, experiments using animals or cultured cells have revealed that comparing high-dose exposures in a short time as experienced by atomic bomb survivors and low-dose exposures over a long period of time, the latter poses lower risks even when the total exposure doses are the same (p.116 of Vol. 1, “Cancer-promoting Effects of Low-dose Exposures”).
(Related to p.91 of Vol. 1, “Cell Deaths and Deterministic Effects (Tissue Reactions)”)

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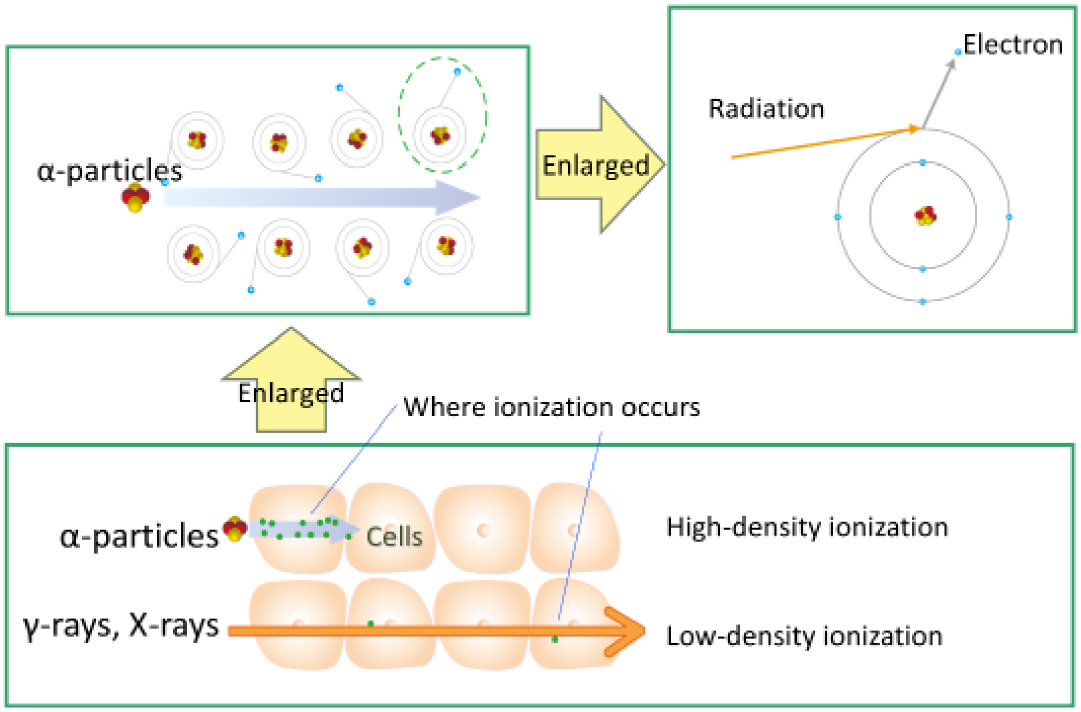
Mechanism of Causing Effects on Human Body

Ionization due to Radiation



Radiation provides energy to substances along its pathway. Electrons of substances along the pathway are ejected with the given energy. This is ionization.

The density of energy provided by radiation differs by the type of radiation. Compared with β (beta)-particles and γ-rays, α (alpha)-particles provide energy more intensively to substances in an extremely small area. Due to such difference in the ionization density, damage to cells differs even with the same absorbed dose.

(Related to p.18 of Vol. 1, “Ionization of Radiation - Property of Ionizing Radiation”)

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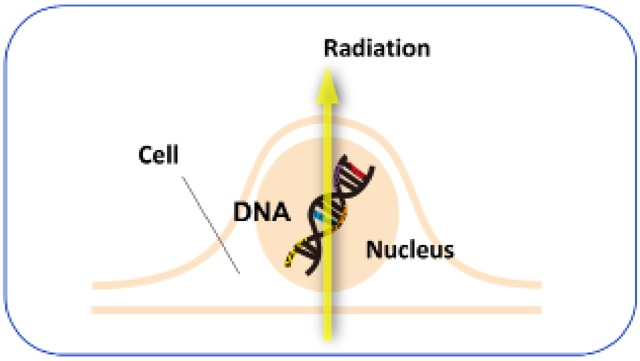
Mechanism of Causing Effects on Human Body

Damage and Repair of DNA

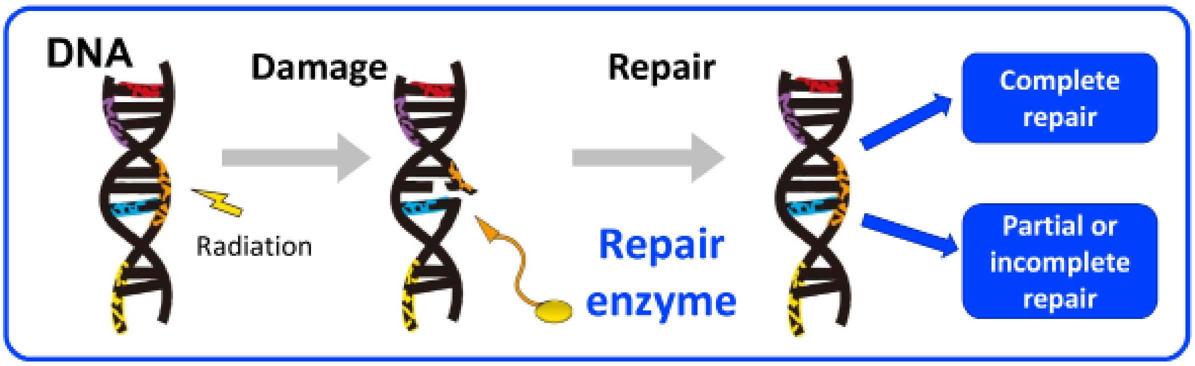


Damage per 1 mGy of X-rays
(per cell)

Base damage: 2.5 locations

Single-strand break: 1 location

Double-strand breaks: 0.04 locations



Source: Morgan, Annual Meeting of the National Committee on Radiation Protection and Measurements (NCRP) (44th, 2008)

Cells have DNA, the blueprint of life. DNA consists of two chains of sugar, phosphate and four different bases. As the genetic information is incorporated in the arrangement of these bases, bases are combined firmly to mutually act as a template in order to maintain the arrangement. When DNA is irradiated, it may be partially damaged depending on the amount of radiation.

1 mGy of X-rays is thought to cause a single-strand break at one location per cell on average. A double-strand break occurs less at 0.04 locations. Therefore, when 100 cells are evenly exposed to 1 mGy of X-rays, double-strand breaks occur in four cells.

DNA is damaged not only by radiation but also by carcinogens in foods, tobacco, chemical substances in the environment and reactive oxygen, etc. It is said that DNA is damaged at 10,000 to 1,000,000 locations per cell every day.

Cells have functions to repair damaged DNA. Damaged DNA is repaired by the action of repair enzymes. There are cases where DNA is completely repaired and partially or incompletely repaired (p.89 of Vol. 1, “DNA→Cells→Human Body”).

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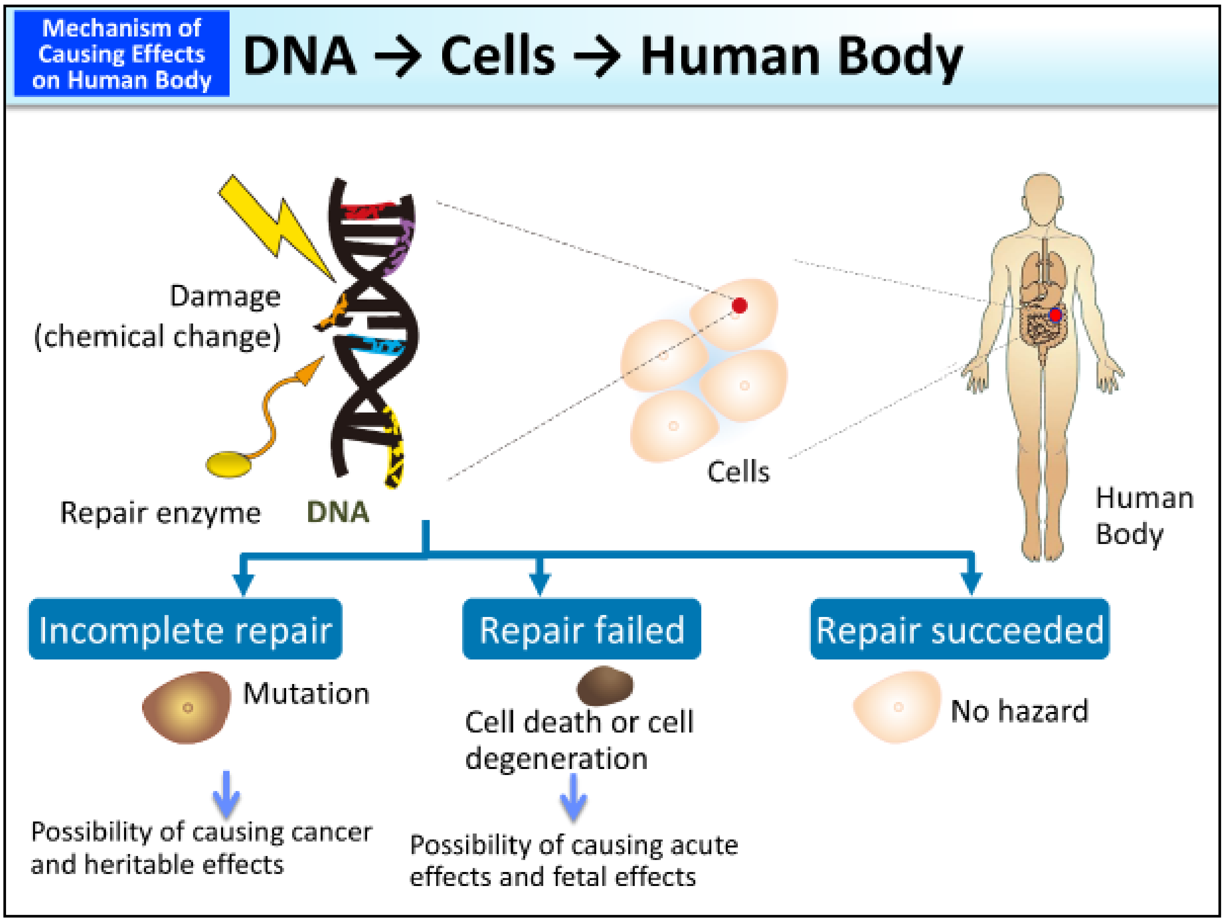

Mechanism of Causing Effects on Human Body

DNA → Cells → Human Body

Damage (chemical change)

Repair enzyme

DNA

Cells

Human Body

Incomplete repair

Mutation

↓

Possibility of causing cancer and heritable effects

Repair failed

Cell death or cell degeneration

↓

Possibility of causing acute effects and fetal effects

Repair succeeded

No hazard

Looking closely into the irradiated portion, radiation may directly or indirectly damage the DNA sequences of a gene. These damaged DNA sequences are repaired by a pre-existing system in the body.

Minor damage is successfully repaired and restored. However, when many parts are damaged, they cannot be fully repaired and cells themselves die. Even when some cells die, if other cells can replace them, dysfunction does not occur in organs and tissues. However, when a large number of cells die or degenerate, there is the possibility that deterministic effects (tissue reactions) will appear, such as hair loss, cataract, skin injury or other acute disorders, as well as fetal disorders (p.90 of Vol. 1, “Lapse of Time after Exposure and Effects,” and p.91 of Vol. 1, “Cell Deaths and Deterministic Effects (Tissue Reactions)”).

When a cell in which DNA was not completely repaired survives, the cell gene may mutate and cause a stochastic effect such as cancer or heritable effect.

DNA is damaged not only by radiation but also by carcinogens in foods, tobacco, chemical substances in the environment and reactive oxygen, etc. It is said that DNA is damaged at 10,000 to 1,000,000 locations per cell every day. Damage due to low-dose exposures is significantly rare compared with metabolic DNA damage. However, radiation provides energy locally and causes complicated damage affecting multiple parts in DNA strands. Approx. 85% of radiation effects are caused by reactive oxygen, etc. created by radiation and approx. 15% is direct damage by radiation.

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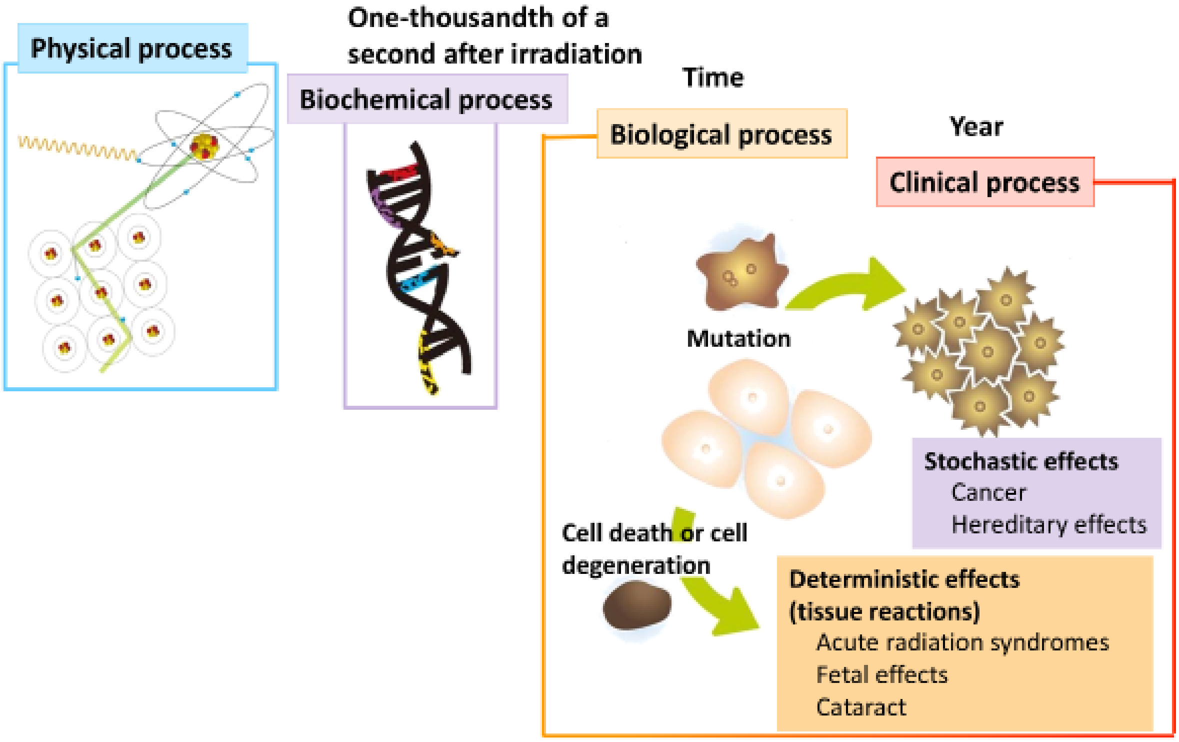
Mechanism of Causing Effects on Human Body

Lapse of Time after Exposure and Effects



One-thousandth of a second after irradiation

Time

Year

Physical process

Biochemical process

Biological process

Clinical process

Mutation

Cell death or cell degeneration

Stochastic effects
Cancer
Hereditary effects

Deterministic effects (tissue reactions)
Acute radiation syndromes
Fetal effects
Cataract

In as short a time as one-thousandth of a second after irradiation, DNA breaks and base damage occur. In a second after irradiation, DNA repair starts, and if repair fails, cell deaths and mutation occur within an hour to one day. It takes some time until such reaction at the cell level develops into clinical symptoms at an individual level. This period is called the incubation period.

Effects due to which symptoms appear within several weeks are called acute (early) effects, while effects that develop symptoms after a relatively long period of time are called late effects. In particular, it takes several years to decades until a person develops cancer. (Related to p.113 of Vol. 1, “Mechanism of Carcinogenesis”)

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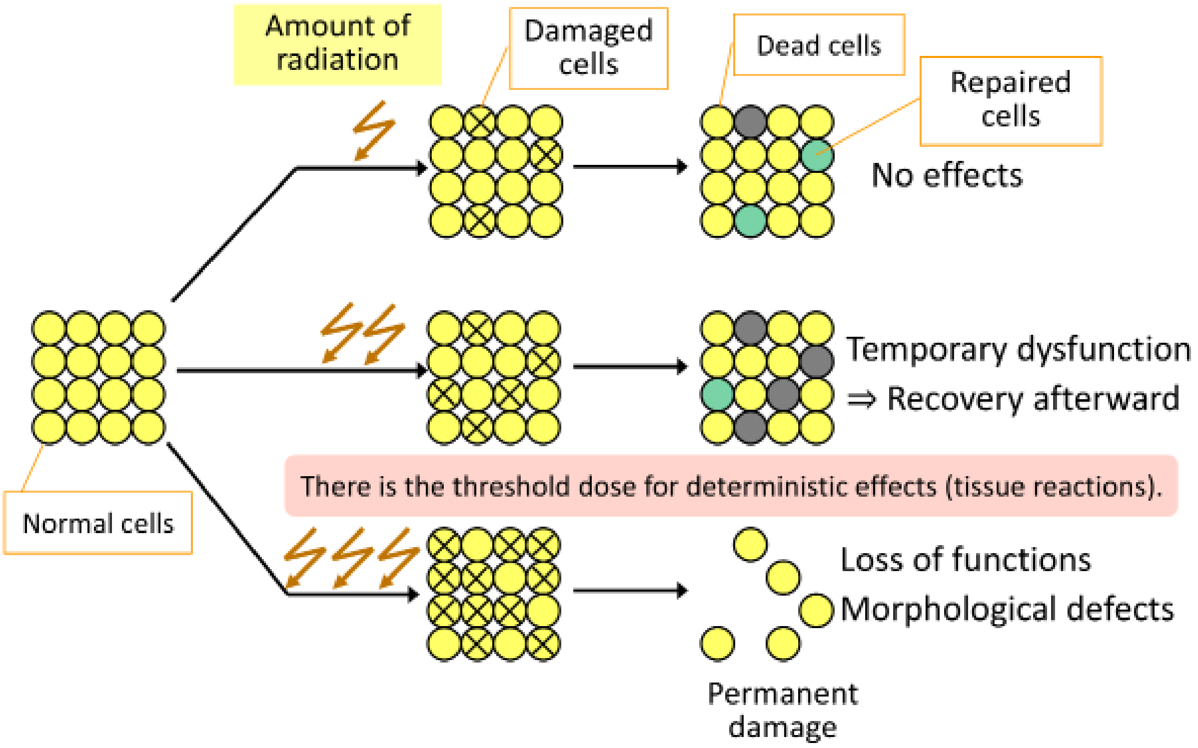
Mechanism of Causing Effects on Human Body

Cell Deaths and Deterministic Effects (Tissue Reactions)



There is the threshold dose for deterministic effects (tissue reactions).

Even if some cells die due to exposure to a small amount of radiation, if tissues and organs can fully function with the remaining cells, clinical symptoms do not appear.

When the amount of radiation increases and a larger number of cells die, relevant tissues and organs suffer temporary dysfunction and some clinical symptoms may appear. However, such symptoms improve when normal cells proliferate and increase in number.

When cells in tissues or organs are damaged severely due to a large amount of radiation, this may lead to permanent cell damage or morphological defects.

In this manner, for deterministic effects (tissue reactions) due to cell deaths, there is a certain exposure dose above which symptoms appear and under which no symptoms appear. Such dose is called the threshold dose (p.97 of Vol. 1, “Threshold Values for Various Effects”).
(Related to p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects”)

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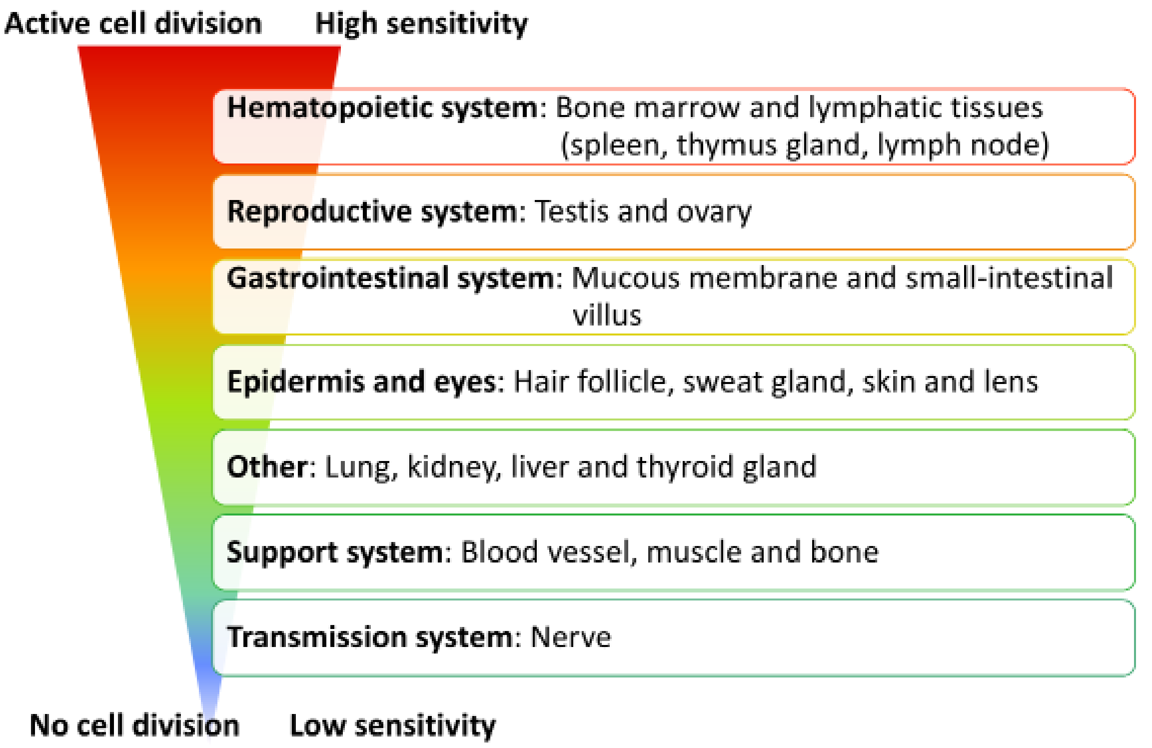
Mechanism of Causing Effects on Human Body

Radiosensitivity of Organs and Tissues



Active cell division **High sensitivity**

- **Hematopoietic system**: Bone marrow and lymphatic tissues (spleen, thymus gland, lymph node)
- **Reproductive system**: Testis and ovary
- **Gastrointestinal system**: Mucous membrane and small-intestinal villus
- **Epidermis and eyes**: Hair follicle, sweat gland, skin and lens
- **Other**: Lung, kidney, liver and thyroid gland
- **Support system**: Blood vessel, muscle and bone
- **Transmission system**: Nerve

No cell division **Low sensitivity**

Actively dividing cells that are less differentiated tend to show higher radiosensitivity. For example, hematopoietic stem cells in bone marrow are differentiated into various blood cells, while dividing actively. Immature (undifferentiated) hematopoietic cells that have divided (proliferated) from stem cells are highly sensitive to radiation and die due to a small amount of radiation more easily than differentiated cells.

As a result, the supply of blood cells is suspended and the number of various types of cells in blood decreases. In addition, the epithelium of the digestive tract is constantly metabolized and is also highly sensitive to radiation.

On the other hand, nerve tissues and muscle tissues, which no longer undergo cell division at the adult stage, are known to be resistant to radiation.

(Related to p.94 of Vol. 1, “Whole-body Exposure and Local Exposure,” and p.97 of Vol. 1, “Threshold Values for Various Effects”)

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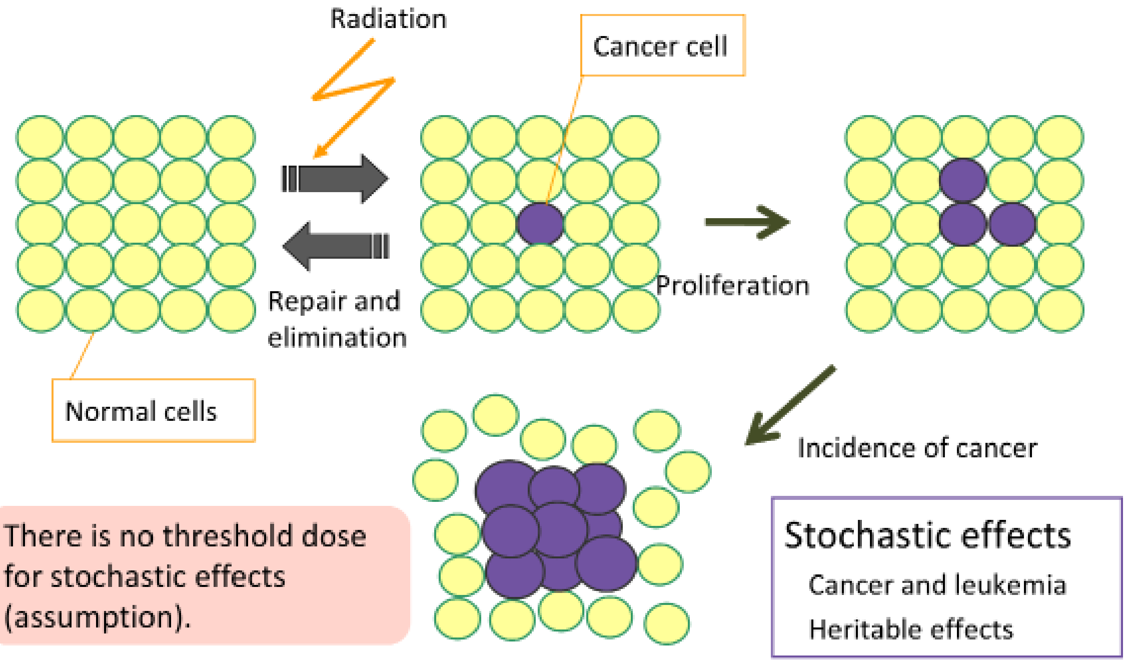
Mechanism of Causing Effects on Human Body

Cellular Mutation and Stochastic Effects



There is no threshold dose for stochastic effects (assumption).

Stochastic effects
Cancer and leukemia
Heritable effects

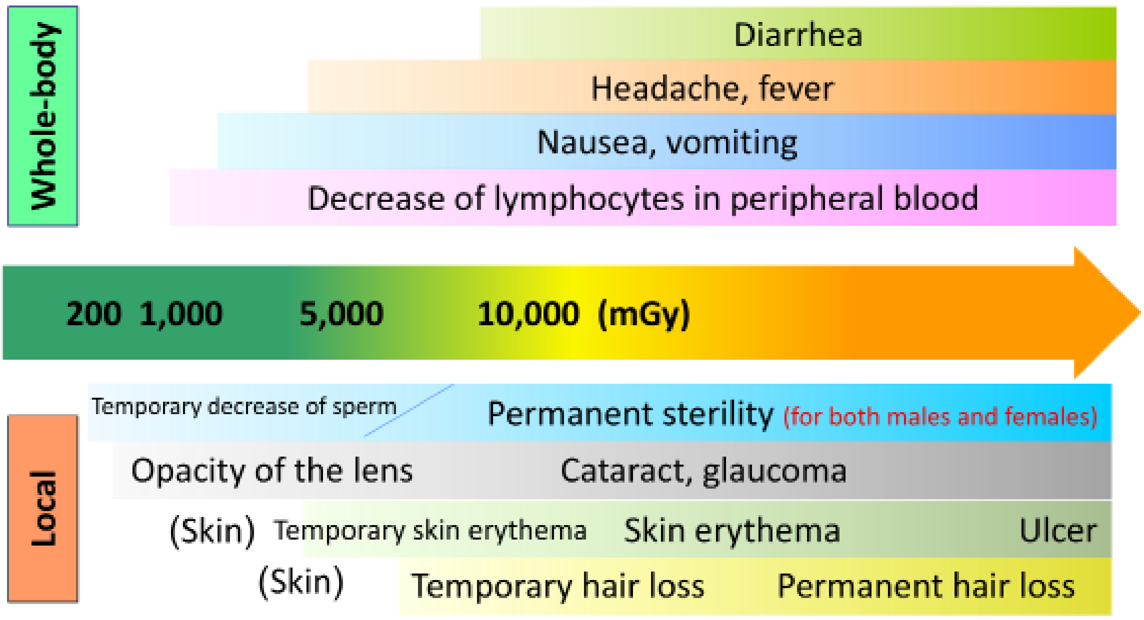
Risks of effects of cellular mutation are considered to increase even if mutation occurs in a single cell.

Mutated cells are mostly repaired or eliminated but some survive and if their descendant cells are additionally mutated or the level of gene expression changes, the possibility of developing cancer cells increases. Proliferation of cancer cells leads to clinically diagnosed cancer (diagnosed by a doctor based on physical symptoms). Cells become cancerous as multiple mutated genes have accumulated without being repaired. Therefore, when assessing cancer-promoting effects, all doses that a person has received so far need to be taken into account.

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

Deterministic Effects (Tissue Reactions)

Whole-body Exposure and Local Exposure



Source: Prepared based on the report of the Health Management Study Committee of the Nuclear Safety Commission (2000), etc.

Radiation exposure at levels exceeding 100 mGy at one time may cause effects on the human body due to cell deaths. Organs highly sensitive to radiation are more likely to be affected with a small amount of radiation.

As the testes in which cells are dividing actively are highly sensitive to radiation, even low doses of radiation at the levels of 100 to 150 mGy temporarily decrease the number of sperm and cause transient sterility. Bone marrow is also highly sensitive to radiation and lymphocytes in blood may decrease due to exposure to radiation even less than 1,000 mGy (= 1 Gy). However, these effects are naturally subdued.

On the other hand, clinical symptoms may appear that require clinical care after exposure to radiation of more than 2,000 mGy at one time.

In the case of local exposure, disorders appear in the exposed organs.

(Related to p.88 of Vol. 1, “Damage and Repair of DNA”)

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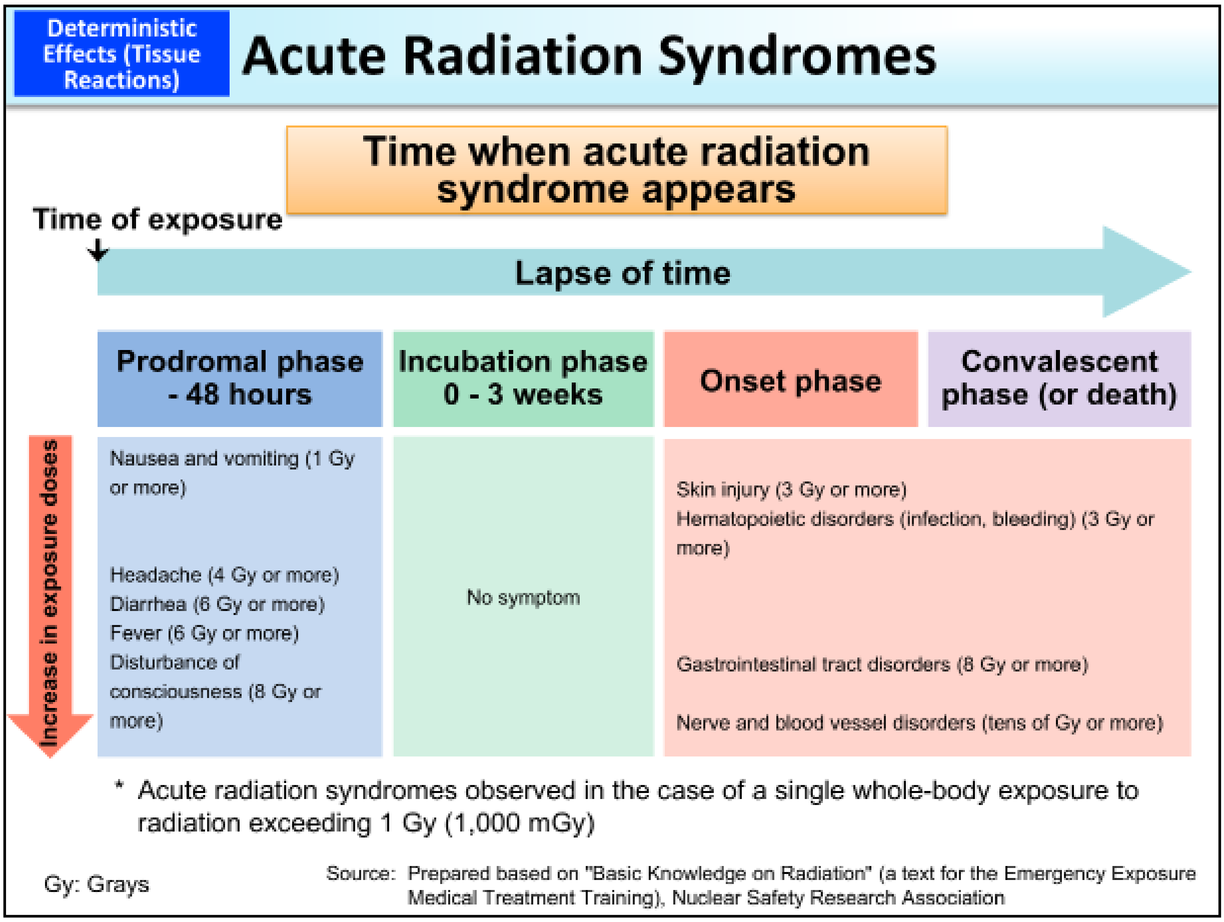

Deterministic Effects (Tissue Reactions)

Acute Radiation Syndromes

Time when acute radiation syndrome appears

Time of exposure

Lapse of time

Increase in exposure doses

Prodromal phase - 48 hours	Incubation phase 0 - 3 weeks	Onset phase	Convalescent phase (or death)
Nausea and vomiting (1 Gy or more) Headache (4 Gy or more) Diarrhea (6 Gy or more) Fever (6 Gy or more) Disturbance of consciousness (8 Gy or more)	No symptom	Skin injury (3 Gy or more) Hematopoietic disorders (infection, bleeding) (3 Gy or more) Gastrointestinal tract disorders (8 Gy or more) Nerve and blood vessel disorders (tens of Gy or more)	

* Acute radiation syndromes observed in the case of a single whole-body exposure to radiation exceeding 1 Gy (1,000 mGy)

Gy: Grays

Source: Prepared based on "Basic Knowledge on Radiation" (a text for the Emergency Exposure Medical Treatment Training), Nuclear Safety Research Association

A single whole-body exposure to radiation exceeding 1 Gy (1,000 mGy) causes disorders in various organs and tissues, leading to complicated clinical developments. This series of disorders in organs is called acute radiation syndrome, which typically follows a course from the prodromal phase to the incubation phase, the onset phase, and finally to the convalescent phase or to death in the worst case.

From prodromal symptoms that appear within 48 hours after the exposure, exposure doses can roughly be estimated (p.96 of Vol. 1, "Prodromal Phase of Acute Radiation Syndrome and Exposure Doses").

In the onset phase after the incubation phase, disorders appear in the order of hematopoietic organ, gastrointestinal tract, skin, and nerves and blood vessels, as doses increase. Disorders mainly appear in organs and tissues highly sensitive to radiation. In general, the larger the exposure dose, the shorter the incubation phase.

Skin covers a large area of 1.3 to 1.8 m^2 of the whole body of adults. Epidermis, which is the result of gradual differentiation of basal cells that are created at the basal stratum, finally becomes a stratum corneum and is separated from the body surface as scurf.

It is said to take approx. 20 to 40 days until basal cells move from the basal stratum to the skin surface, which means[1] that two to more than four weeks is required for exposed subcutaneous cells existing in the stratum corneum to the basal stratum to come up to the skin surface. Therefore, skin erythema may appear immediately after exposure depending on radiation intensity, but skin injury generally appears after the lapse of a few weeks or more (p.25 of Vol. 1, "External Exposure and Skin").

1. Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1988 "Radiation Sources, Effects and Risks," translated by the National Institute for Radiological Sciences (Jitsugyo-koho Co., Ltd.; March 1990)

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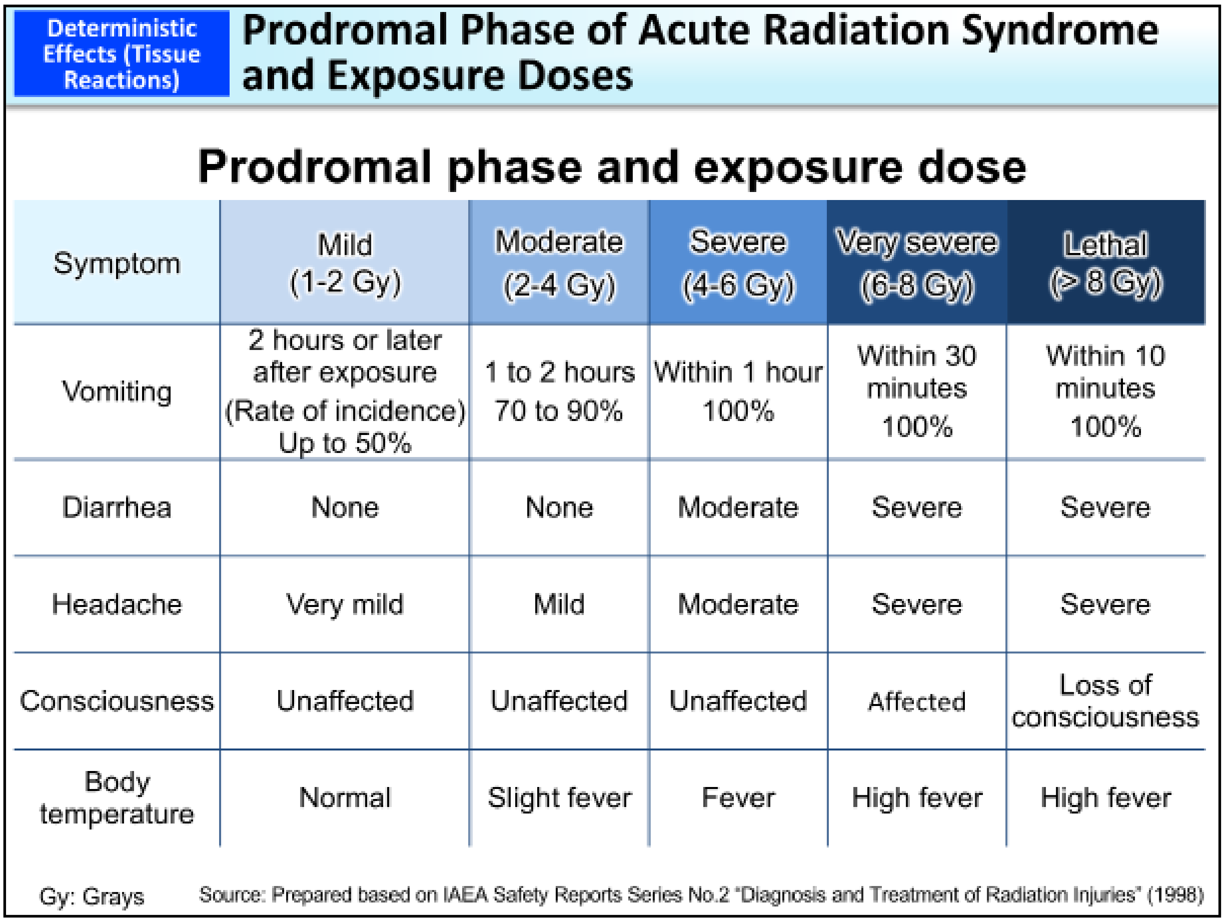


Deterministic Effects (Tissue Reactions)

Prodromal Phase of Acute Radiation Syndrome and Exposure Doses

Prodromal phase and exposure dose

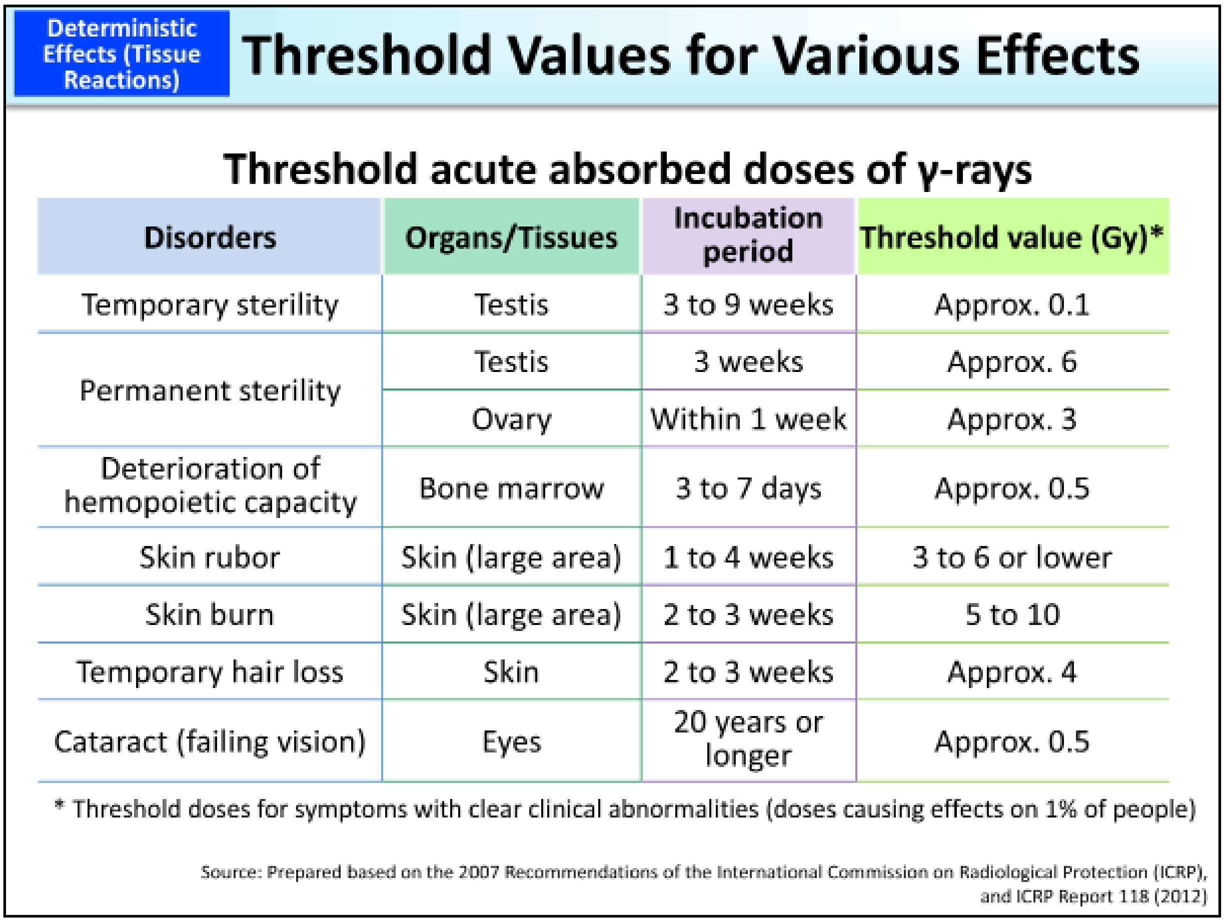
Symptom	Mild (1-2 Gy)	Moderate (2-4 Gy)	Severe (4-6 Gy)	Very severe (6-8 Gy)	Lethal (>8 Gy)
Vomiting	2 hours or later after exposure (Rate of incidence) Up to 50%	1 to 2 hours 70 to 90%	Within 1 hour 100%	Within 30 minutes 100%	Within 10 minutes 100%
Diarrhea	None	None	Moderate	Severe	Severe
Headache	Very mild	Mild	Moderate	Severe	Severe
Consciousness	Unaffected	Unaffected	Unaffected	Affected	Loss of consciousness
Body temperature	Normal	Slight fever	Fever	High fever	High fever

Gy: Grays

Source: Prepared based on IAEA Safety Reports Series No.2 "Diagnosis and Treatment of Radiation Injuries" (1998)

From prodromal symptoms that appear within 48 hours after the exposure, exposure doses can roughly be estimated in the case of acute exposure. Exposure to radiation of 1 to 2 Gy may cause loss of appetite, nausea and vomiting. In addition, very mild headache appears. Exposure to radiation of 2 to 4 Gy may cause vomiting, mild headache or slight fever (1 to 3 hours, 10 to 80% incidence). Exposure of 4 to 6 Gy causes 100% incidence of vomiting within one hour after exposure and also causes moderate diarrhea and headache as well as 80 to 100% incidence of fever. Exposure of 6 to 8 Gy causes 100% incidence of vomiting within 30 minutes and also causes severe diarrhea/headache as well as 100% incidence of high fever. Furthermore, disturbance of consciousness may appear. Exposure to radiation exceeding 8 Gy causes 100% incidence of vomiting within 10 minutes and causes symptoms such as severe diarrhea/headache, high fever and loss of consciousness.

Included in this reference material on March 31, 2021



Deterministic Effects (Tissue Reactions)

Threshold Values for Various Effects

Threshold acute absorbed doses of γ-rays

Disorders	Organs/Tissues	Incubation period	Threshold value (Gy)*
Temporary sterility	Testis	3 to 9 weeks	Approx. 0.1
Permanent sterility	Testis	3 weeks	Approx. 6
	Ovary	Within 1 week	Approx. 3
Deterioration of hemopoietic capacity	Bone marrow	3 to 7 days	Approx. 0.5
Skin rubor	Skin (large area)	1 to 4 weeks	3 to 6 or lower
Skin burn	Skin (large area)	2 to 3 weeks	5 to 10
Temporary hair loss	Skin	2 to 3 weeks	Approx. 4
Cataract (failing vision)	Eyes	20 years or longer	Approx. 0.5

* Threshold doses for symptoms with clear clinical abnormalities (doses causing effects on 1% of people)

Source: Prepared based on the 2007 Recommendations of the International Commission on Radiological Protection (ICRP), and ICRP Report 118 (2012)

Sensitivity to radiation differs by organ (p.92 of Vol. 1, "Radiosensitivity of Organs and Tissues").

The most sensitive organs include the testes. When the testes are exposed to γ-rays or other types of radiation exceeding 0.1 Gy (100 mGy) at one time, this may cause temporary sterility with a temporary decrease in the number of sperm, which is due to radiation damage to cells in the testes that create sperm.

Also if bone marrow is irradiated by more than 0.5 Gy (500 mGy) at one time, the hematopoietic function is impaired and a total number of blood cells may decrease.

Some deterministic effects (tissue reactions), such as cataract, take several years to appear.

The threshold dose for cataract had been set at 1.5 Gy, but the ICRP revised this value downward to approx. 0.5 Gy and set a new equivalent dose limit for the eye lens for occupational exposures.

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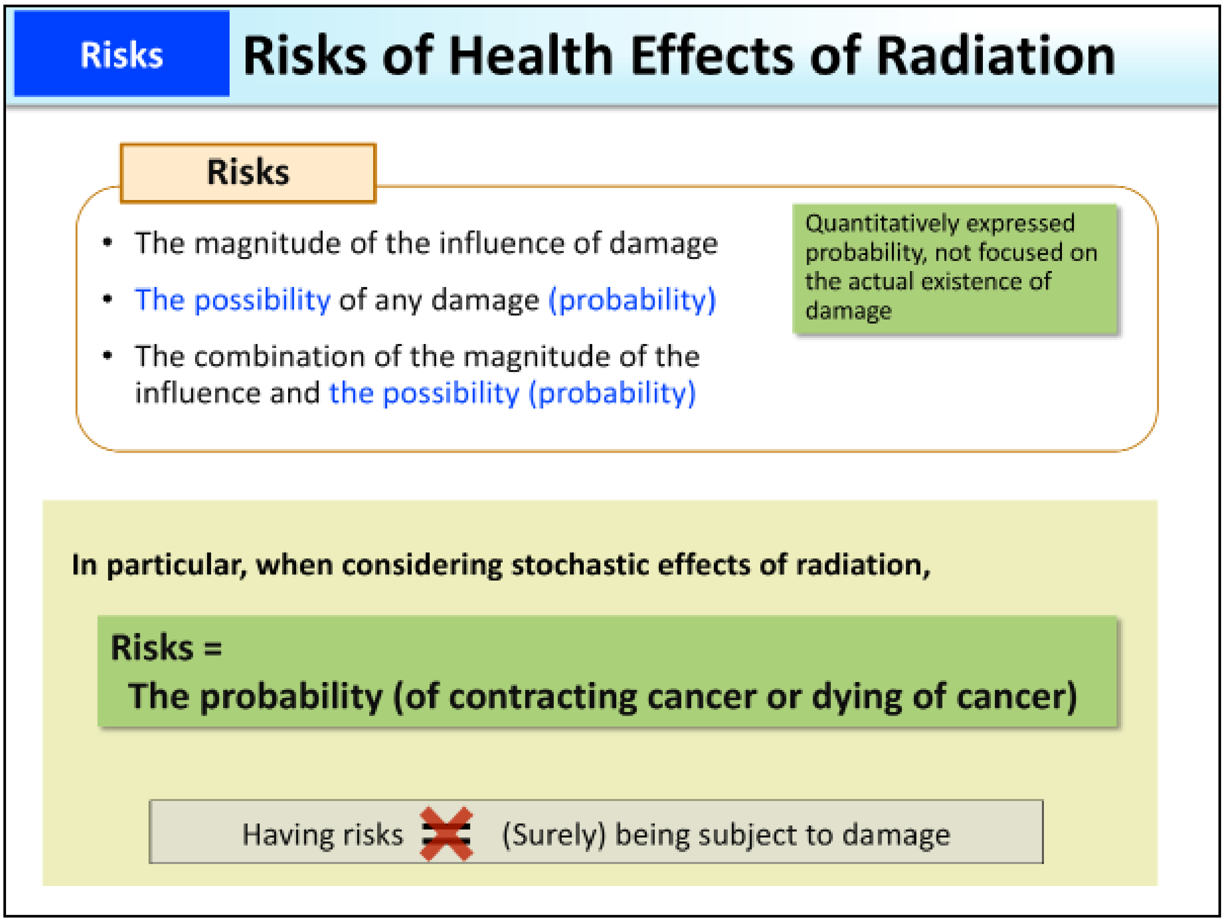


Risks Risks of Health Effects of Radiation

Risks

- The magnitude of the influence of damage
- The possibility of any damage (probability)
- The combination of the magnitude of the influence and the possibility (probability)

Quantitatively expressed probability, not focused on the actual existence of damage

In particular, when considering stochastic effects of radiation,

Risks =
The probability (of contracting cancer or dying of cancer)

Having risks ≠ (Surely) being subject to damage

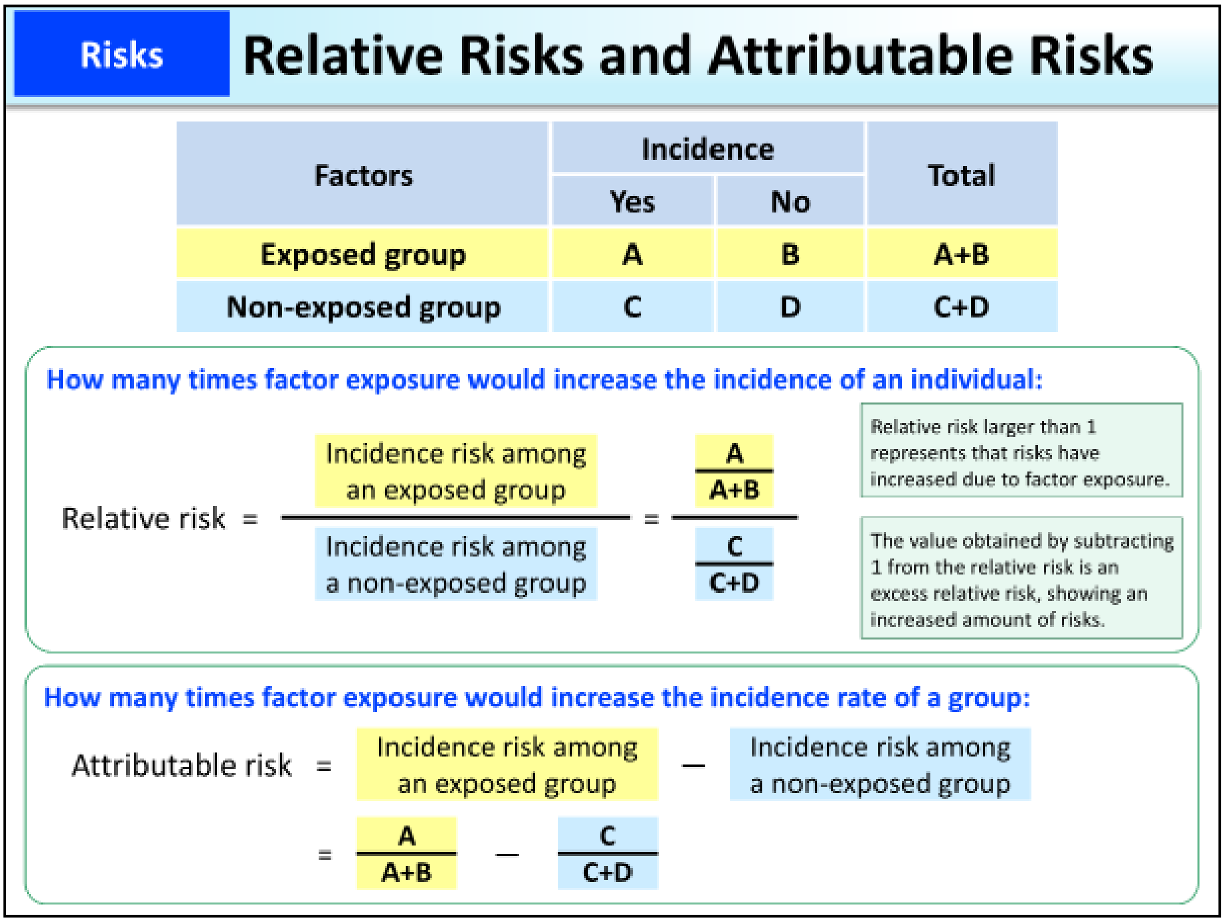
The term “risk” generally means “dangerousness” or “degree of hazard.” However, more strictly, the term is used to refer to “the magnitude of the influence of damage,” “the possibility of any damage (probability),” or “the combination of the magnitude of the influence and the possibility (probability).” The focus is not on “whether or not there are any risks” but on “to what extent or by how many times risks increase.”

On the other hand, what causes damage is called “hazard.” It is important to clearly distinguish hazard information on the existence or non-existence of hazards and risk information on the degree and probability of damage, and properly communicate and utilize these two types of information.

When considering health effects of radiation, in particular, stochastic effects of radiation, it is common to use the term “risk” in the sense of “the probability (of contracting cancer or dying of cancer).”

In this case, it should be noted that “having risks” is not equal to “(surely) being subject to damage.”

Included in this reference material on February 28, 2018



Risks

Relative Risks and Attributable Risks

Factors	Incidence		Total
	Yes	No	
Exposed group	**A**	**B**	**A+B**
Non-exposed group	**C**	**D**	**C+D**

How many times factor exposure would increase the incidence of an individual:

$$\text{Relative risk} = \frac{\text{Incidence risk among an exposed group}}{\text{Incidence risk among a non-exposed group}} = \frac{\frac{A}{A+B}}{\frac{C}{C+D}}$$

Relative risk larger than 1 represents that risks have increased due to factor exposure.

The value obtained by subtracting 1 from the relative risk is an excess relative risk, showing an increased amount of risks.

How many times factor exposure would increase the incidence rate of a group:

$$\text{Attributable risk} = \text{Incidence risk among an exposed group} - \text{Incidence risk among a non-exposed group}$$

$$= \frac{A}{A+B} - \frac{C}{C+D}$$

A relative risk represents how many times a certain factor increases the risk of an individual exposed thereto. In epidemiology, the term “risk” normally refers to a relative risk. The value obtained by subtracting 1 from the relative risk is an excess relative risk and shows an increased amount of risks compared with a group free from risk factors. There is also an attributable risk that represents how much a certain factor increases the incidence or mortality rate of a group.

Suppose a group is exposed to some risk factor while another group is not, and there are 2 patients of a certain disease among one million people in the non-exposed group, while there are 3 patients among one million people in the exposed group.

Then, an increase in the number of patients from 2 to 3 is construed to mean that the relative risk has increased by 1.5 times from the perspective of how much more an individual is likely to develop a disease.

On the other hand, as an attributable risk focuses on increases in the number of patients in a group, the increase is construed as one in a million, that is, an increase of 10^{-6} in risk.

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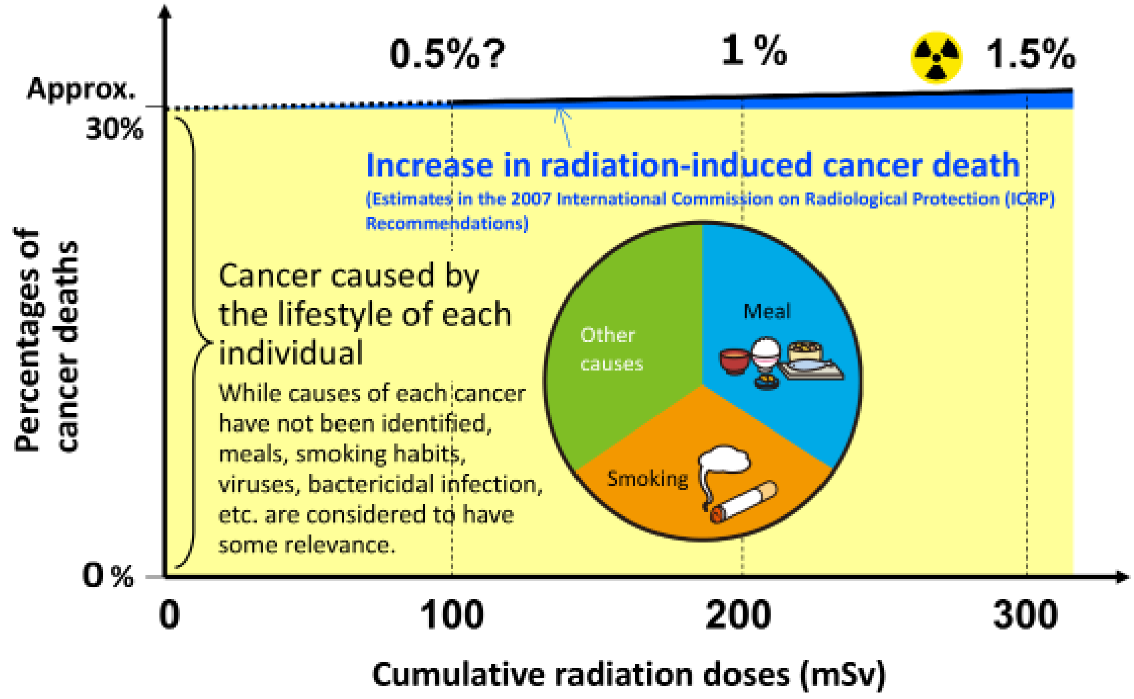
Risks

Risks of Cancer Death from Low-Dose Exposure



The International Commission on Radiological Protection (ICRP) considers radiological protection based on the idea that in a group of people including both adults and children, the probability of cancer death increases by 0.5% per 100-mSv exposure. This value shows estimated risk of low-dose exposure based on data obtained from atomic bomb survivors (p.117 of Vol. 1, “Relationship between Solid Cancer Deaths and Doses”).

Currently, the leading cause of deaths among Japanese people is cancer, with around 30% of the entire population dying of cancer.

That is, 300 people in a group of 1,000 will die of cancer. If the probability of death from radiation-induced cancer is added, it can be estimated that if all people in such group of 1,000 people are exposed to 100 mSv, 305 will die of cancer in their lifetime.

However, in actuality, the value of 300 out of 1,000 people could vary from year to year and from region to region,[1] and no methods have been established yet to confirm if cancer is really attributable to radiation exposure. It is thus considered very difficult to actually detect an increase in cancer deaths among people exposed to not higher than 100 mSv, i.e., an increase of up to 5 people in a group of 1,000.

1. Comparison of age-adjusted mortality rates among prefectures in Japan in FY2010 shows that the mortality against 100,000 people varies from 248.8 people (Nagano) to 304.3 people (Aomori) for females and from 477.3 people (Nagano) to 662.4 people (Aomori) for males. The mortality rate from cancer also varies from 29.0% (Okinawa) to 35.8% (Nara) for males and from 29.9% (Yamanashi) to 36.1% (Kyoto) for females.

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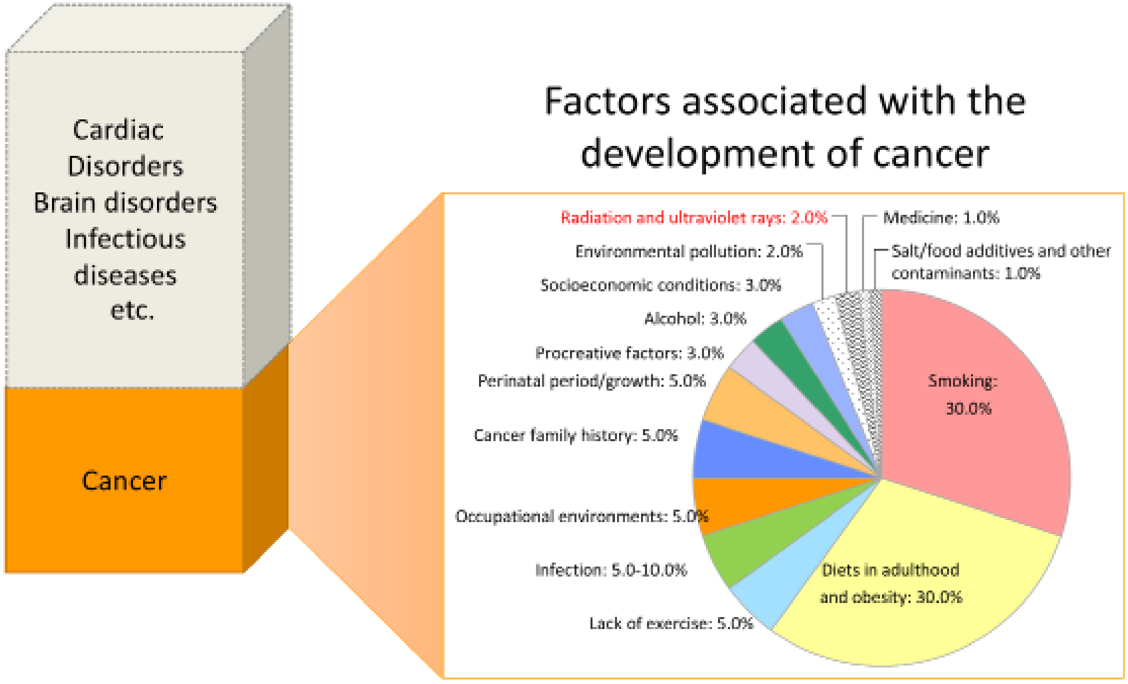
Risks Factors Associated with Carcinogenesis



Source: Prepared based on Cancer Causes Control 1996.7.S55-S58

We are surrounded by various risk factors for cancer in our lives. The pie chart above provides U.S. data, which gives an idea that meals and smoking habits are closely associated with the development of cancer. If having been exposed to radiation, risks due to radiation are to be added to these factors. Accordingly, it is best to avoid radiation exposure from the viewpoint of reducing risks of cancer.

It may be possible to refuse X-ray examinations or avoid taking flights, but that would make early detection of diseases impossible and make life inconvenient, and such efforts would not dramatically reduce the risks of developing cancer due to the existence of various cancer-causing factors other than radiation in our lives.

(Related to p.102 of Vol. 1, “Risks of Cancer (Radiation),” and p.103 of Vol. 1, “Risks of Cancer (Life Habits)”)

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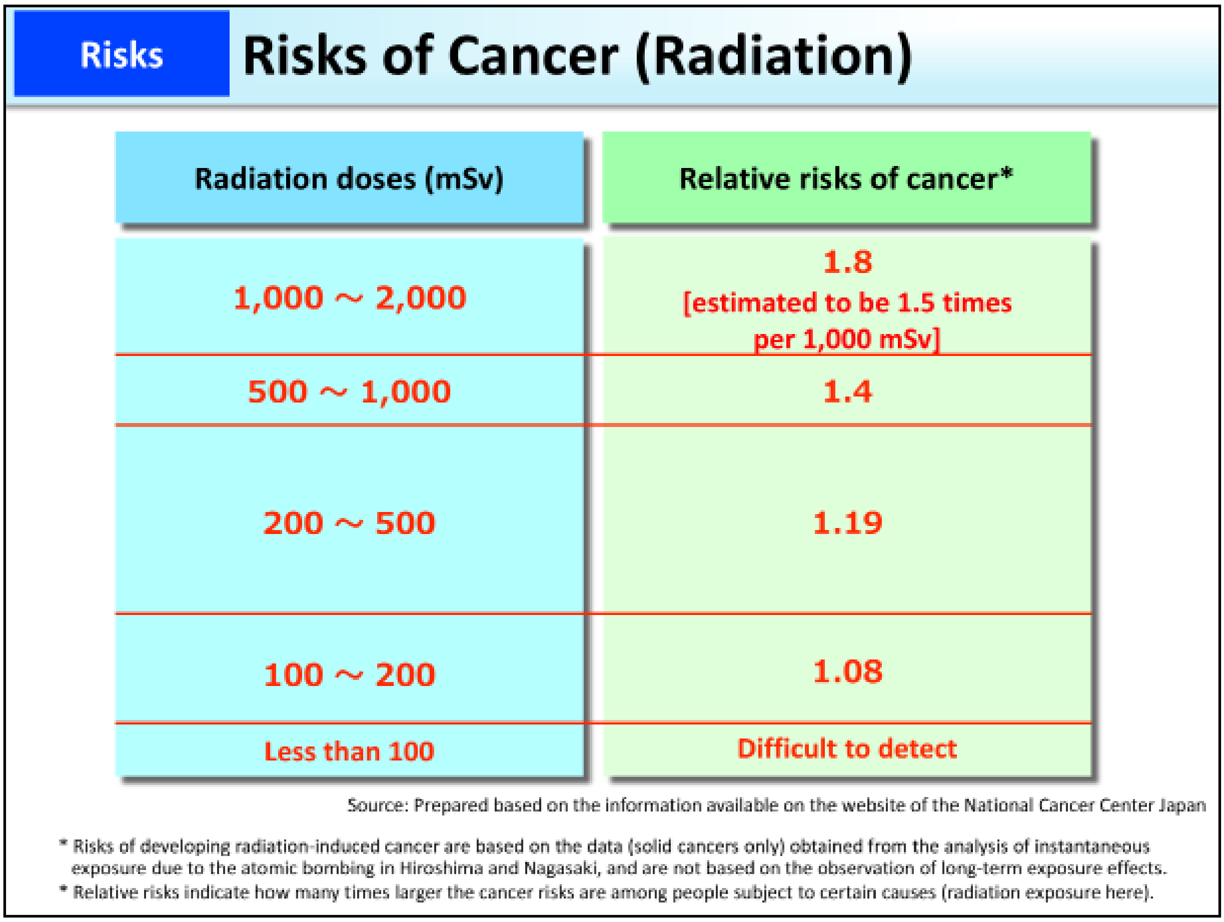
Updated on March 31, 2019



Risks Risks of Cancer (Radiation)

Radiation doses (mSv)	Relative risks of cancer*
1,000 ～ 2,000	1.8 [estimated to be 1.5 times per 1,000 mSv]
500 ～ 1,000	1.4
200 ～ 500	1.19
100 ～ 200	1.08
Less than 100	Difficult to detect

Source: Prepared based on the information available on the website of the National Cancer Center Japan

* Risks of developing radiation-induced cancer are based on the data (solid cancers only) obtained from the analysis of instantaneous exposure due to the atomic bombing in Hiroshima and Nagasaki, and are not based on the observation of long-term exposure effects.

* Relative risks indicate how many times larger the cancer risks are among people subject to certain causes (radiation exposure here).

The table above shows the effects of radiation exposure doses on the relative risks of cancer released by the National Cancer Center Japan.

It is estimated that the relative risk increases by 1.8 times due to radiation exposure doses of 1,000 to 2,000 mSv, by 1.4 times due to doses of 500 to 1,000 mSv and by 1.19 times due to doses of 200 to 500 mSv.

In the case of radiation exposure below 100 mSv, it is considered to be extremely difficult to detect the risk of developing cancer.

(Related to p.103 of Vol. 1, “Risks of Cancer (Life Habits)”)

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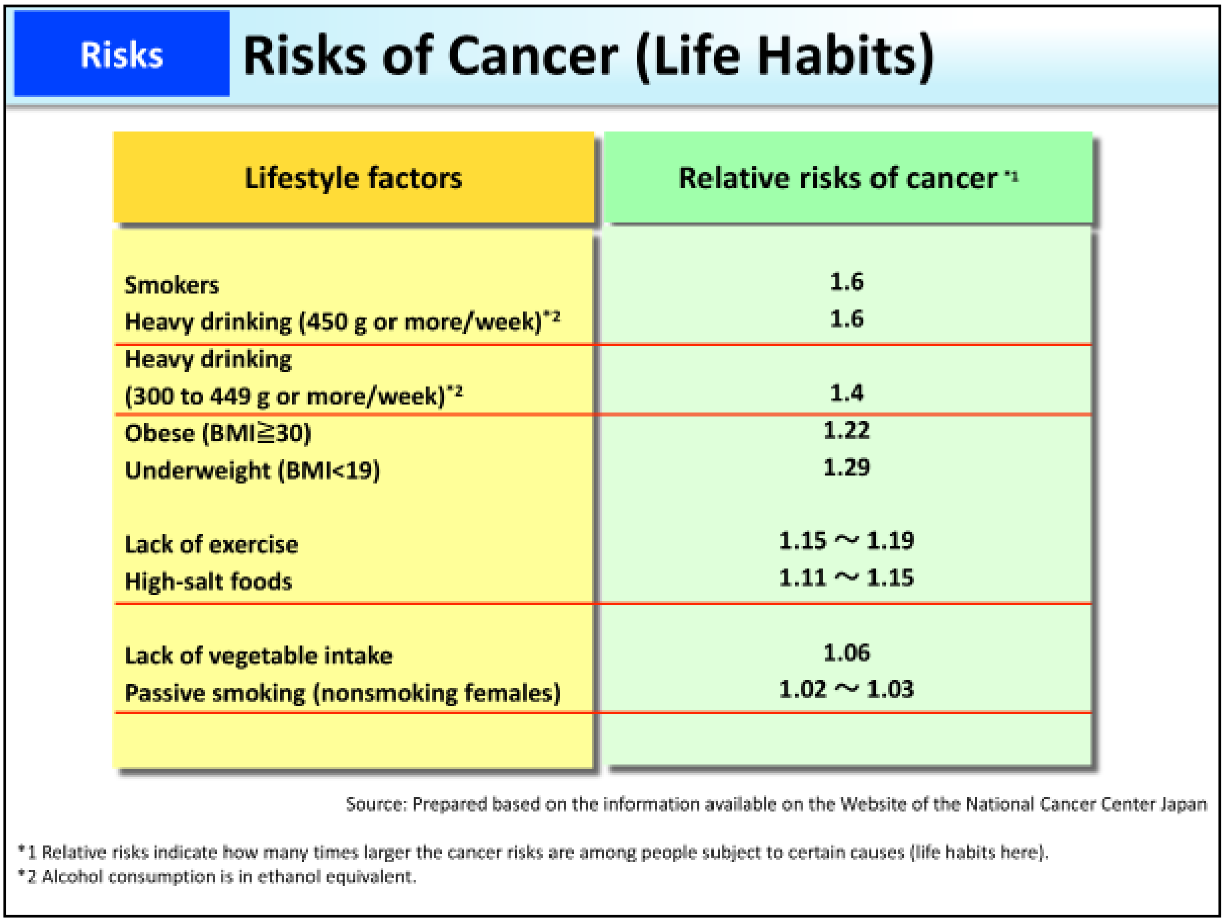

Risks

Risks of Cancer (Life Habits)

Lifestyle factors	Relative risks of cancer [1]
Smokers	1.6
Heavy drinking (450 g or more/week)[2]	1.6
Heavy drinking (300 to 449 g or more/week)[2]	1.4
Obese (BMI≧30)	1.22
Underweight (BMI<19)	1.29
Lack of exercise	1.15 ～ 1.19
High-salt foods	1.11 ～ 1.15
Lack of vegetable intake	1.06
Passive smoking (nonsmoking females)	1.02 ～ 1.03

Source: Prepared based on the information available on the Website of the National Cancer Center Japan

[1] Relative risks indicate how many times larger the cancer risks are among people subject to certain causes (life habits here).
[2] Alcohol consumption is in ethanol equivalent.

The table above shows relative risks of cancer due to respective life habits as released by the National Cancer Center Japan.

It is estimated that the relative risk of cancer for people who smoke or drink a lot is 1.6 times higher than that for people who do not. It is also estimated that factors, such as obesity, lack of exercise, and lack of vegetable intake, will make the relative risks of cancer higher by 1.22 times, 1.15 to 1.19 times and 1.06 times, respectively.

(Related to p.101 of Vol. 1, “Factors Associated with Carcinogenesis,” and p.102 of Vol. 1, “Risks of Cancer (Radiation)”)

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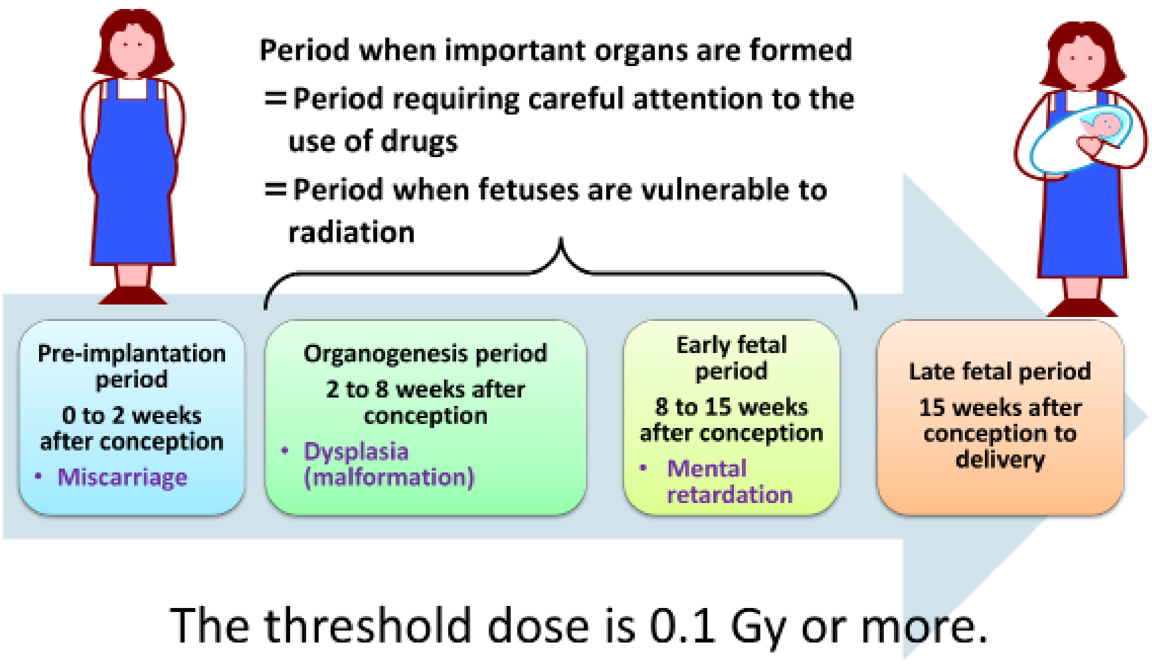
Effects on Fetuses

Deterministic Effects (Tissue Reactions) and Time Specificity



Period when important organs are formed
= Period requiring careful attention to the use of drugs
= Period when fetuses are vulnerable to radiation

Pre-implantation period
0 to 2 weeks after conception
- Miscarriage

Organogenesis period
2 to 8 weeks after conception
- Dysplasia (malformation)

Early fetal period
8 to 15 weeks after conception
- Mental retardation

Late fetal period
15 weeks after conception to delivery

The threshold dose is 0.1 Gy or more.

* The time generally considered as two-week pregnancy is equivalent to zero weeks after conception.

Deterministic effects (tissue reactions) include fetal effects for which the threshold dose is especially low. When a pregnant woman is exposed to radiation and radiation passes through her womb or radioactive materials migrate into her womb, her unborn baby may also be exposed to radiation.

It is known that fetuses are highly sensitive to radiation and incidence of effects has time specificity. Radiation exposure exceeding 0.1 Gy at an early stage of pregnancy (pre-implantation period) may lead to miscarriage.

After this period, the possibility of miscarriage decreases, but radiation exposure exceeding 0.1 Gy during the period when important organs are formed (organogenesis period) may cause dysplasia (malformation). Radiation exposure exceeding 0.3 Gy during the period when the cerebrum is actively growing (early fetal period) poses risks of mental retardation (p.105 of Vol. 1, “Mental Retardation”).

The period when fetuses are highly sensitive to radiation coincides with the period during which pregnant women are advised not to take drugs carelessly. During this period before the stable period, fetuses are vulnerable to both drugs and radiation. Fetal effects are caused by radiation exposure exceeding 0.1 Gy. Therefore, the International Commission on Radiological Protection (ICRP) states in its 2007 Recommendations that a fetal absorbed dose less than 0.1 Gy should not be considered as a ground for abortion. Exposure to 0.1 Gy of radiation is equivalent to exposure to 100 mSv of γ-rays or X-rays at one time. Incidentally, fetuses’ exposure doses are not always the same as their mothers’ exposure doses. Risks of stochastic effects such as cancer or heritable effects also increase depending on exposure dose levels.

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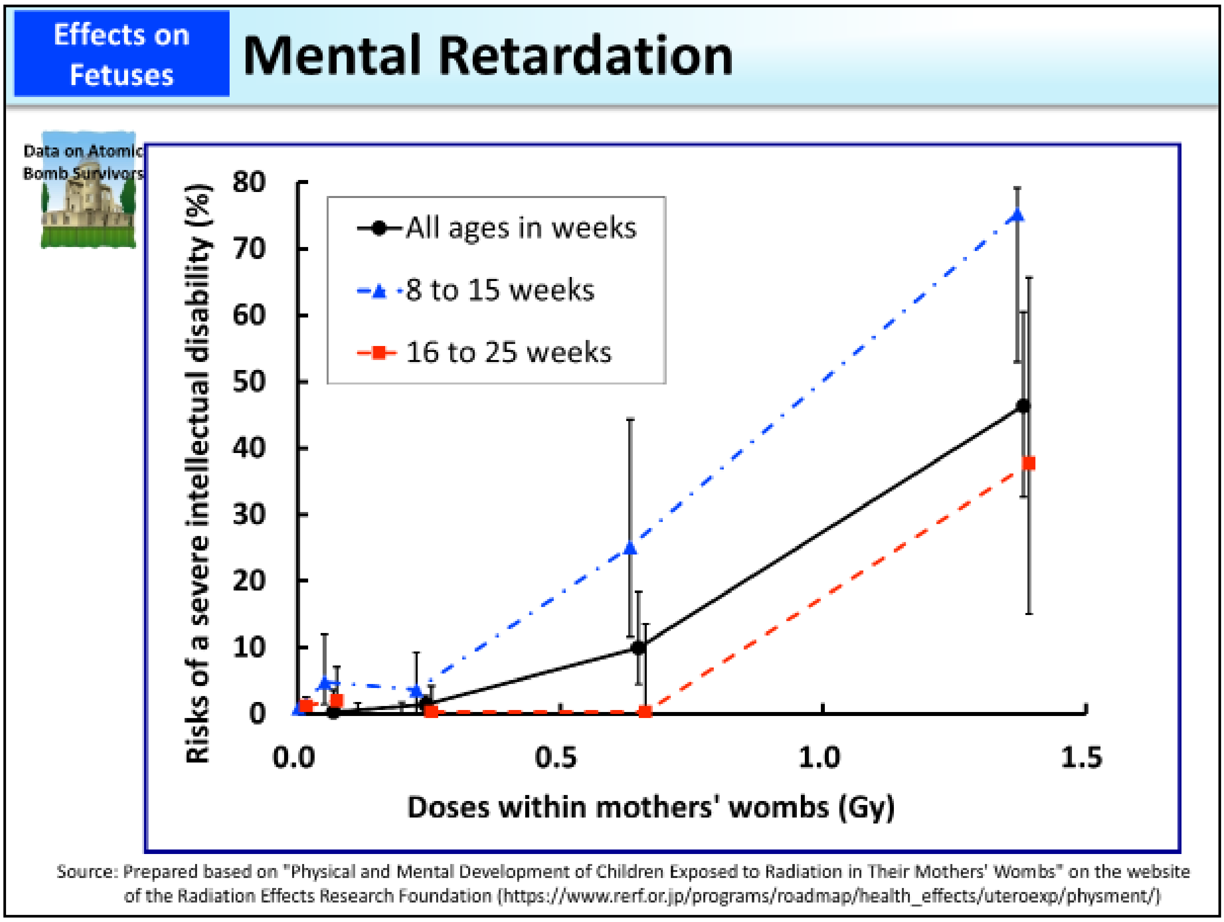

Effects on Fetuses

Mental Retardation

Source: Prepared based on "Physical and Mental Development of Children Exposed to Radiation in Their Mothers' Wombs" on the website of the Radiation Effects Research Foundation (https://www.rerf.or.jp/programs/roadmap/health_effects/uteroexp/physment/)

Time specificity in fetal effects was made clear through health surveys on a group of people who were exposed to radiation in their mothers' wombs due to the atomic bombing.

This figure shows the relationship between ages in weeks at the time of the atomic bombing and its effects on fetuses' mental development.

Those aged 8 to 15 weeks show high radiosensitivity and the threshold value for exposure doses in mothers' wombs seems to be between 0.1 Gy and 0.2 Gy. In the range above this level, the incidence rate of a severe intellectual disability increases as doses increase, as observed in the figure.

On the other hand, a severe intellectual disability is not observed among those who were aged 16 to 25 weeks and were exposed to radiation at doses around 0.5 Gy, but radiation exposure exceeding 1 Gy caused mental disorders at a significant frequency.

In other words, the incidence rates of disorders differ depending on whether radiation exposure occurred at the age of 8 to 15 weeks or at the age of 16 to 25 weeks, even if the total exposure doses were the same.

(Related to p.104 of Vol. 1, "Deterministic Effects (Tissue Reactions) and Time Specificity")

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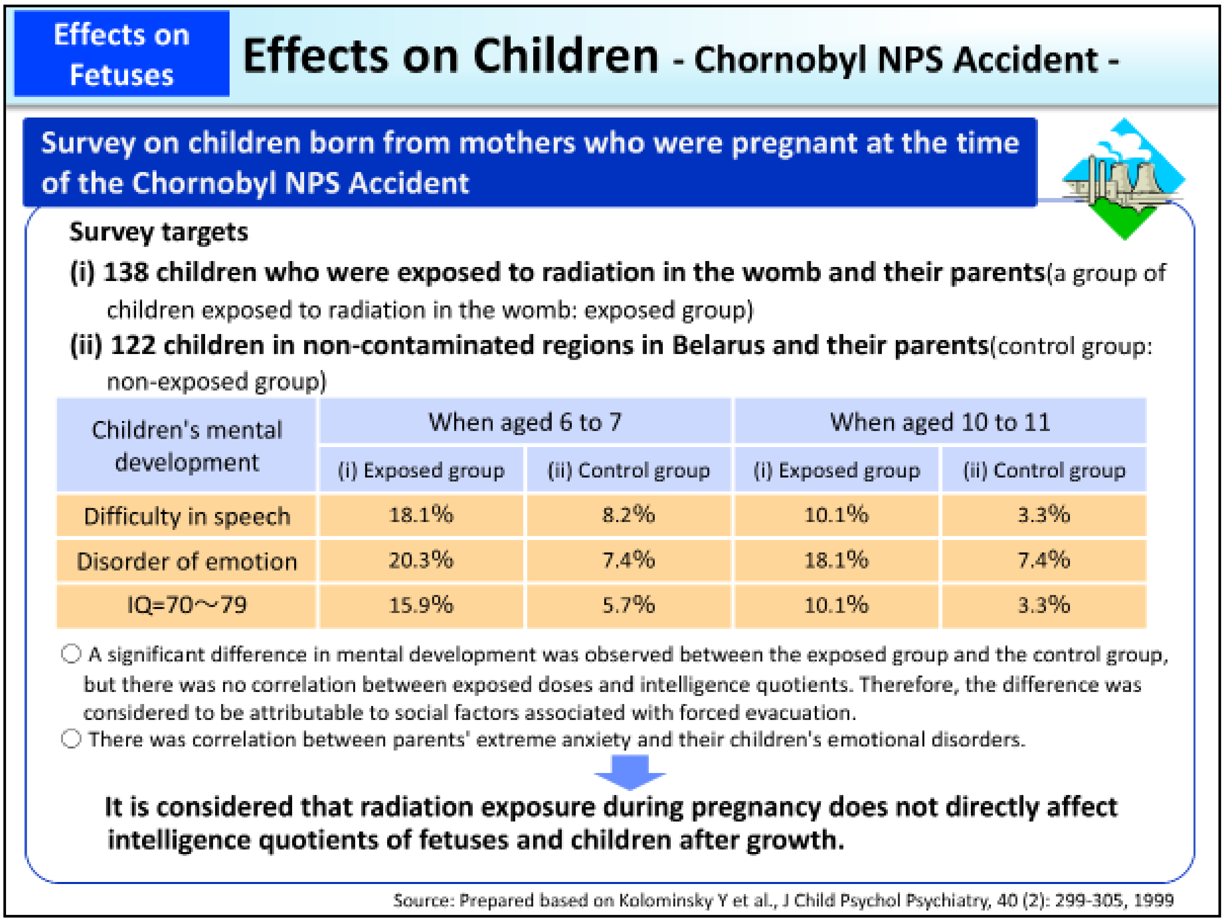

Effects on Fetuses

Effects on Children - Chornobyl NPS Accident -

Survey on children born from mothers who were pregnant at the time of the Chornobyl NPS Accident

Survey targets

(i) 138 children who were exposed to radiation in the womb and their parents(a group of children exposed to radiation in the womb: exposed group)

(ii) 122 children in non-contaminated regions in Belarus and their parents(control group: non-exposed group)

Children's mental development	When aged 6 to 7		When aged 10 to 11	
	(i) Exposed group	(ii) Control group	(i) Exposed group	(ii) Control group
Difficulty in speech	18.1%	8.2%	10.1%	3.3%
Disorder of emotion	20.3%	7.4%	18.1%	7.4%
IQ=70～79	15.9%	5.7%	10.1%	3.3%

○ A significant difference in mental development was observed between the exposed group and the control group, but there was no correlation between exposed doses and intelligence quotients. Therefore, the difference was considered to be attributable to social factors associated with forced evacuation.

○ There was correlation between parents' extreme anxiety and their children's emotional disorders.

It is considered that radiation exposure during pregnancy does not directly affect intelligence quotients of fetuses and children after growth.

Source: Prepared based on Kolominsky Y et al., J Child Psychol Psychiatry, 40 (2): 299-305, 1999

Researchers in Belarus conducted surveys targeting 138 children born from mothers who were pregnant and were residing near the nuclear power plant at the time of the Chornobyl NPS Accident and 122 children born from mothers who were pregnant at the time of the accident but were exposed to little radiation. The surveys were conducted twice when survey targets were aged 6 to 7 and when they were aged 10 to 11 in order to study effects of radiation exposure in the womb on their mental development.

In both surveys, incidences of difficulty in speech and disorder of emotion were larger among the exposed group than among non-exposed group with statistically significant differences.

Regarding intelligence quotient, fewer children in the exposed group were above the average compared with the non-exposed group and children on the borderline between normal levels and mental retardation were clearly larger in number.

However, no correlation has been found between estimated absorbed doses to the thyroid in fetal life and intelligence quotient and possibilities of other factors are suggested such as social-psychological and sociocultural factors (school education and guardians' academic levels, etc.) associated with forced evacuation from contaminated regions. The possibility that radiation exposure during pregnancy has directly affected the intelligence quotients of fetuses and children after growth is considered to be low.

A survey targeting parents using a stress evaluation index revealed clear correlation between parents' anxiety and children's emotional disorders.

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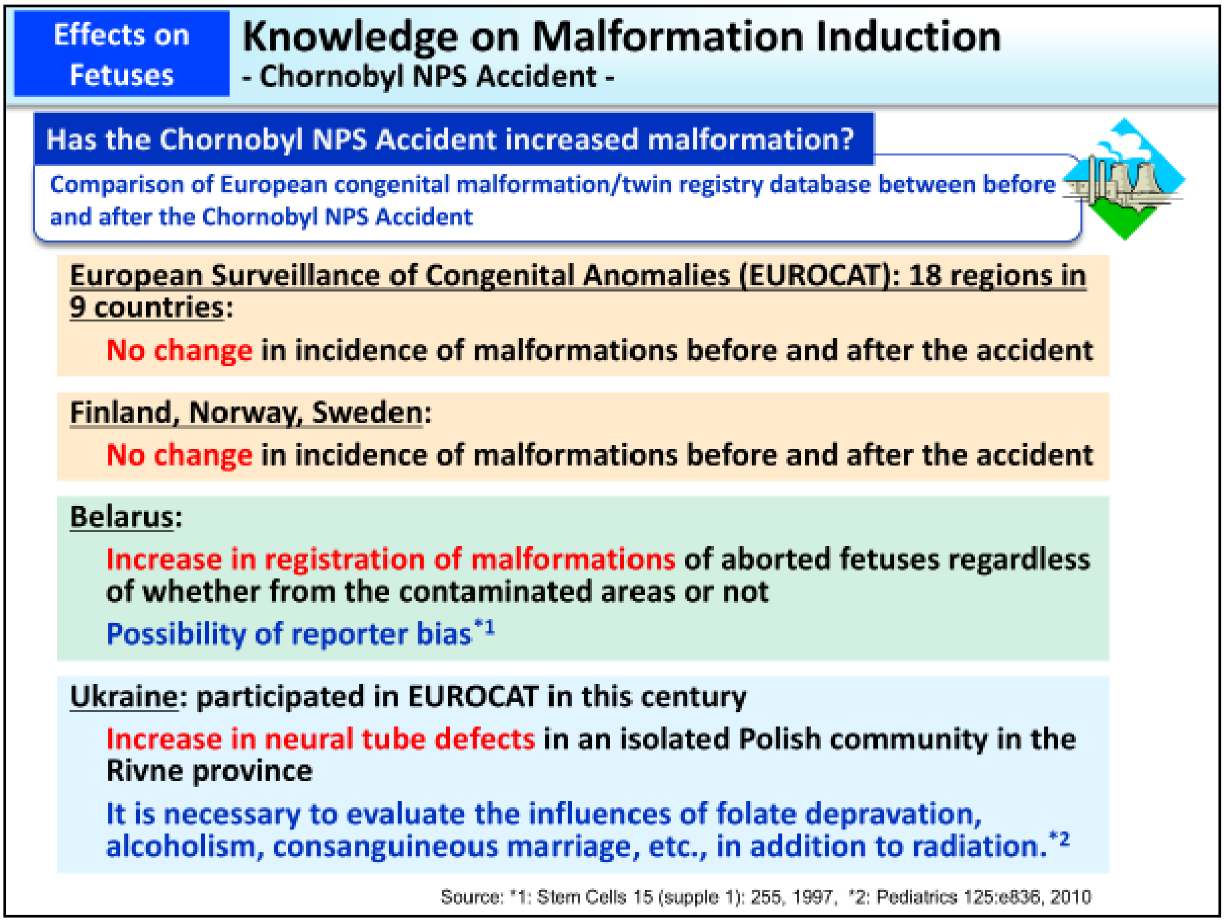

Effects on Fetuses

Knowledge on Malformation Induction

- Chornobyl NPS Accident -

Has the Chornobyl NPS Accident increased malformation?

Comparison of European congenital malformation/twin registry database between before and after the Chornobyl NPS Accident

European Surveillance of Congenital Anomalies (EUROCAT): 18 regions in 9 countries:

No change in incidence of malformations before and after the accident

Finland, Norway, Sweden:

No change in incidence of malformations before and after the accident

Belarus:

Increase in registration of malformations of aborted fetuses regardless of whether from the contaminated areas or not

Possibility of reporter bias*1

Ukraine: participated in EUROCAT in this century

Increase in neural tube defects in an isolated Polish community in the Rivne province

It is necessary to evaluate the influences of folate depravation, alcoholism, consanguineous marriage, etc., in addition to radiation.*2

Source: *1: Stem Cells 15 (supple 1): 255, 1997, *2: Pediatrics 125:e836, 2010

There have been various reports on the incidence of congenital anomalies before and after the Chornobyl NPS Accident. Comparison of databases of the European Surveillance of Congenital Anomalies (EUROCAT), and of Finland, Norway, and Sweden showed no change in incidence of malformations before and after the accident.

In the northern part of the Rivne province of Ukraine, there are people who live a self-sufficient life in a contaminated area. There is a report that neural tube defects have been increasing among them, and analysis is underway to determine whether it has been caused by radiation.

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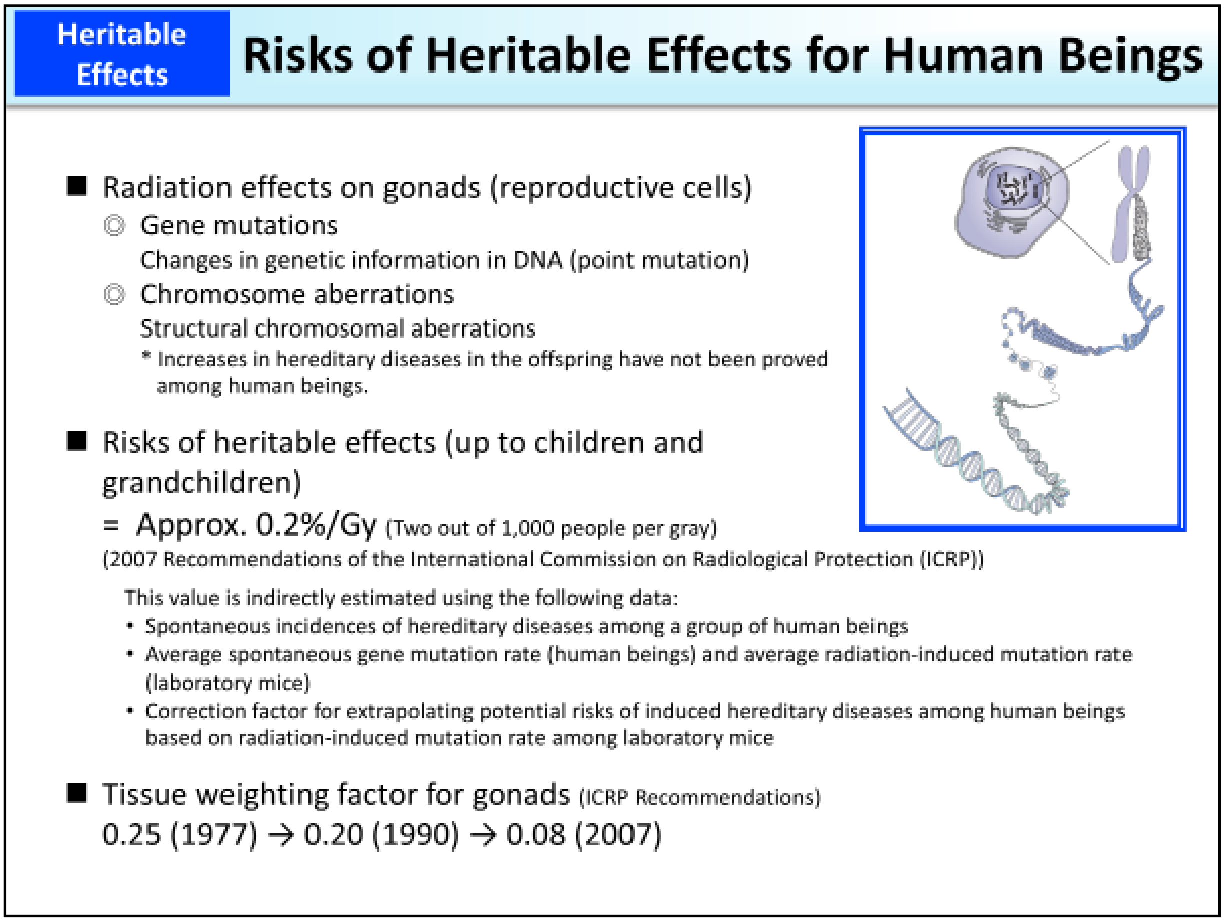

Heritable Effects

Risks of Heritable Effects for Human Beings

- Radiation effects on gonads (reproductive cells)
  - ◎ Gene mutations
    Changes in genetic information in DNA (point mutation)
  - ◎ Chromosome aberrations
    Structural chromosomal aberrations
    * Increases in hereditary diseases in the offspring have not been proved among human beings.
- Risks of heritable effects (up to children and grandchildren)
  = Approx. 0.2%/Gy (Two out of 1,000 people per gray)
  (2007 Recommendations of the International Commission on Radiological Protection (ICRP))

  This value is indirectly estimated using the following data:
  - Spontaneous incidences of hereditary diseases among a group of human beings
  - Average spontaneous gene mutation rate (human beings) and average radiation-induced mutation rate (laboratory mice)
  - Correction factor for extrapolating potential risks of induced hereditary diseases among human beings based on radiation-induced mutation rate among laboratory mice
- Tissue weighting factor for gonads (ICRP Recommendations)
  0.25 (1977) → 0.20 (1990) → 0.08 (2007)

In animal testing, when parents are exposed to high-dose radiation, congenital disorders and chromosomal aberrations are sometimes found in their offspring. However, there has been no evidence to prove that parents' radiation exposure increases hereditary diseases in their offspring in the case of human beings. The ICRP estimates risks of heritable effects as 0.2% per gray. This is even less than one-twentieth of the risk of death by cancer. Furthermore, the ICRP assumes that the exposure dose that doubles the spontaneous gene mutation rate (doubling dose) is the same at 1 Gy for human beings and laboratory mice. However, heritable effects have not been confirmed for human beings and there is the possibility that this ICRP estimate is overrated.

Targeting children of atomic bomb survivors, life-span surveys, health effects checks, and surveys on various molecular levels have been conducted. Results of these surveys have made it clear that risks of heritable effects had been overestimated. Accordingly, the tissue weighting factor for gonads was reduced in the ICRP Recommendations released in 1990 and further in the ICRP Recommendations released in 2007.

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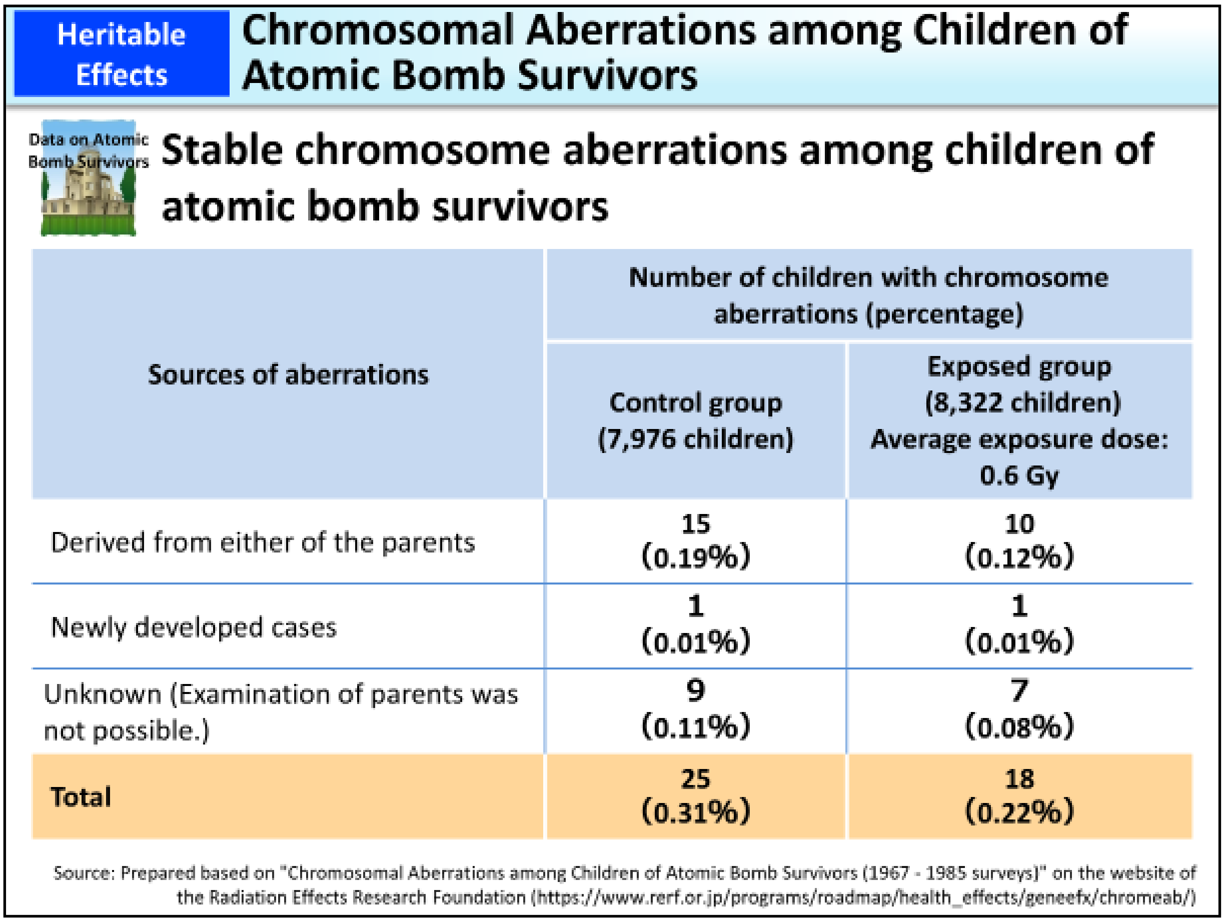

Heritable Effects

Chromosomal Aberrations among Children of Atomic Bomb Survivors

Data on Atomic Bomb Survivors

Stable chromosome aberrations among children of atomic bomb survivors

Sources of aberrations	Number of children with chromosome aberrations (percentage)	
	Control group (7,976 children)	Exposed group (8,322 children) Average exposure dose: 0.6 Gy
Derived from either of the parents	15 (0.19%)	10 (0.12%)
Newly developed cases	1 (0.01%)	1 (0.01%)
Unknown (Examination of parents was not possible.)	9 (0.11%)	7 (0.08%)
Total	25 (0.31%)	18 (0.22%)

Source: Prepared based on "Chromosomal Aberrations among Children of Atomic Bomb Survivors (1967 - 1985 surveys)" on the website of the Radiation Effects Research Foundation (https://www.rerf.or.jp/programs/roadmap/health_effects/geneefx/chromeab/)

Surveys of health effects on children of atomic bomb survivors examine incidence rates of serious congenital disorders, gene mutations, chromosome aberrations and cancer, as well as mortality rates from cancer or other diseases. However, no significant differences were found between the survey targets and the control group regarding any of these.

Stable chromosome aberrations do not disappear through cell divisions and are passed on from parents to their offspring. As a result of a survey targeting 8,322 children (exposed group), either or both of whose parents were exposed to radiation within 2,000 m from the center of the explosion (estimated exposure doses: 0.01 Gy or more), stable chromosome aberrations were found in 18 children. On the other hand, among 7,976 children (control group), both of whose parents were exposed to radiation at locations 2,500 m or farther from the center of the explosion (estimated exposure doses: less than 0.005 Gy) or were outside the city at the time of the atomic bombing, stable chromosome aberrations were found in 25 children.

However, a later examination of their parents and siblings revealed that most of the detected chromosome aberrations were not those newly developed but those that had already existed in either of their parents and were passed on to them. Given these, it was made clear that radiation effects, such that stable chromosome aberrations newly developed in parents' reproductive cells due to radiation exposure were passed on to the offspring, have not been found among atomic bomb survivors.
(Related to p.89 of Vol. 1, "DNA→Cells→Human Body")

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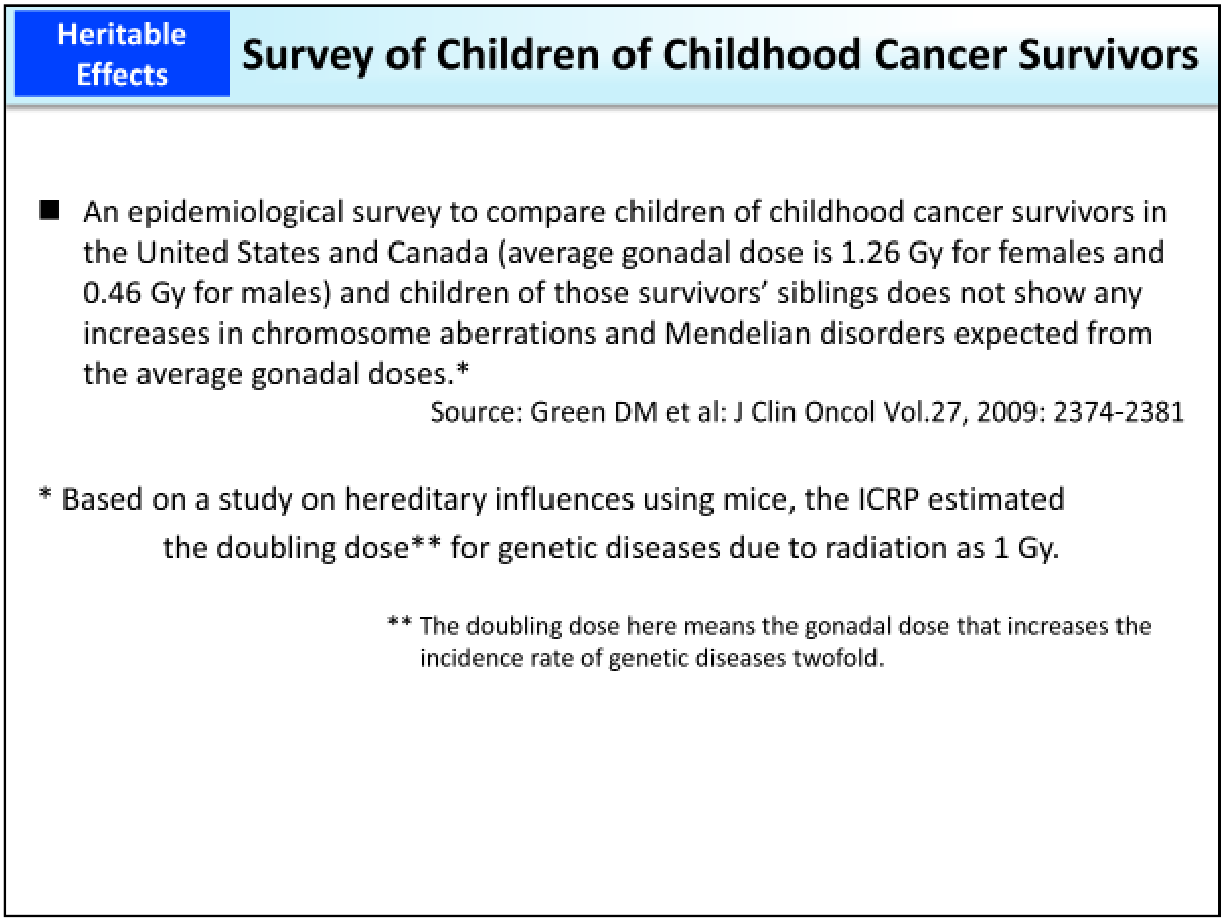

Heritable Effects

Survey of Children of Childhood Cancer Survivors

- An epidemiological survey to compare children of childhood cancer survivors in the United States and Canada (average gonadal dose is 1.26 Gy for females and 0.46 Gy for males) and children of those survivors' siblings does not show any increases in chromosome aberrations and Mendelian disorders expected from the average gonadal doses.*

Source: Green DM et al: J Clin Oncol Vol.27, 2009: 2374-2381

* Based on a study on hereditary influences using mice, the ICRP estimated the doubling dose** for genetic diseases due to radiation as 1 Gy.

** The doubling dose here means the gonadal dose that increases the incidence rate of genetic diseases twofold.

According to the results of the survey of children of childhood cancer survivors in the United States and Canada, as in the case of the surveys targeting children of atomic bomb survivors, excess incidence of chromosome aberrations, Mendelian disorders and malformation was not observed. Based on the study on heritable effects among laboratory mice, the International Commission on Radiological Protection (ICRP) estimates the doubling dose for hereditary disorders to be 1 Gy. However, these survey results do not show any increases in chromosome aberrations and Mendelian disorders expected from the average gonadal doses.

Source
- D.M. Green et al.: J. Clin. Oncol. 27: 2374-2381, 2009.

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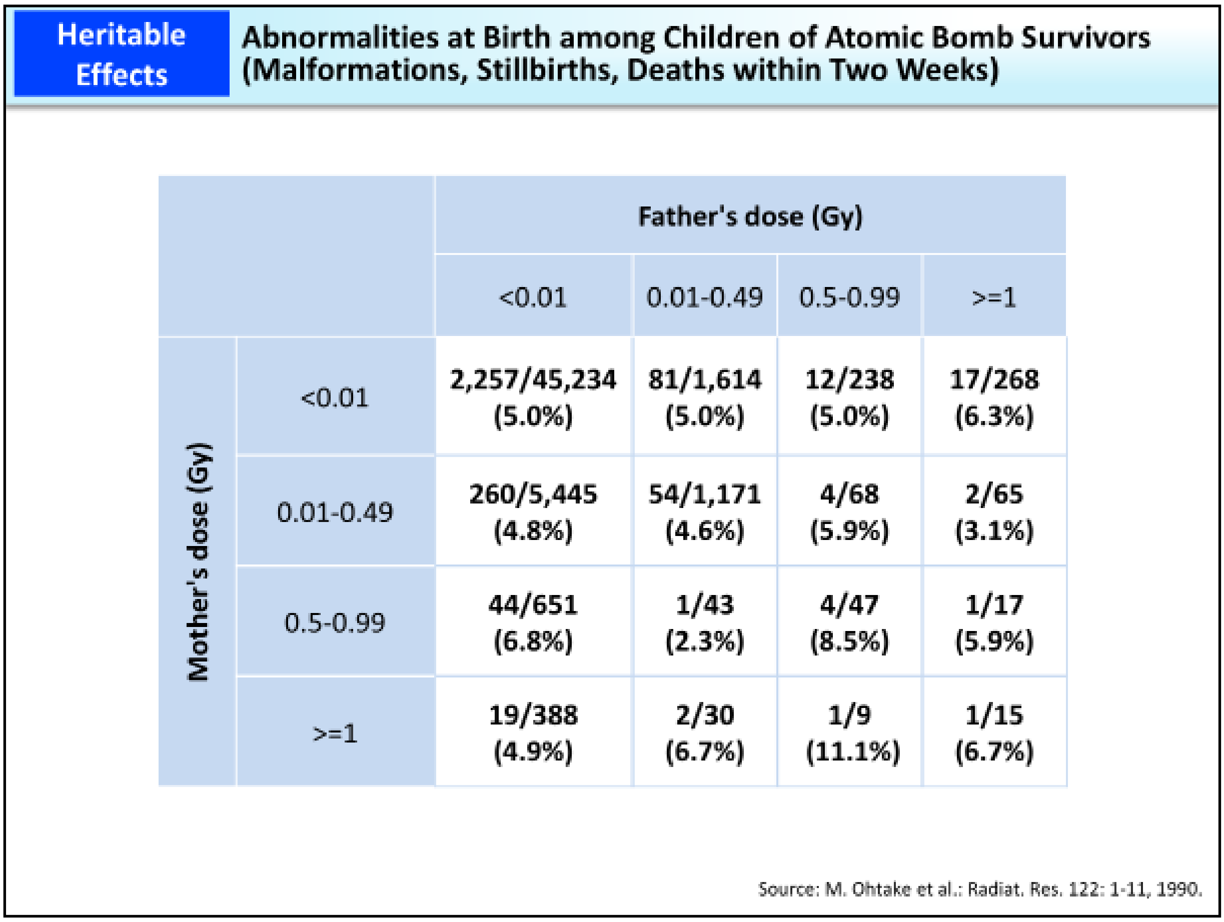

Heritable Effects

Abnormalities at Birth among Children of Atomic Bomb Survivors (Malformations, Stillbirths, Deaths within Two Weeks)

		Father's dose (Gy)			
		<0.01	0.01-0.49	0.5-0.99	>=1
Mother's dose (Gy)	<0.01	**2,257/45,234 (5.0%)**	**81/1,614 (5.0%)**	**12/238 (5.0%)**	**17/268 (6.3%)**
	0.01-0.49	**260/5,445 (4.8%)**	**54/1,171 (4.6%)**	**4/68 (5.9%)**	**2/65 (3.1%)**
	0.5-0.99	**44/651 (6.8%)**	**1/43 (2.3%)**	**4/47 (8.5%)**	**1/17 (5.9%)**
	>=1	**19/388 (4.9%)**	**2/30 (6.7%)**	**1/9 (11.1%)**	**1/15 (6.7%)**

Source: M. Ohtake et al.: Radiat. Res. 122: 1-11, 1990.

Surveys targeting newborns of atomic bomb survivors were conducted between 1948 and 1954 in order to examine the possibility that genetic mutations in the genome of germ-line cells induced by radiation exposure due to the atomic bombing may impair growth of fertilized embryos, fetuses or newborn babies. However, radiation effects were not observed.[1]

Furthermore, in the United States and Canada[2,3] and in Denmark,[4,5] abnormalities at birth among children of childhood cancer survivors were epidemiologically surveyed (p.110 of Vol. 1, “Survey of Children of Childhood Cancer Survivors”). These surveys also do not show any risks of congenital anomalies or stillbirths caused by fathers’ radiation exposure. On the other hand, it was found that mothers’ exposure to radiation exceeding 10 Gy in the ovary or womb increased premature births and stillbirths caused by deterioration of uterine function.[3]

1. M. Ohtake et al.: Radiat. Res. 122: 1-11, 1990.
2. L.B. Signorello et al.: J. Clin. Oncol. 30: 239-45, 2012.
3. L.B. Signorello et al.: Lancet 376(9741): 624-30, 2010.
4. J.F. Winther et al.: J. Clin. Oncol. 30: 27-33, 2012.
5. J.F. Winther et al.: Clin. Genet. 75: 50-6, 2009.

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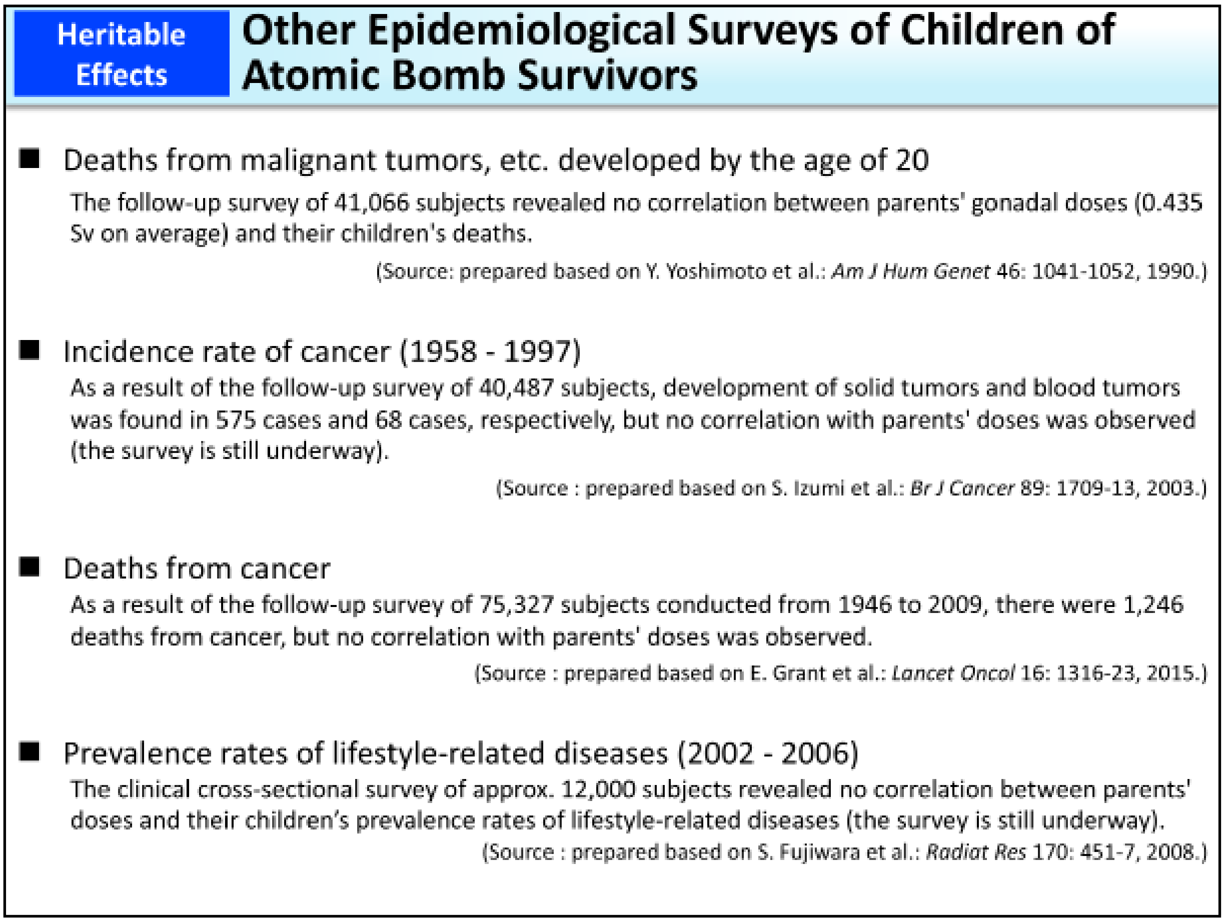
Updated on March 31, 2019



Heritable Effects

Other Epidemiological Surveys of Children of Atomic Bomb Survivors

- Deaths from malignant tumors, etc. developed by the age of 20

The follow-up survey of 41,066 subjects revealed no correlation between parents' gonadal doses (0.435 Sv on average) and their children's deaths.

(Source: prepared based on Y. Yoshimoto et al.: *Am J Hum Genet* 46: 1041-1052, 1990.)

- Incidence rate of cancer (1958 - 1997)

As a result of the follow-up survey of 40,487 subjects, development of solid tumors and blood tumors was found in 575 cases and 68 cases, respectively, but no correlation with parents' doses was observed (the survey is still underway).

(Source : prepared based on S. Izumi et al.: *Br J Cancer* 89: 1709-13, 2003.)

- Deaths from cancer

As a result of the follow-up survey of 75,327 subjects conducted from 1946 to 2009, there were 1,246 deaths from cancer, but no correlation with parents' doses was observed.

(Source : prepared based on E. Grant et al.: *Lancet Oncol* 16: 1316-23, 2015.)

- Prevalence rates of lifestyle-related diseases (2002 - 2006)

The clinical cross-sectional survey of approx. 12,000 subjects revealed no correlation between parents' doses and their children's prevalence rates of lifestyle-related diseases (the survey is still underway).

(Source : prepared based on S. Fujiwara et al.: *Radiat Res* 170: 451-7, 2008.)

The Radiation Effects Research Foundation has been conducting follow-up surveys to ascertain whether parents' radiation exposure increases their children's incidence or prevalence rates of lifestyle-related diseases, which are multifactorial disorders. The Foundation has so far conducted a survey of development of malignant tumors by the age of 20,[1] a survey of cancer,[2,3] and a survey of lifestyle-related diseases,[4] but none of them revealed specific radiation effects.

1. Y. Yoshimoto et al.: Am J Hum Genet 46: 1041-1052, 1990.
2. S. Izumi et al.: Br J Cancer 89: 1709-13, 2003.
3. E. Grant et al.: Lancet Oncol 16: 1316-23, 2015.
4. S Fujiwara et al.: Radiat Res 170: 451-7, 2008.

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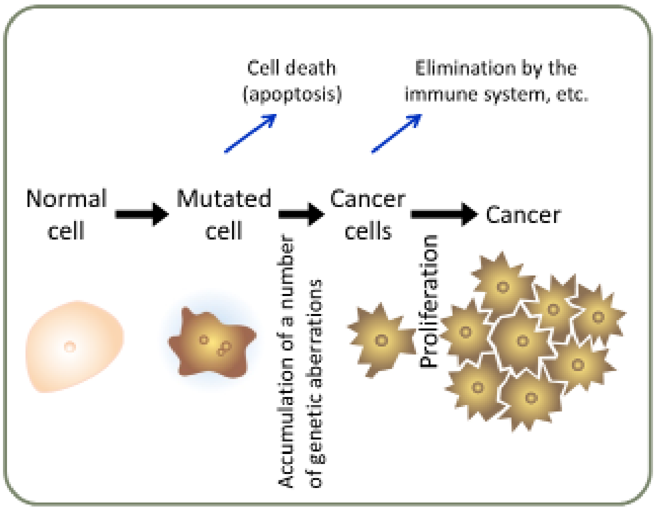
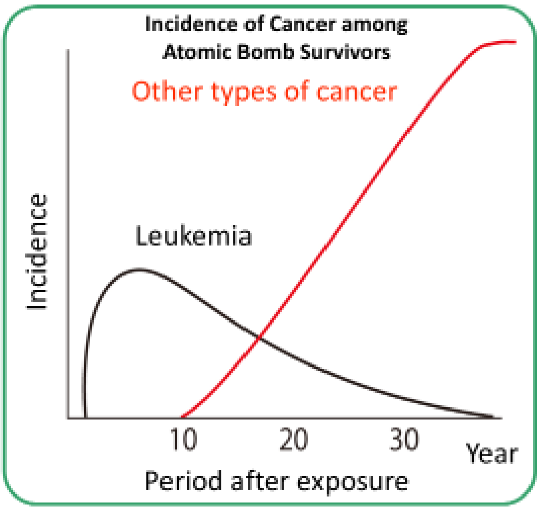
Cancer and Leukemia

Mechanism of Carcinogenesis





- Radiation is only one of various factors that induce cancer.
- Mutated cells follow multiple processes until developing into cancer cells.
  → It takes several years to decades.

Not only radiation but also various chemical substances and ultraviolet rays, etc. damage DNA. However, cells have a mechanism to repair damaged DNA and DNA damage is mostly repaired. Even if repair was not successful, the human body has a function to eliminate cells wherein DNA damage has not been completely repaired (p.88 of Vol. 1, “Damage and Repair of DNA”).

Nevertheless, cells with incompletely repaired DNA survive as mutated cells in very rare cases. Genetic aberrations may be accumulated in cells that happen to survive and these cells may develop into cancer cells. However, this process requires a long period of time. Among atomic bomb survivors, leukemia increased in around two years, but the incidence decreased thereafter. On the other hand, cases of solid cancer started to increase after an incubation period of around 10 years.
(Related to p.90 of Vol. 1, “Lapse of Time after Exposure and Effects”)

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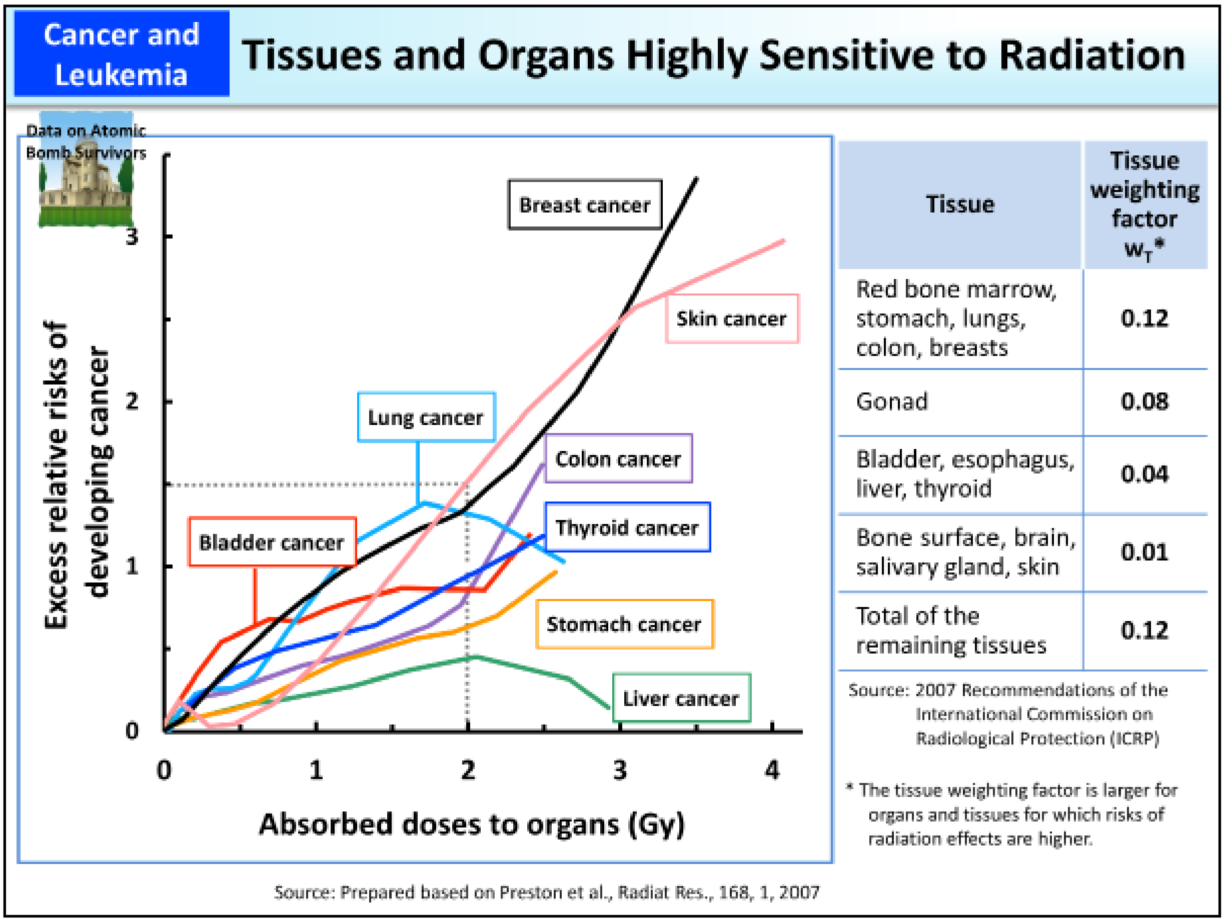


Cancer and Leukemia

Tissues and Organs Highly Sensitive to Radiation

Tissue	Tissue weighting factor w_T*
Red bone marrow, stomach, lungs, colon, breasts	0.12
Gonad	0.08
Bladder, esophagus, liver, thyroid	0.04
Bone surface, brain, salivary gland, skin	0.01
Total of the remaining tissues	0.12

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

* The tissue weighting factor is larger for organs and tissues for which risks of radiation effects are higher.

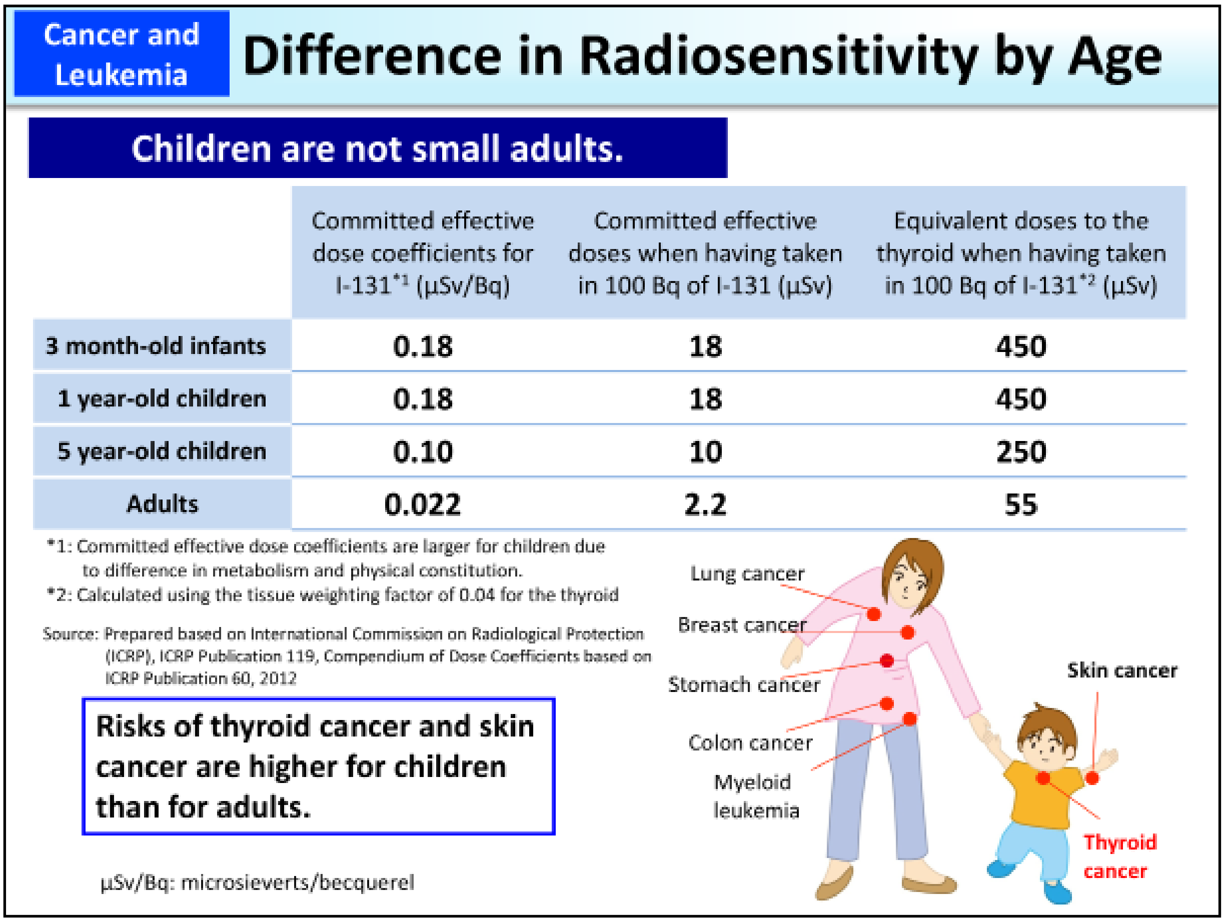
Source: Prepared based on Preston et al., Radiat Res., 168, 1, 2007

This figure shows how cancer risks have increased for each organ depending on exposure doses, targeting atomic bomb survivors. The horizontal axis indicates the absorbed doses to organs through a single high-dose exposure at the time of the atomic bombing, while the vertical axis indicates excess relative risks, which show how cancer risks have increased among the exposed group compared with the non-exposed group.

For example, when the absorbed dose to organs is 2 Gy, the excess relative risk for skin cancer is 1.5, meaning that the risk increased in excess of 1.5 times compared with the non-exposed group (in other words, among the group of people exposed to 2 Gy of radiation, the relative risk of developing skin cancer is 2.5 times higher (1 + 1.5) than among the non-exposed group).

As a result of these epidemiological studies, it was found that the mammary gland, skin, and colon, etc. are tissues and organs that are easily affected by radiation and develop cancer. The 2007 Recommendations of the ICRP specify tissue weighting factors while taking into account the radiosensitivity of each organ and tissue and the lethality of each type of cancer.
(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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



Cancer and Leukemia

Difference in Radiosensitivity by Age

Children are not small adults.

	Committed effective dose coefficients for I-131[*1] (μSv/Bq)	Committed effective doses when having taken in 100 Bq of I-131 (μSv)	Equivalent doses to the thyroid when having taken in 100 Bq of I-131[*2] (μSv)
3 month-old infants	0.18	18	450
1 year-old children	0.18	18	450
5 year-old children	0.10	10	250
Adults	0.022	2.2	55

*1: Committed effective dose coefficients are larger for children due to difference in metabolism and physical constitution.

*2: Calculated using the tissue weighting factor of 0.04 for the thyroid

Source: Prepared based on International Commission on Radiological Protection (ICRP), ICRP Publication 119, Compendium of Dose Coefficients based on ICRP Publication 60, 2012

Risks of thyroid cancer and skin cancer are higher for children than for adults.

μSv/Bq: microsieverts/becquerel

In the case of adults, bone marrow, colon, mammary gland, lungs and stomach easily develop cancer due to radiation exposure, while it has become clear that risks of developing thyroid cancer and skin cancer are also high in the case of children.

In particular, children's thyroids are more sensitive to radiation and committed effective doses per unit intake (Bq) are much larger than adults (p.127 of Vol. 1, "Thyroid"). Therefore, the exposure dose to the thyroids of 1-year-old children is taken into account as the standard when considering radiological protection measures in an emergency. Additionally, much larger values are adopted as children's committed effective dose coefficients per unit intake (Bq) than those for adults.
(Related to p.120 of Vol. 1, "Relationship between Ages at the Time of Radiation Exposure and Oncogenic Risks")

Included in this reference material on March 31, 2013
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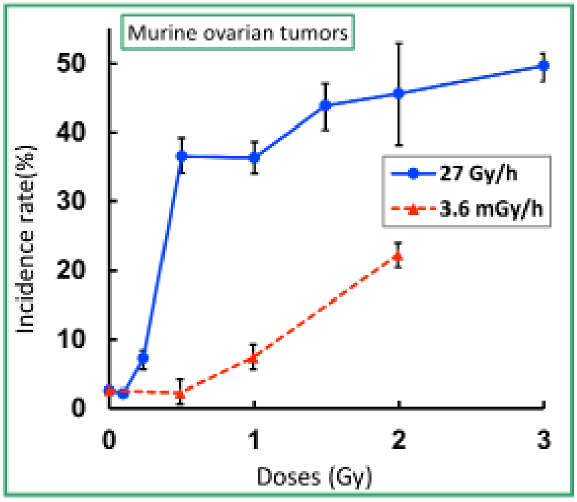
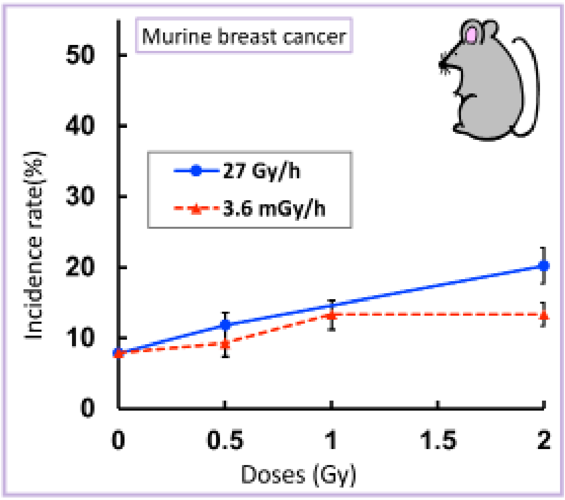
Cancer and Leukemia

Cancer-promoting Effects of Low-dose Exposures





Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1993

Risks of low-dose and low-dose-rate exposures

$$= \frac{\text{Risks of high-dose and high-dose-rate exposures}}{\text{Dose and dose-rate effectiveness factor}}$$

Organizations	Dose and dose-rate effectiveness factors
UNSCEAR 1993	Less than 3 (1 to 10)
National Academy of Sciences (NAS) 2005	1.5
International Commission on Radiological Protection (ICRP) 1990 and 2007	2

Surveys targeting atomic bomb survivors have examined effects of large-amount radiation exposure at one time, while occupational exposures and exposures caused by environmental contamination due to a nuclear accident are mostly chronic low-dose exposures.

Therefore, animal testing using mice has been conducted to ascertain differences in oncogenic risks between a single large-amount radiation exposure and low-dose exposures over time. Although test results vary by type of cancer, it has become clear that radiation effects are generally smaller for low-dose exposures over a long period of time.

Dose and dose-rate effectiveness factors are correction values used in the case of estimating risks of low-dose exposures, for which no concrete data is available, on the basis of risks of high-dose exposures (exposure doses and incidence rates), or estimating risks of chronic exposures or repeated exposures based on risks of acute exposures. Researchers have various opinions on specific values to be used for considering radiological protection, but the ICRP uses 2 as the dose and dose-rate effectiveness factor in its Recommendations and concludes that long-term low-dose exposure would cause half the effects as those caused by exposure at one time, if the total exposure dose is the same.
(Related to p.124 of Vol. 1, “Effects of Long-Term Low-Dose Exposure”)

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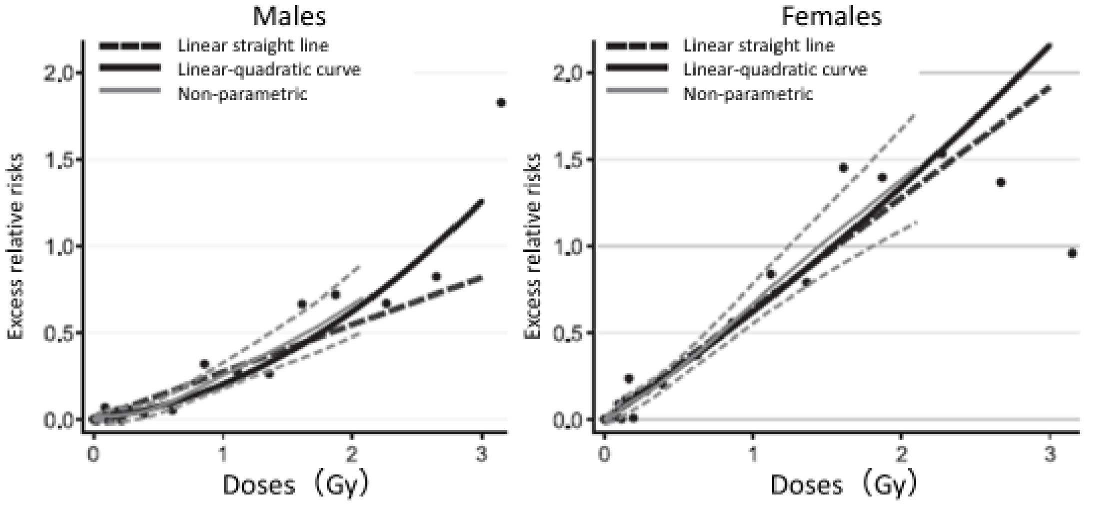
Cancer due to Acute External Exposure

Relationship between Solid Cancer Deaths and Doses

Data on Atomic Bomb Survivors

Deaths from solid cancer (results among atomic bomb survivors)



Source: Prepared based on Grant *et al.*, Radiat Res, 187, 513-537, 2017

Excess relative risks: How cancer risks have increased among a group of people exposed to radiation compared with a group of non-exposed people

Health effects surveys targeting atomic bomb survivors have revealed that cancer risks increase as exposure doses increase. The latest epidemiological survey on solid cancer risks shows proportionate relationships between doses and risks, i.e., between exposure doses exceeding 100 mSv and the risk of solid cancer incidence[1] and between exposure doses exceeding 200 mSv and the risk of death from solid cancer.[2]

However, there is no consensus among researchers concerning a relationship between cancer risks and exposure doses below 100 to 200 mSv. It is expected to be clarified in future studies whether a proportionate relationship can be found between cancer risks and all levels of exposure doses, whether there is any substantial threshold value, or whether any other correlations are found.

(Related to p.99 of Vol. 1, "Relative Risks and Attributable Risks," and p.166 of Vol. 1, "Disputes over the LNT Model")

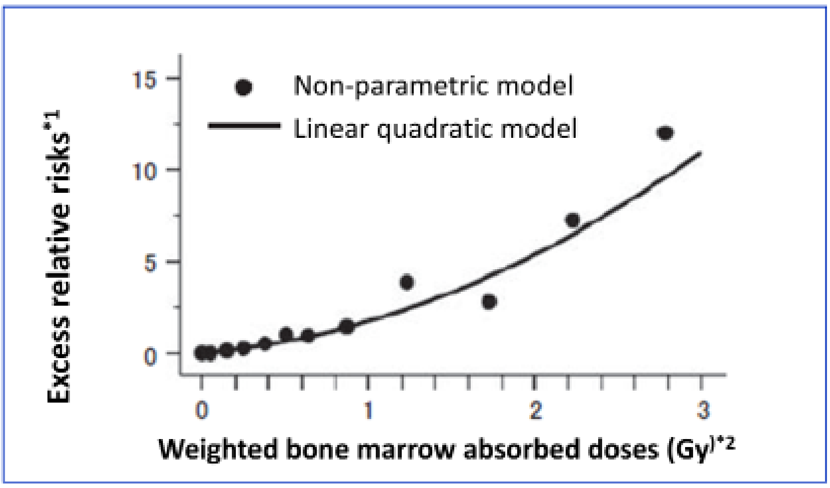
1. E. J. Grant et. al., "Solid Cancer Incidence among the Life Span Study of Atomic Bomb Survivors: 1958-2009" RADIATION RESEARCH 187, 513-537 (2017)
2. K. Ozasa et. al., "Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950-2003: An Overview of Cancer and Noncancer Diseases" RADIATION RESEARCH 177, 229-243 (2012)

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Dose-response Relationship of Radiation-induced Leukemia

Data on Atomic Bomb Survivors

Dose-response relationship of radiation-induced leukemia among atomic bomb survivors in Hiroshima and Nagasaki



*1: An indicator to show increments in the mortality rate (or incidence rate) in the case of having been exposed to radiation against the mortality rate (or incidence rate) in the case of having been free from radiation exposure; showing how many times increase was caused by radiation exposure

*2: In the case of leukemia, weighted bone marrow doses (sum of 10 times the neutron doses and total amount of γ-rays) are used.

Source: Prepared based on Wan-Ling Hsu et al. The Incidence of Leukemia, Lymphoma and Multiple Myeloma among Atomic Bomb Survivors: 1950–2001, Radiation Research 179, 361–382 (2013)

Surveys targeting atomic bomb survivors made it clear that the dose-response relationship of leukemia, excluding chronic lymphocytic leukemia and adult T-cell leukemia, is quadric, and the higher an exposure dose is, the more sharply risks increase, showing a concave dose-response relationship (the linear quadratic curve in the figure). On the other hand, risks posed by low-dose exposure are considered to be lower than estimated based on a simple linear dose-response model.

In the figure above, black dots show excess relative risks depending on levels of bone marrow absorbed doses and the black line shows excess relative risks based on a linear quadratic model.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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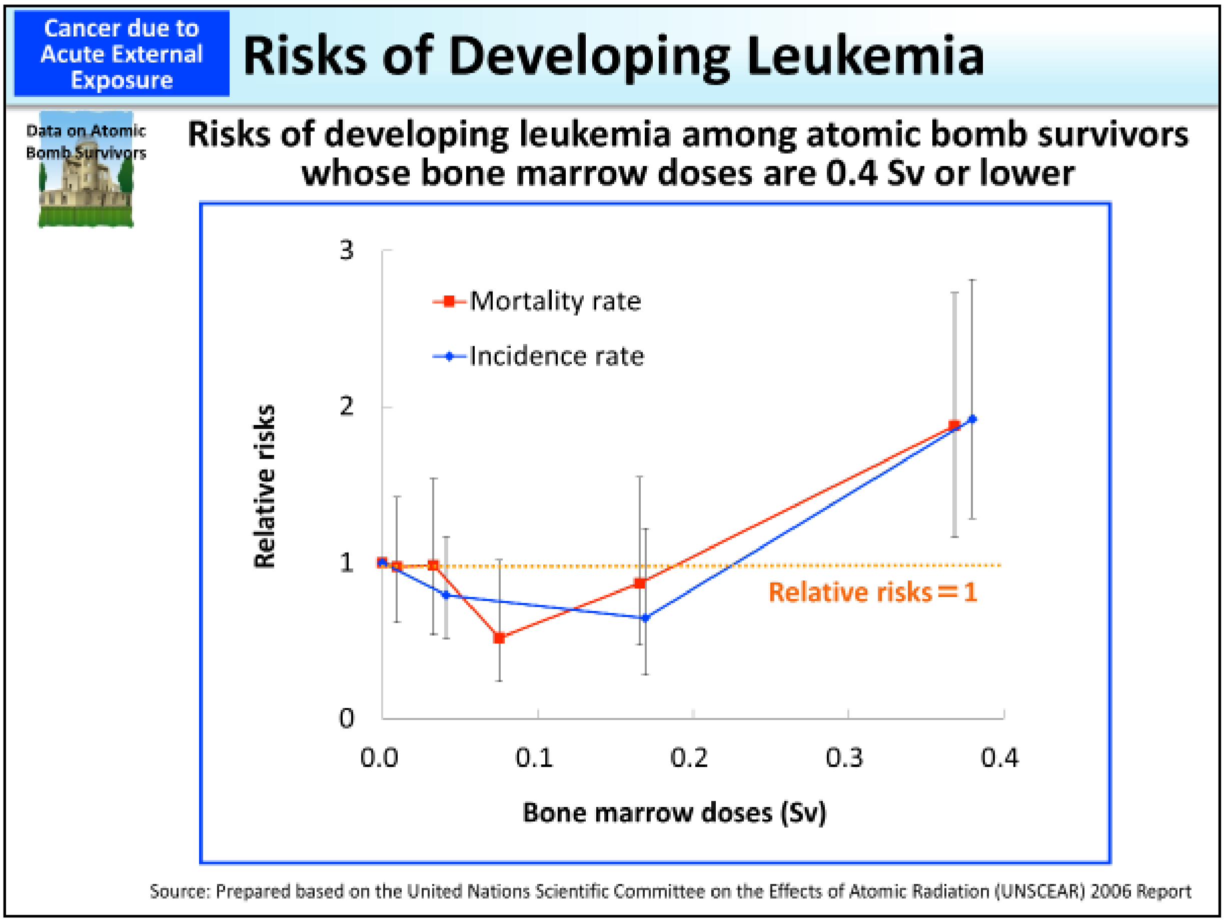

Cancer due to Acute External Exposure

Risks of Developing Leukemia

Data on Atomic Bomb Survivors

Risks of developing leukemia among atomic bomb survivors whose bone marrow doses are 0.4 Sv or lower

Source: Prepared based on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2006 Report

Relative risks of developing leukemia (values indicating how many times larger the risks are among people exposed to radiation when assuming the risks among non-exposed people as 1) among atomic bomb survivors do not increase notably among those whose bone marrow doses are below 0.2 Sv but increase significantly among those whose bone marrow doses are around 0.4 Sv.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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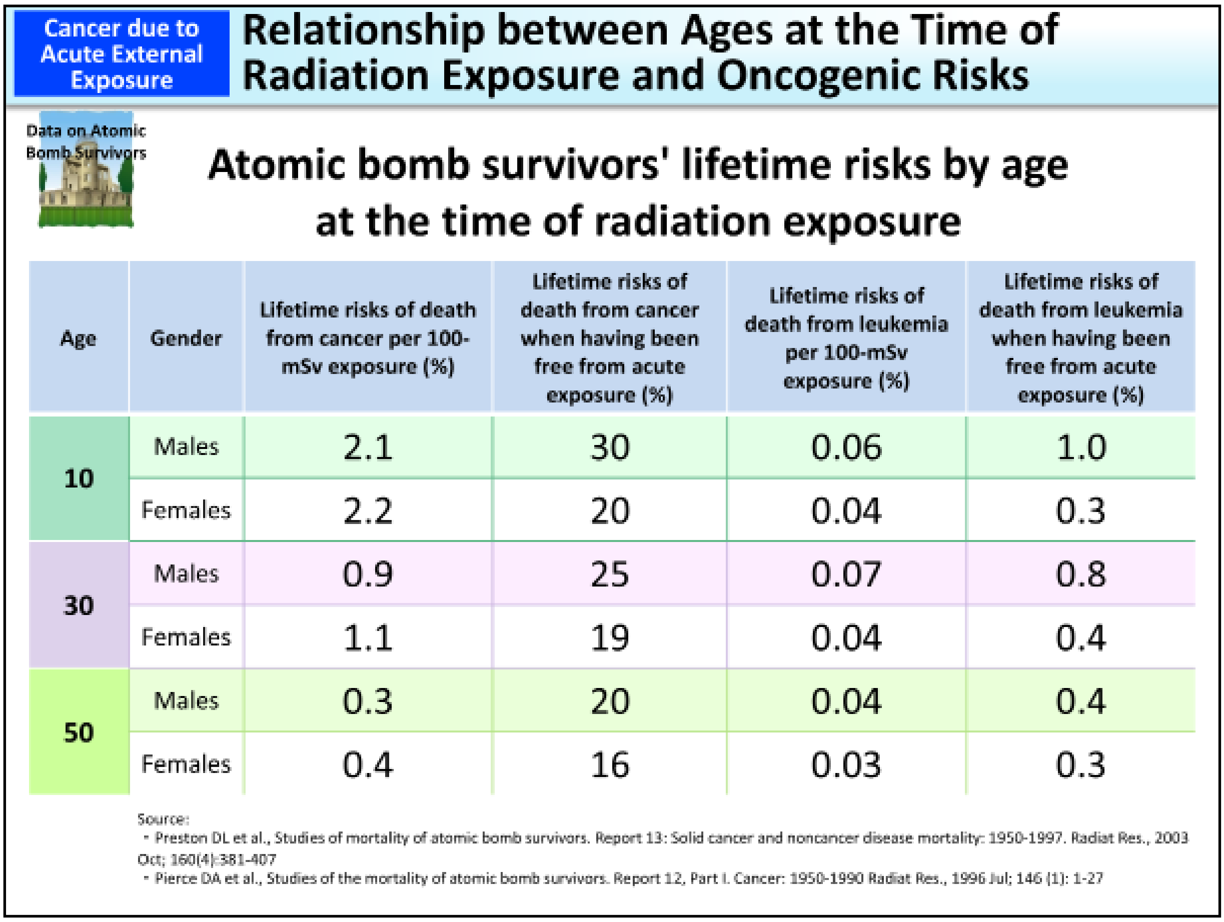

Cancer due to Acute External Exposure

Relationship between Ages at the Time of Radiation Exposure and Oncogenic Risks

Data on Atomic Bomb Survivors

Atomic bomb survivors' lifetime risks by age at the time of radiation exposure

Age	Gender	Lifetime risks of death from cancer per 100-mSv exposure (%)	Lifetime risks of death from cancer when having been free from acute exposure (%)	Lifetime risks of death from leukemia per 100-mSv exposure (%)	Lifetime risks of death from leukemia when having been free from acute exposure (%)
10	Males	2.1	30	0.06	1.0
	Females	2.2	20	0.04	0.3
30	Males	0.9	25	0.07	0.8
	Females	1.1	19	0.04	0.4
50	Males	0.3	20	0.04	0.4
	Females	0.4	16	0.03	0.3

Source:
- Preston DL et al., Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiat Res., 2003 Oct; 160(4):381-407
- Pierce DA et al., Studies of the mortality of atomic bomb survivors. Report 12, Part I. Cancer: 1950-1990 Radiat Res., 1996 Jul; 146 (1): 1-27

This table shows lifetime risks of death from cancer due to radiation exposure based on data obtained through epidemiological surveys targeting atomic bomb survivors. Specifically, comparisons are made between lifetime risks of deaths from cancer and leukemia per 100-mSv acute exposure and respective death risks when having been free from acute exposure, i.e., background death risks due to naturally developing cancer and leukemia.

The table suggests that a 10-year-old boy, for example, is likely to die of cancer in the future with a probability of 30% (the background risk of death from cancer for 10-year-old boys is 30% as shown in the table), but if the boy is acutely exposed to radiation at the level of 100 mSv, the risk of death from cancer increases by 2.1% to 32.1% in total.

The table shows the tendency that in the case of acute exposure to 100 mSv, lifetime risks of death from cancer are higher for those who are younger at the time of the exposure.

The reasons therefor include the facts that younger people have a larger number of stem cells that may develop into cancer cells in the future and cell divisions are more active and frequent compared with aged people.
(Related to p.115 of Vol. 1, “Difference in Radiosensitivity by Age”)

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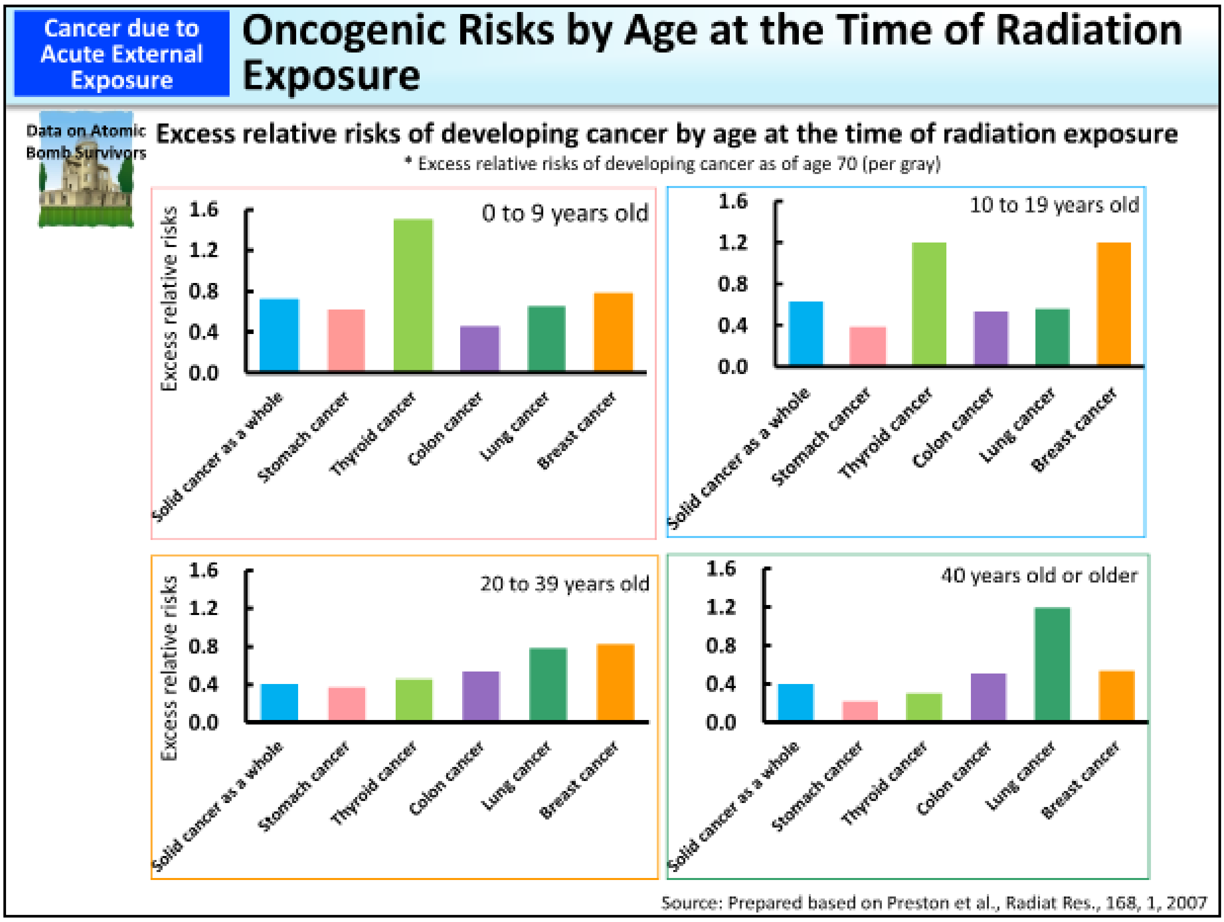

Cancer due to Acute External Exposure

Oncogenic Risks by Age at the Time of Radiation Exposure

Data on Atomic Bomb Survivors

Excess relative risks of developing cancer by age at the time of radiation exposure

* Excess relative risks of developing cancer as of age 70 (per gray)

Source: Prepared based on Preston et al., Radiat Res., 168, 1, 2007

These figures show excess relative risks of developing cancer (values indicating how much cancer risks have increased among a group of people exposed to radiation compared with a group of non-exposed people) per gray as of age 70, using the results of the surveys targeting atomic bomb survivors.

It can be observed that types of cancer with higher risks differ by age at the time of radiation exposure.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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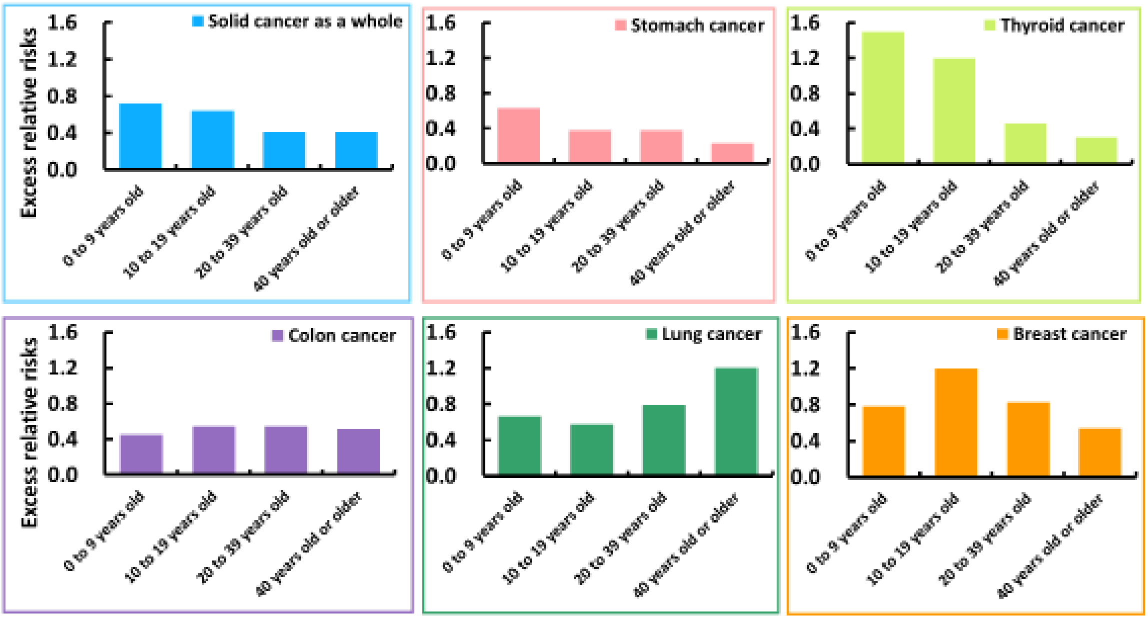
Cancer due to Acute External Exposure

Ages at the Time of Radiation Exposure and Risks by Type of Cancer

Data on Atomic Bomb Survivors

Excess relative risks of developing cancer by age for each type of cancer

* Excess relative risks of developing cancer as of age 70 (per gray)



Source: Prepared based on Preston et al., Radiat Res., 168, 1, 2007

These figures show excess relative risks of developing cancer (values indicating how cancer risks have increased among a group of people exposed to radiation compared with a group of non-exposed people) per gray as of age 70, using the results of the surveys targeting atomic bomb survivors.

For example, the excess relative risk of developing solid cancer as a whole for the age group of 0 to 9 years old is approx. 0.7, which means that the excess relative risk increases by 0.7 among a group of people exposed to 1 Gy compared with a group of non-exposed people. In other words, supposing the risk for a group of non-exposed people is 1, the risk for a group of people aged 0 to 9 who were exposed to 1 Gy increases by 1.7 times. The excess relative risk of developing solid cancer as a whole for people aged 20 or older is approx. 0.4 and the risk for a group of people exposed to 1 Gy will be 1.4 times larger than the risk for a group of non-exposed people.

As shown in the figures above, risks differ by age at the time of radiation exposure and type of cancer.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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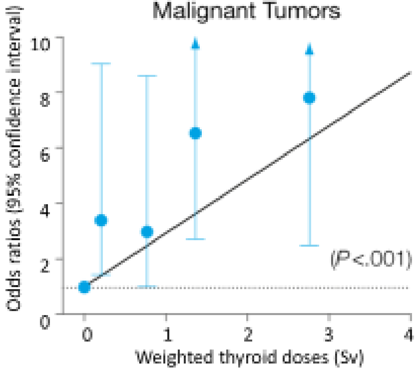
Cancer due to Acute External Exposure

Incidence of Thyroid Cancer among Atomic Bomb Survivors

Data on Atomic Bomb Survivors

Thyroid cancer
Malignant Tumors



Source: Radiation Effects Research Foundation; JAMA 2006; 295(9): 1011-1022

Analysis of micro papillary cancer

mGy: milligrays

Weighted thyroid doses	Average doses (mGy)	Targets (people)	Cancer detected in (people)	Odds ratios (95% confidence interval)
<5mGy	—	755	33	1
5～100mGy	32	936	36	0.85 (0.52～1.39)
100～500mGy	241	445	22	1.12 (0.64～1.95)
500mGy<	1237	236	15	1.44 (0.75～2.67)

Source: Hayashi et al., Cancer, 116, 1646, 2010

* Odds ratio: A statistical scale for comparing the probability of a certain incident between two groups
Odds ratios larger than 1 suggest that the probability is larger. When the probability that a certain incident occurs is p (Group 1) and q (Group 2), respectively, the odds ratio is obtained by the following formula.

$$\text{Odds of } p / \text{Odds of } q = p / (1-p) \div q / (1-q)$$

When the 95% confidence interval does not include 1, the difference in the probability is statistically significant.

Odds ratios (statistical scales for comparing the probability of a certain incident between two groups) regarding incidence of thyroid cancer among atomic bomb survivors show that risks of thyroid cancer increase as doses increase.

A survey only targeting micro papillary thyroid cancer shows that the odds ratio remains low until the weighted thyroid dose exceeds 100 mGy, and that the ratio slightly exceeds 1 when the weighted thyroid dose becomes 100 mGy or larger, but no significant difference was found.[1,2] (When the odds ratio is larger than 1, the relevant incident is more highly likely to occur. However, in this data, as the 95% confidence interval includes 1, there is no statistically significant difference in the probability.)

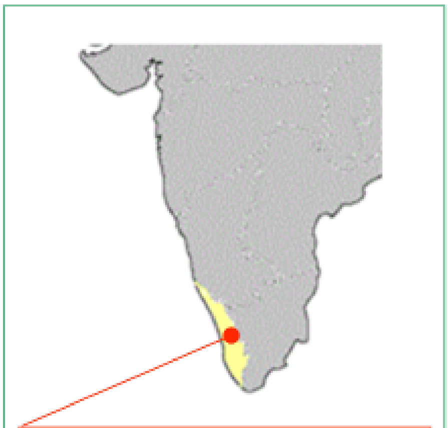
1. M. Imaizumi, et.al., “Radiation Dose-Response Relationships for Thyroid Nodules and Autoimmune Thyroid Diseases in Hiroshima and Nagasaki Atomic Bomb Survivors 55-58 Years After Radiation Exposure” JAMA 2006;295(9):1011-1022
2. Y. Hayashi, et.al., “Papillary Microcarcinoma of the Thyroid Among Atomic Bomb Survivors Tumor Characteristics and Radiation Risk” Cancer April 1, 2010, 1646-1655

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

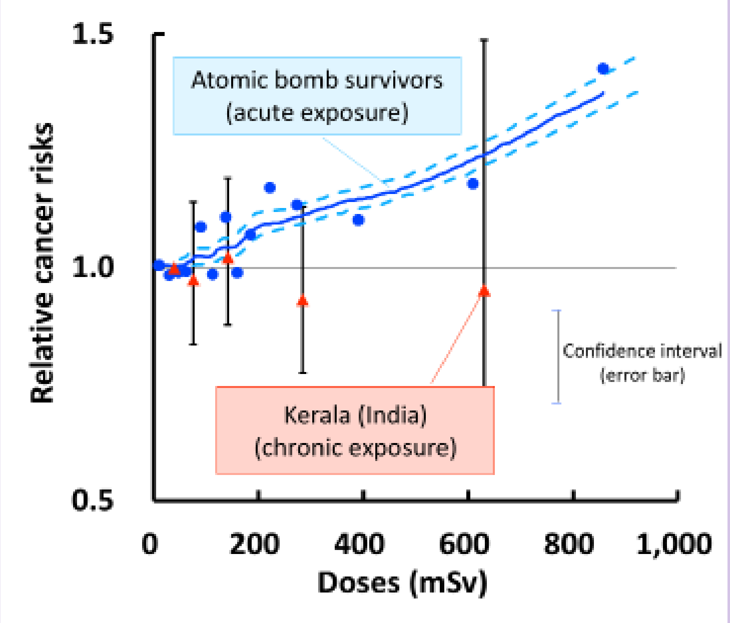
Carcinogenesis due to Chronic Exposure

Effects of Long-Term Low-Dose Exposure

Carcinogenesis among residents in high natural radiation area in India



Kerala (India)
Outdoor average dose:
4 mSv/year or more
Up to 70 mSv/year in some areas



mSv: millisieverts

Source: Prepared based on Nair et al., Health Phys 96, 55, 2009; Preston et al., Radiat Res. 168, 1, 2007

It is considered that effects appear in different manners depending on whether it is a low-dose-rate radiation exposure or a high-dose-rate radiation exposure.

The figure on the right compares the data on atomic bomb survivors and risks for residents in high natural radiation areas such as Kerala in India. No increase is observed in relative risks for cancer (values indicating how many times cancer risks increase among exposed people when supposing the risk for non-exposed people as 1) among residents in Kerala even if their accumulated doses reach several hundred mSv. This suggests that risks are smaller in the case of chronic exposure than in the case of acute exposure, although further examination is required as the range of the confidence interval (the error bar on the figure) is very large (p.116 of Vol. 1, "Cancer-promoting Effects of Low-dose Exposures").
(Related to p.99 of Vol. 1, "Relative Risks and Attributable Risks")

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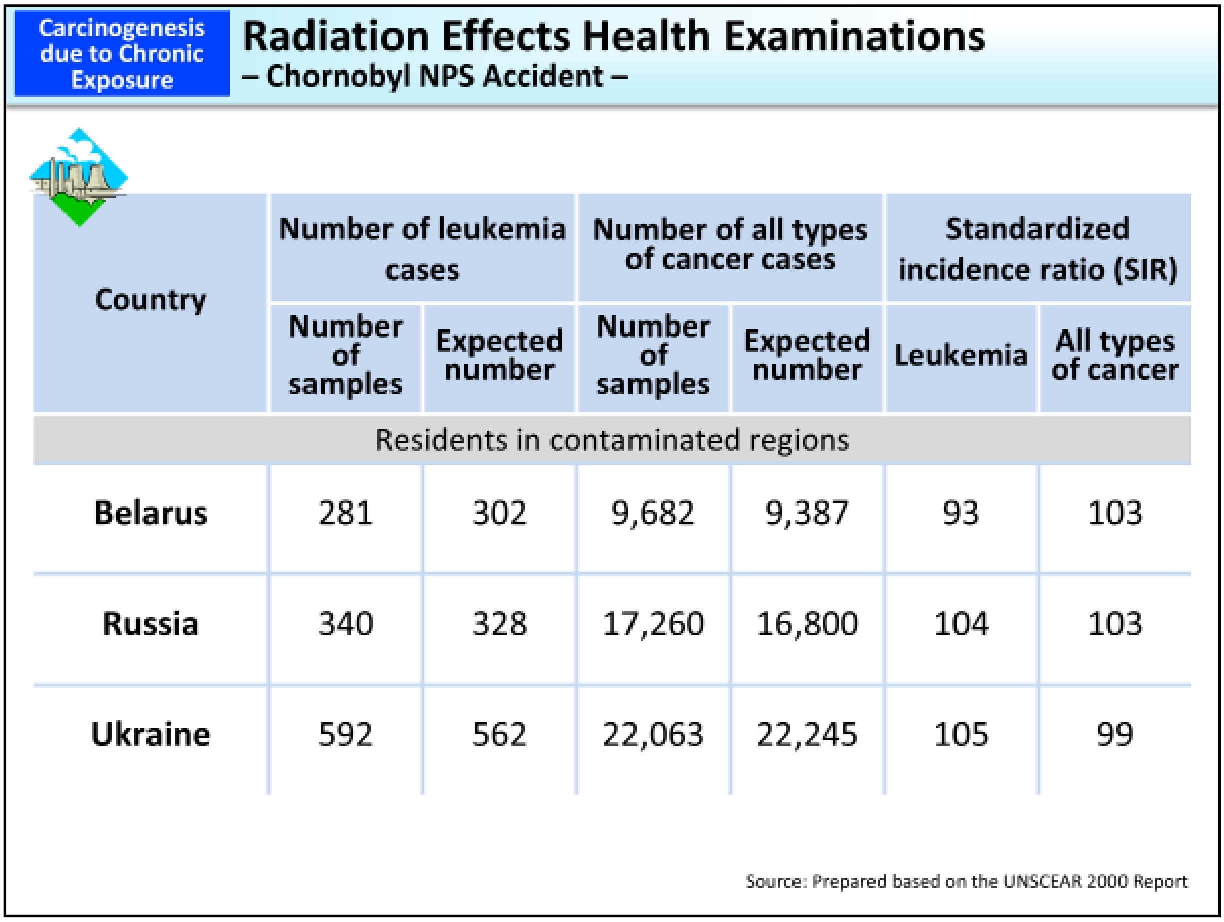
Updated on February 28, 2018



Carcinogenesis due to Chronic Exposure

Radiation Effects Health Examinations

– Chornobyl NPS Accident –

Country	Number of leukemia cases		Number of all types of cancer cases		Standardized incidence ratio (SIR)	
	Number of samples	Expected number	Number of samples	Expected number	Leukemia	All types of cancer
Residents in contaminated regions						
Belarus	281	302	9,682	9,387	93	103
Russia	340	328	17,260	16,800	104	103
Ukraine	592	562	22,063	22,245	105	99

Source: Prepared based on the UNSCEAR 2000 Report

After the Chornobyl NPS Accident, an epidemiological study on effects of radiation on health was conducted with regard to various diseases. However, no causal relationship with the accident has been confirmed regarding leukemia.

The table shows the results of the examinations analyzing cancer cases found in 1993 and 1994 among residents of regions contaminated due to the Chornobyl NPS Accident from 1986 to 1987. In the three affected countries, no significant increase in cancer cases was observed. Contaminated regions are regions where the deposition density of Cs-137 is 185 kBq/m^2 or larger. The UNSCEAR 2000 Report states that no increase was found in risks of radiation-related leukemia either for workers dealing with the accident or residents in the contaminated regions.

Thereafter, there were research reports stating that an increase in relative risks of leukemia was observed, although the increase was not statistically significant, and that the incidence rate of leukemia was approximately twice for workers who were employed in 1986 compared with workers who were employed in 1987, when radiation doses became lower. Despite these reports, the UNSCEAR 2008 Report evaluates them to be far from conclusive to explain any significant increases.

With regard to the general public, the report concludes that no persuasive evidence has been found to suggest any measurable increases in risks of leukemia among people who were exposed to radiation in utero or during childhood.

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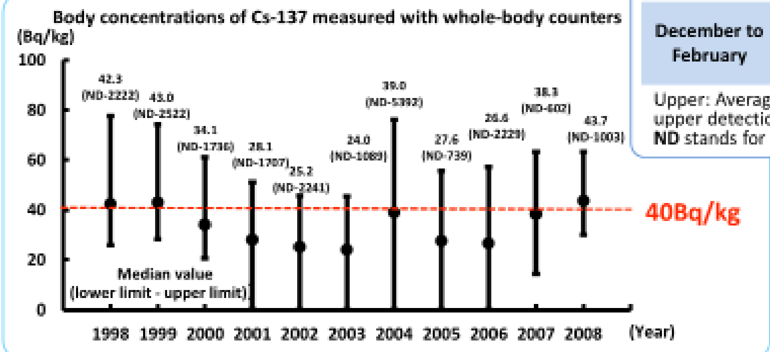
Updated on March 31, 2024

Internal Exposure due to Cesium

- Chornobyl NPS Accident -



Seasonal changes in body concentrations of Cs-137 (Bq/kg) and number of examinees

	1998 to 2001	2002 to 2005	2006 to 2008
March to May	34.6 (ND-2154.9) 10,993	27.3 (ND-5392.2) 18,722	32.0 (ND-1757.1) 9,284
June to August	71.5 (ND-399.0) 265	32.2 (ND-393.0) 268	21.2 (ND-271.1) 451
September to November	40.9 (ND-2521.7) 9,590	33.5 (ND-1089.3) 8,999	44.2 (ND-2229.3) 4,080
December to February	33.5 (ND-1735.8) 8,971	20.6 (ND-607.0) 6,603	39.8 (ND-1454.3) 6,404

Upper: Average **(Bq/kg)**; Middle: Lower detection limit to upper detection limit; Lower: Number of examinees (people); **ND** stands for below the detection limit.

The annual internal exposure of 40 Bq/kg was detected in the Bryansk State from 1998 to 2008.

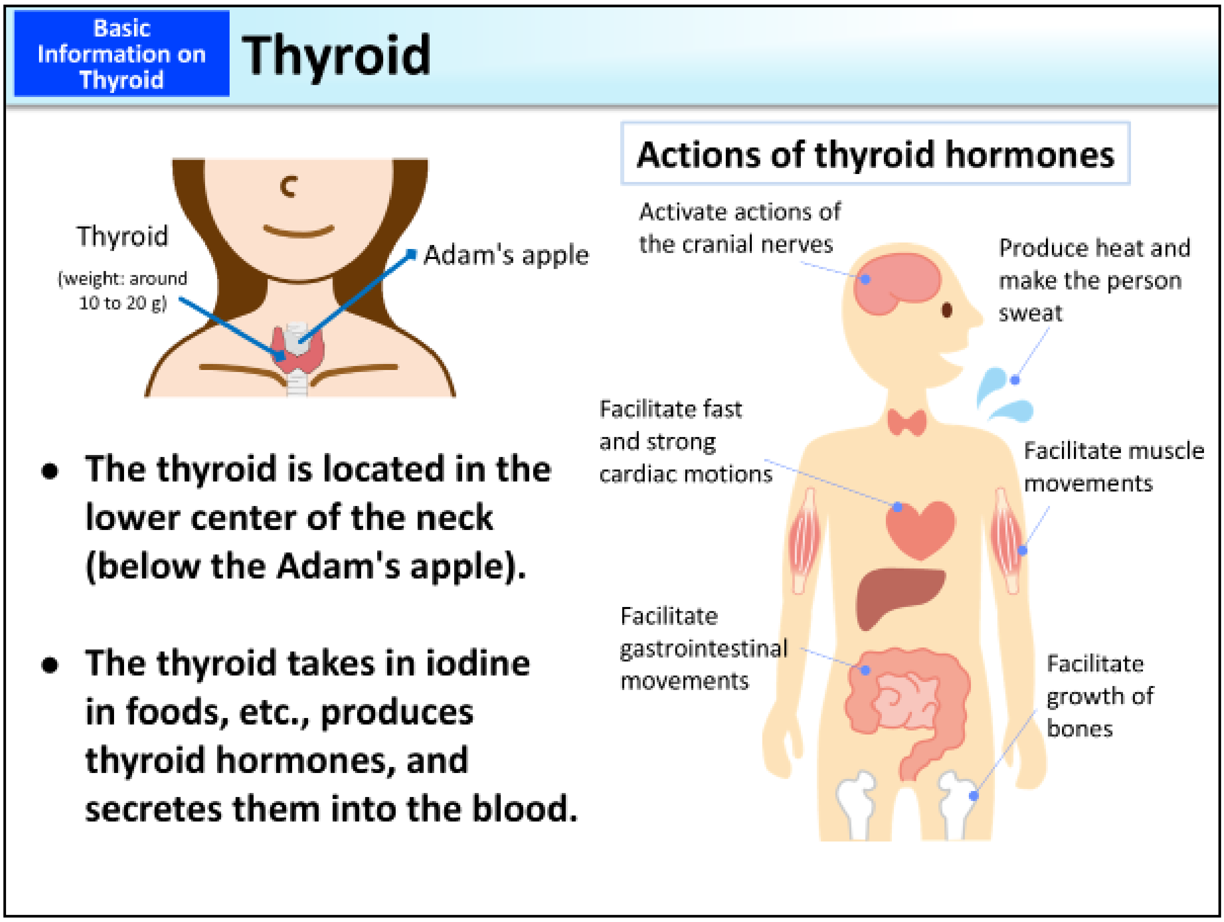
Bq/kg: Becquerels per kilogram

Source: Prepared based on Sekitani et al., Radiat Prot Dosimetry, 141, 1, 2010

Due to the Chornobyl Nuclear Power Station (NPS) Accident in 1986, much larger amounts of radioactive materials were released compared with those released by the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. At first, the government of the former Soviet Union did not publicize the accident nor did it take any evacuation measures for residents around the nuclear facilities. In late April, when the accident occurred, pasturing had already started in the southern part of the former Soviet Union and cow milk was also contaminated with radionuclides.

As a result of the whole-body counter measurements of body concentrations of Cs-137, which were conducted for residents in the Bryansk State from 1998 to 2008, it was found that the median value of body concentrations of Cs-137 had decreased within a range of 20 to 50 Bq/kg until 2003 but has been on a rise since 2004. This is considered to be because residents in especially highly contaminated districts came to be included in the measurement targets in 2004 onward and because the contraction of off-limits areas has made it easier for residents to enter contaminated forests. At any rate, this suggests that exposure to Cs-137 due to the Chornobyl NPS Accident has been continuing over years.

Included in this reference material on March 31, 2013
Updated on March 31, 2024



Basic Information on Thyroid

Thyroid

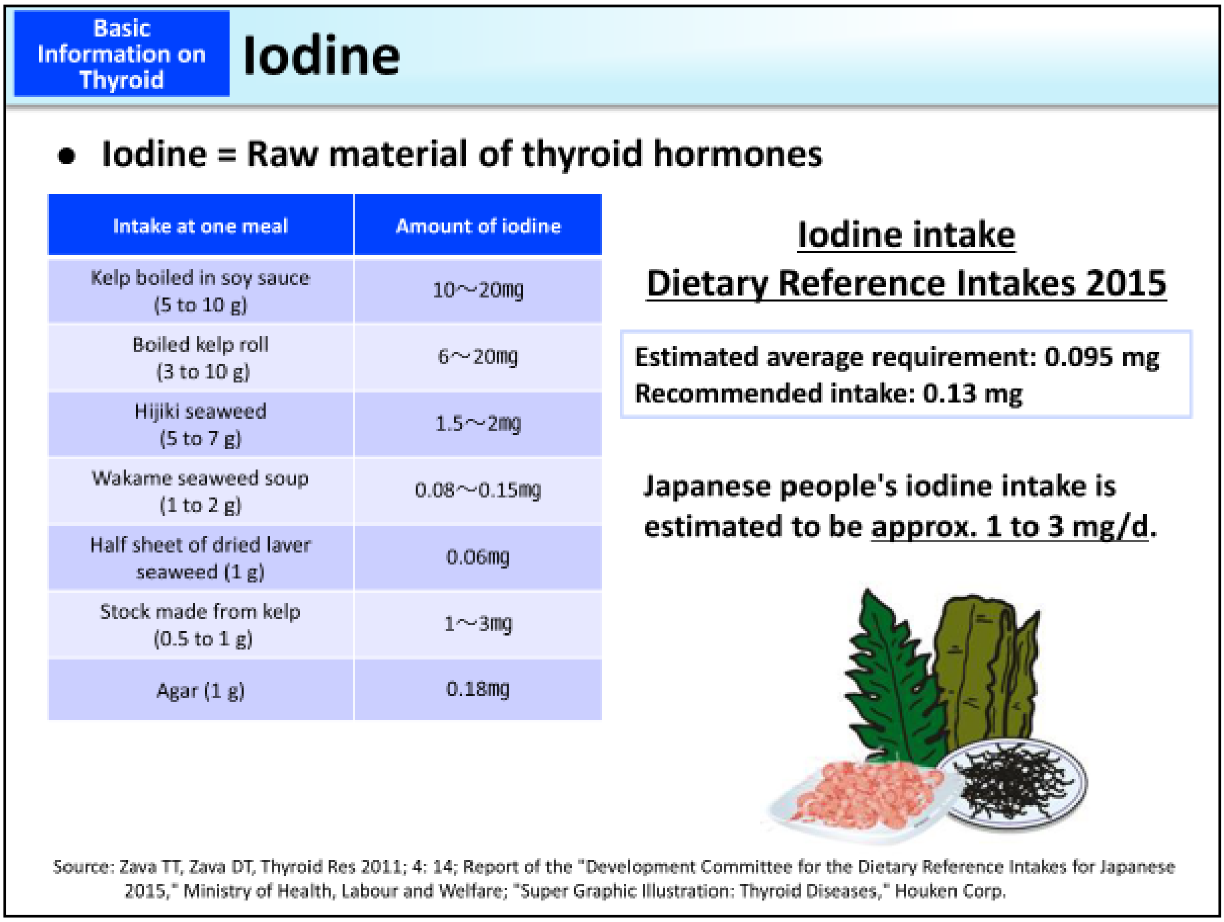
- **The thyroid is located in the lower center of the neck (below the Adam's apple).**
- **The thyroid takes in iodine in foods, etc., produces thyroid hormones, and secretes them into the blood.**

Actions of thyroid hormones

The thyroid is a small organ weighing around 10 to 20 g and shaped like a butterfly with its wings extended. It is located in the lower center of the neck (below the Adam’s apple) as if surrounding the windpipe. The thyroid actively takes in iodine in the blood to produce thyroid hormones therefrom. Produced thyroid hormones are secreted into the blood and are transported to the whole body to act in various manners.

Thyroid hormones play roles of promoting metabolism to facilitate protein synthesis in the body and maintenance of energy metabolism and also roles of promoting growth and development of children’s body and brains.

Included in this reference material on March 31, 2017



Basic Information on Thyroid

Iodine

- **Iodine = Raw material of thyroid hormones**

Intake at one meal	Amount of iodine
Kelp boiled in soy sauce (5 to 10 g)	10～20㎎
Boiled kelp roll (3 to 10 g)	6～20㎎
Hijiki seaweed (5 to 7 g)	1.5～2㎎
Wakame seaweed soup (1 to 2 g)	0.08～0.15㎎
Half sheet of dried laver seaweed (1 g)	0.06㎎
Stock made from kelp (0.5 to 1 g)	1～3㎎
Agar (1 g)	0.18㎎

Iodine intake
Dietary Reference Intakes 2015

Estimated average requirement: 0.095 mg
Recommended intake: 0.13 mg

Japanese people's iodine intake is estimated to be approx. 1 to 3 mg/d.

Source: Zava TT, Zava DT, Thyroid Res 2011; 4: 14; Report of the "Development Committee for the Dietary Reference Intakes for Japanese 2015," Ministry of Health, Labour and Welfare; "Super Graphic Illustration: Thyroid Diseases," Houken Corp.

Iodine, which is a raw material of thyroid hormones, is contained in large quantities in seaweed, fish and seafood that are familiar to Japanese people.

The “Dietary Reference Intakes for Japanese” released by the Ministry of Health, Labour and Welfare states that the estimated average iodine requirement is 0.095 mg per day and recommended intake is 0.13 mg per day. Japanese people consume a lot of seaweed, fish and seafood on a daily basis and are considered to take in a sufficient amount of iodine (estimated to be approx. 1 to 3 mg/d).

When a person habitually consumes iodine, the thyroid constantly retains a sufficient amount of iodine. It is known that once the thyroid retains a sufficient amount of iodine, any iodine newly ingested is only partially taken into the thyroid and most of it is excreted in the urine.

Accordingly, even in the case where radioactive iodine is released due to such reasons as an accident at a nuclear power plant, accumulation of the released radioactive iodine in the thyroid can be subdued among a group of people who take in iodine on a daily basis.

In preparation for any emergency exposure such as due to a nuclear accident, efforts are being made to deliver stable iodine tablets, non-radioactive iodine tablets formulated for oral administration, in advance or in an emergency.

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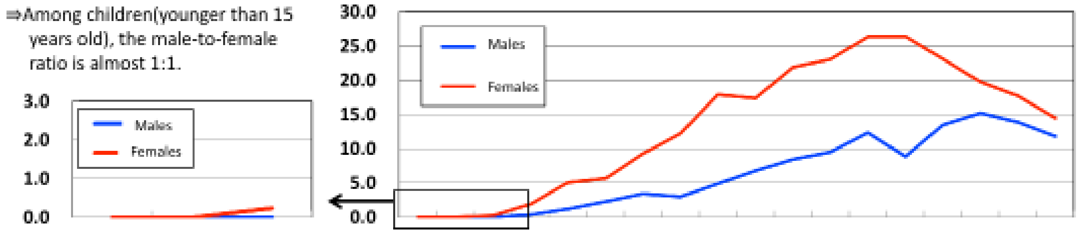
Basic Information on Thyroid

Characteristics of Thyroid Cancer

- **The incidence rate of thyroid cancer is higher for females** (estimated age-adjusted incidence rate (nationwide) (against 100,000 people), 2010).

  ⇒Females: 11.5 (people); Males: 4.5 (people)
- **Thyroid cancer is found in all age groups from younger people to aged people** (estimated incidence rate by age group (nationwide) (against 100,000 people), 2010).



⇒Among children(younger than 15 years old), the male-to-female ratio is almost 1:1.

- **In many cases, prognosis after surgery is good** (crude cancer mortality rate by organ/tissue (against 100,000 people), 2010).

	Thyroid	Stomach	Liver	Lungs	Leukemia
Male	**0.9**	53.5	34.9	81.8	7.9
Female	**1.7**	26.5	17.4	30.0	5.0

- **There is also occult thyroid cancer that does not exert any effects on people's health throughout their lifetime.**

Source: Prepared based on "Cancer Registration and Statistics," Cancer Information Service, National Cancer Center Japan

Thyroid cancer has some unique characteristics compared with other types of cancer.

The first is the higher incidence rate for females (11.5 females and 4.5 males against 100,000 people (national age-adjusted incidence rate)), but the male-to-female ratio is almost 1:1 among children younger than 15 years old.

It is known that breast cancer is most frequently detected in females in their 40s and 50s and the incidence rate of stomach cancer is higher among both males and females over 60 years old. On the other hand, thyroid cancer is characteristically found broadly in all age groups from teenagers to people in their 80s. Thyroid cancer is mostly a differentiated cancer, and the crude cancer mortality rate (national mortality rate by age group (against 100,000 people), all age groups, 2010) is lower for thyroid cancer than other cancers and better prognosis after surgery is also one of the characteristics of thyroid cancer. Nevertheless, some thyroid cancer may cause invasion into other organs or distant metastases or may affect vital prognosis. Therefore, careful evaluation is required.

Furthermore, thyroid cancer has long been known as a type of cancer, some of which are occult (latent) cancers without exerting any effects on people’s health throughout their lifetime (p.130 of Vol. 1, “Occult (Latent) Thyroid Cancer”).

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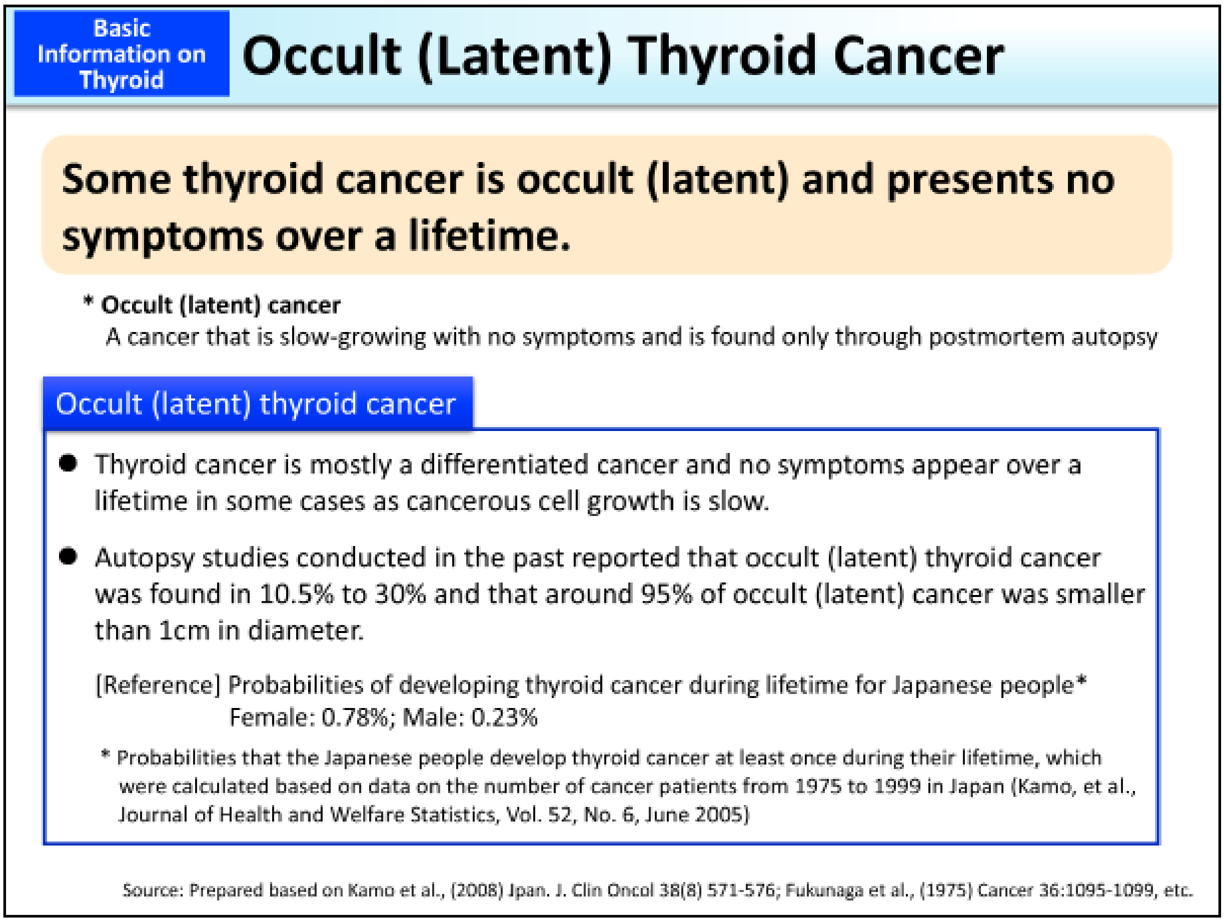
Updated on March 31, 2023



Basic Information on Thyroid

Occult (Latent) Thyroid Cancer

Some thyroid cancer is occult (latent) and presents no symptoms over a lifetime.

*** Occult (latent) cancer**
A cancer that is slow-growing with no symptoms and is found only through postmortem autopsy

Occult (latent) thyroid cancer

- Thyroid cancer is mostly a differentiated cancer and no symptoms appear over a lifetime in some cases as cancerous cell growth is slow.
- Autopsy studies conducted in the past reported that occult (latent) thyroid cancer was found in 10.5% to 30% and that around 95% of occult (latent) cancer was smaller than 1cm in diameter.

[Reference] Probabilities of developing thyroid cancer during lifetime for Japanese people*
Female: 0.78%; Male: 0.23%

* Probabilities that the Japanese people develop thyroid cancer at least once during their lifetime, which were calculated based on data on the number of cancer patients from 1975 to 1999 in Japan (Kamo, et al., Journal of Health and Welfare Statistics, Vol. 52, No. 6, June 2005)

Source: Prepared based on Kamo et al., (2008) Jpan. J. Clin Oncol 38(8) 571-576; Fukunaga et al., (1975) Cancer 36:1095-1099, etc.

Some types of cancer present no symptoms and exert no effects on people's health throughout their lifetime and are not clinically detected but are later found through histopathology diagnosis (including postmortem autopsy). Such cancer is called occult (latent) cancer.

One of the criteria for expressing the property of cancer cells is the degree of differentiation. This shows to what extent the relevant tumor resembles the normal tissue from which it originated, and the lower the degree is, the more malignant the tumor is and the easier the cancer grows.

Thyroid cancer is roughly categorized into differentiated cancer such as papillary cancer and follicular cancer, most of which are cancers with an especially high degree of differentiation, poorly differentiated cancer, undifferentiated cancer, and others. Out of these, in differentiated cancer, which accounts for the majority of thyroid cancer, cancer cells are mature and grow slowly and no symptoms appear over a lifetime in some cases. Such differentiated thyroid cancer is sometimes found as an occult (latent) cancer only through an autopsy conducted after a person's death due to other causes.

Based on an analysis using the cancer registry, probabilities that a Japanese person will develop thyroid cancer during his/her lifetime are 0.78% for females and 0.23% for males.[1] The results of the five autopsy studies targeting Japanese and Japanese Hawaiians[2-6] show that occult (latent) cancer was found with high frequency at 10.5% to 27.1% among males and 12.4% to 30.2% among females. In around 95% of the 525 cases found in the autopsy studies in Hiroshima and Nagasaki[2] and the 139 cases found in the autopsy studies in Sendai and Honolulu,[3] the sizes of tumors were smaller than 1cm.

These results also show that in many cases, thyroid cancer presents as an occult (latent) cancer without displaying symptoms throughout an individual's lifetime.

1. Kamo K et al., "Lifetime and Age-Conditional Probabilities of Developing or Dying of Cancer in Japan" Jpn. J. Clin. Oncol. 38(8) 571-576, 2008.
2. Sampson et al., "Thyroid carcinoma in Hiroshima and Nagasaki. I. Prevalence of thyroid carcinoma at autopsy" JAMA 209:65-70, 1969.
3. Fukunaga FH, Yatani R., "Geographic pathology of occult thyroid carcinomas" Cancer 36:1095-1099, 1975.
4. Seta K, Takahashi S., "Thyroid carcinoma" Int Surg 61:541-4, 1976.
5. Yatani R, et al., "PREVALENCE OF CARCINOMA IN THYROID GLANDS REMOVED IN 1102 CONSECUTIVE AUTOPSY CASES" Mie Medical Journal XXX:273-7, 1981.
6. Yamamoto Y, et al., "Occult papillary carcinoma of the thyroid ~ A study of 408 autopsy cases~" Cancer 65:1173-9, 1990.

Source
- International Classification of Diseases for Oncology, Third Edition. First Revision, ICD-O, edited by the Director-General for Policy Planning and Evaluation (in charge of statistics and information policy) of the Ministry of Health, Labour and Welfare (printed by Toukei Insatsu Industries, 2018)
- General Rules for the Description of Thyroid Cancer (the 8the Edition) edited by the Japan Association of Endocrine Surgery and the Japanese Society of Thyroid Pathology (printed by Kanehara & Co., Ltd., Tokyo, 2019)

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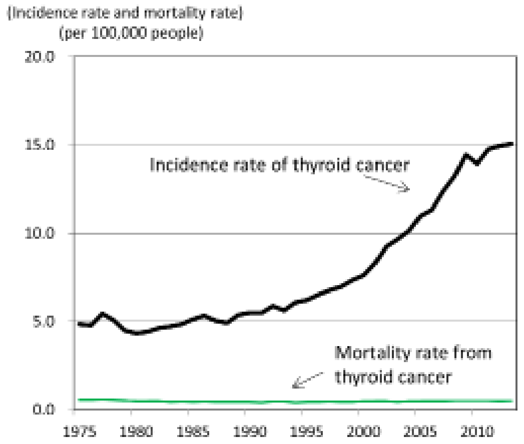
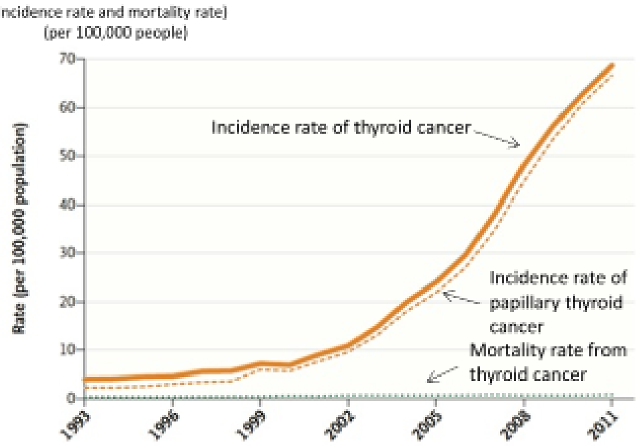
Basic Information on Thyroid

Incidence Rates of Thyroid Cancer: Overseas

Incidence rates and mortality rates (against 100,000 people) in America and South Korea



America*1



South Korea*2

Adapted with permission from [N Engl J Med., Ahn HS, Korea's thyroid-cancer "epidemic"--screening and overdiagnosis, 371(19), 1765-1767]. Copyright © 2014 Massachusetts Medical Society.

*1: Prepared based on NATIONAL CANCER INSTITUTE, Surveillance, Epidemiology, and End Results Program, SEER Cancer Statistics Review 1975-2013
*2: Prepared based on Ahn HS, N Engl J Med. 2014

In recent years, sharp increases in the incidence rate of thyroid cancer have been reported, which is said to be due to increases in the frequencies of medical surveys and use of healthcare services as well as the introduction of new diagnostic technologies, resulting in detection of many cases of micro thyroid cancer (micro papillary carcinoma).

As the mortality rate has remained almost unchanged despite sharp increases in the incidence rate, the possibility of overdiagnoses (detection of many cases of non-fatal micro papillary carcinoma that have no symptoms) is pointed out.[1]

Increases in the incidence rate of thyroid cancer are global trends observed in such countries as America, Australia, France and Italy, but are especially notable in South Korea. In South Korea, official assistance for thyroid cancer screening was commenced in 1999 to enable people to receive the most-advanced screening at low cost. This is considered to have prompted a larger number of people to receive screening, leading to significant increases in the incidence rate of thyroid cancer.

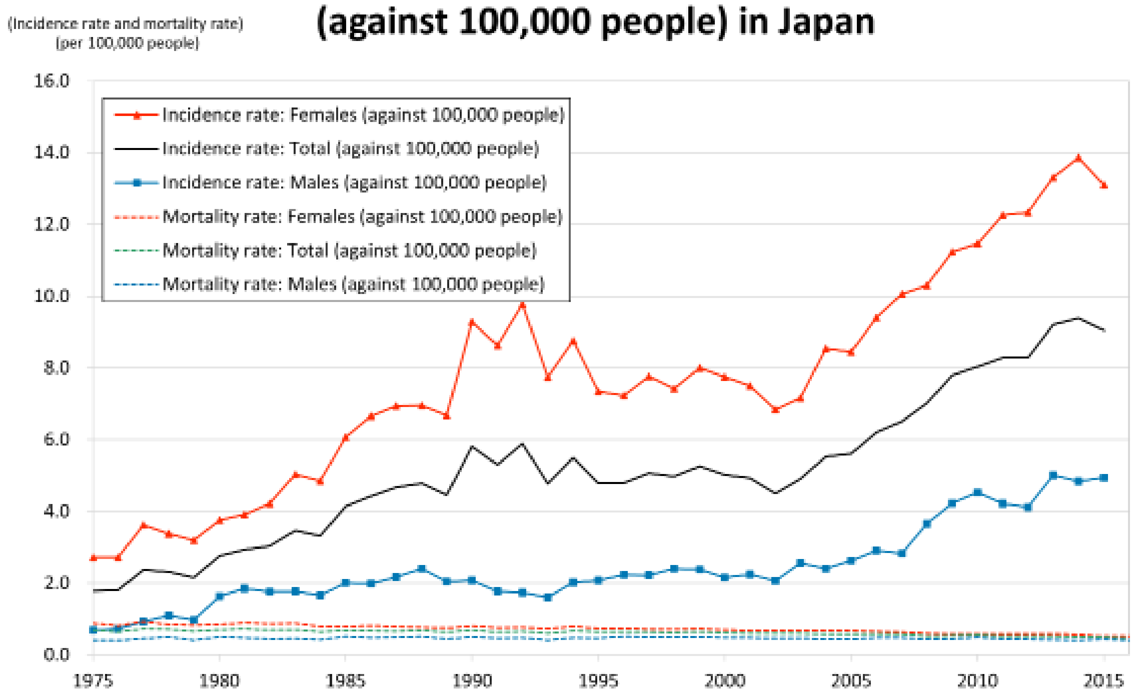
1. International Agency for Research on Cancer “Overdiagnosis is a major driver of the thyroid cancer epidemic: up to 50–90% of thyroid cancers in women in high-income countries estimated to be overdiagnoses” (August 18,2016)

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

Basic Information on Thyroid

Incidence Rates of Thyroid Cancer: Japan

Annual changes in age-adjusted incidence rates and mortality rates (against 100,000 people) in Japan



Source: Prepared based on the "Cancer Registration and Statistics," Cancer Information Service, National Cancer Center Japan

This figure shows annual changes in incidence rates (percentage of patients against the population during a certain period of time) and mortality rates concerning thyroid cancer in Japan.

The incidence rates of thyroid cancer have been on a rise both for males and females in Japan. The increasing trend is more notable among females and the incidence rate, which was around three per 100,000 people in 1975, exceeded 13 in 2014. In the meantime, the mortality rate from thyroid cancer has not shown any significant changes and has been slightly decreasing both for males and females. The total incidence rate of thyroid cancer including both males and females per 100,000 people in 2010 was approx. 15 in America, approx. 60 in South Korea, and approx. 8 in Japan (p.131 of Vol. 1, “Incidence Rates of Thyroid Cancer: Overseas”).

In Japan, palpation by doctors has long been conducted broadly as thyroid screening, but ultrasound neck examination is increasingly being adopted in complete medical checkups and mass-screening. Furthermore, thanks to recent advancement of ultrasonic diagnostic equipment, diagnostic capacity has been improving and the detection rate of tumoral lesions, in particular, is said to be increasing.[1]

[1] Hiroki Shimura, Journal of the Japan Thyroid Association, 1 (2), 109-113, 2010-10

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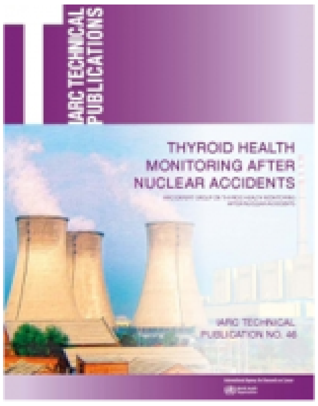
Updated on March 31, 2020

Basic Information on Thyroid

Recommendations by the IARC Expert Group

- In September 2018, an international Expert Group convened by the International Agency for Research on Cancer (IARC) published the Report on Thyroid Health Monitoring after Nuclear Accidents.
- In order to present the principles upon conducting a thyroid ultrasound examination in the event of a nuclear accident, the report compiles the latest knowledge on epidemiology and clinical practice concerning thyroid cancer and provides the following two recommendations. Incidentally, the report does not intend to remark on or evaluate thyroid ultrasound examinations conducted so far after nuclear accidents in the past.



Recommendation 1

The Expert Group recommends against population thyroid screening*1 after a nuclear accident.

*1 Actively recruiting all residents of a defined area, irrespective of any individual thyroid dose assessment, to participate in thyroid examinations followed by clinical management according to an established protocol

Recommendation 2

The Expert Group recommends that consideration be given to offering a long-term thyroid monitoring programme for higher-risk individuals*2 after a nuclear accident.

*2 Those who were exposed in utero or during childhood or adolescence (younger than 19 years old) with a thyroid dose of 100-500 mGy or more

Source: Prepared based on the "Thyroid Health Monitoring after Nuclear Accidents" by the IARC (2018) and "Long-term strategies for thyroid health monitoring after nuclear accidents - A summary of IARC Technical Publication No. 46" by the IARC (2018) (translated into Japanese: http://www.env.go.jp/chemi/rhm/post_132.html)

In April 2017, the International Agency for Research on Cancer (IARC), an external organization of the World Health Organization (WHO), established an international Expert Group on long-term strategies for thyroid health monitoring after nuclear accidents with the aim of providing scientific information and advice concerning effects of radiation exposure to policy making personnel and medical personnel of individual countries.

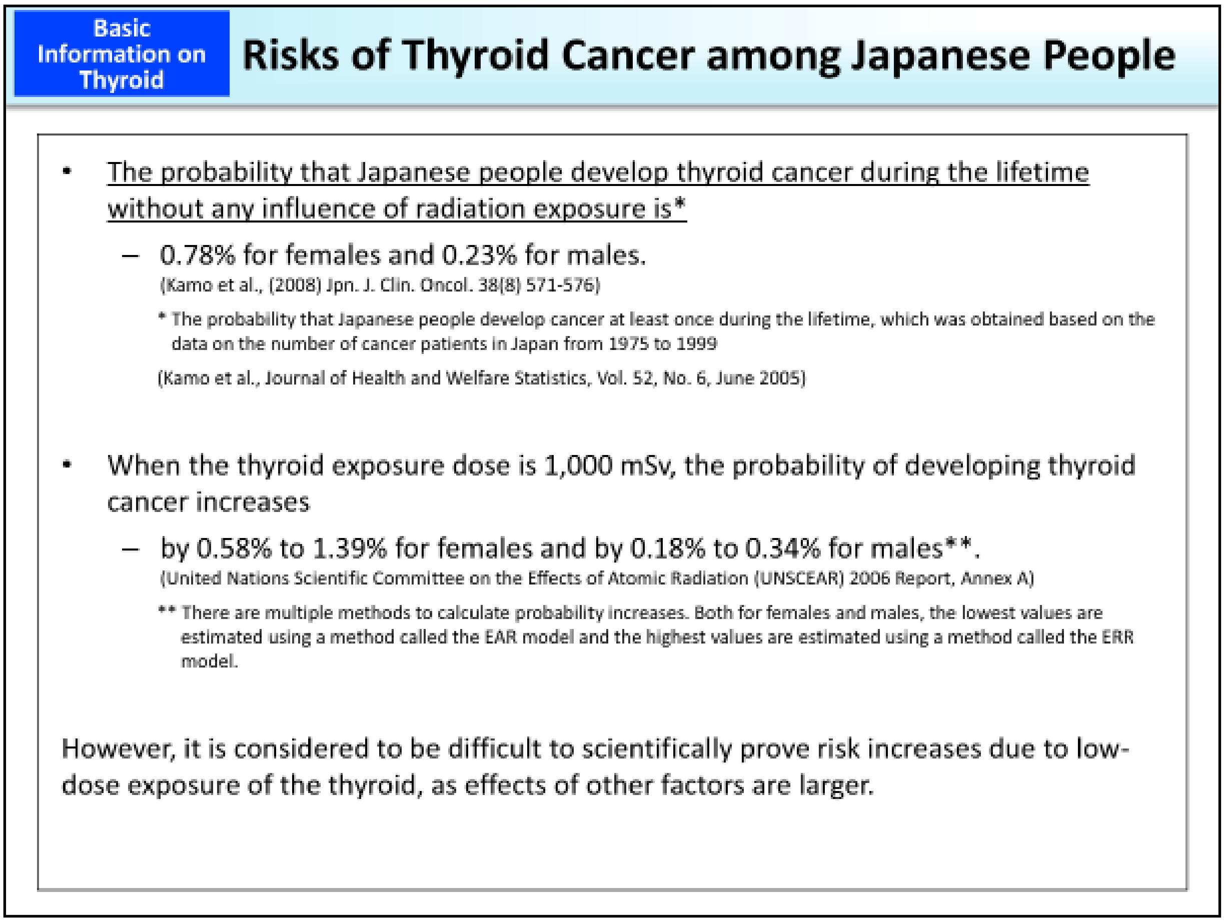
The Expert Group's Report on Thyroid Health Monitoring after Nuclear Accidents published in September 2018 compiles the latest knowledge on epidemiology and clinical practice concerning thyroid cancer and provides two recommendations concerning long-term strategies for thyroid health monitoring in the event of a nuclear accident, based on the currently available scientific evidence and on past experiences.

Firstly, the Expert Group recommends against population thyroid screening to actively recruiting all residents of a defined area to participate in thyroid ultrasound examinations.

Secondly, the Expert Group recommends that consideration be given to offering a long-term thyroid monitoring programme for higher-risk individuals who were exposed in utero or during childhood or adolescence with a thyroid dose of 100-500 mGy or more. A thyroid monitoring program here refers to one that is distinct from population screening and is defined as “including education to improve health literacy, registration of participants, centralized data collection from thyroid examinations, and clinical management.” Targeted persons may choose how and whether to undergo thyroid examinations in an effort to benefit from early detection and treatment of less advanced disease. The Report also adds as follows: “Some individuals with lower risks may worry about thyroid cancer and may receive thyroid ultrasound examinations for peace of mind. If such individuals with lower risks seek to have an examination after receiving detailed explanations on potential advantages and disadvantages of thyroid ultrasound examinations, they should be provided with opportunities for thyroid ultrasound examinations under the framework of the developed thyroid monitoring programs.”

Incidentally, this report does not remark on or evaluate thyroid ultrasound examinations conducted so far after nuclear accidents in the past.

Included in this reference material on March 31, 2020



Basic Information on Thyroid

Risks of Thyroid Cancer among Japanese People

- The probability that Japanese people develop thyroid cancer during the lifetime without any influence of radiation exposure is*
  - 0.78% for females and 0.23% for males.

(Kamo et al., (2008) Jpn. J. Clin. Oncol. 38(8) 571-576)

* The probability that Japanese people develop cancer at least once during the lifetime, which was obtained based on the data on the number of cancer patients in Japan from 1975 to 1999

(Kamo et al., Journal of Health and Welfare Statistics, Vol. 52, No. 6, June 2005)

- When the thyroid exposure dose is 1,000 mSv, the probability of developing thyroid cancer increases
  - by 0.58% to 1.39% for females and by 0.18% to 0.34% for males**.

(United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2006 Report, Annex A)

** There are multiple methods to calculate probability increases. Both for females and males, the lowest values are estimated using a method called the EAR model and the highest values are estimated using a method called the ERR model.

However, it is considered to be difficult to scientifically prove risk increases due to low-dose exposure of the thyroid, as effects of other factors are larger.

The probability that a Japanese person will develop thyroid cancer during their lifetime is 0.78% for females and 0.23% for males, which is the probability that they will develop thyroid cancer at least once during the lifetime, obtained based on the thyroid cancer incidence rate among the total cancer incidence data in Japan from 1975 to 1999. This is an index devised with the aim of explaining cancer risks to ordinary people in an easy-to-understand manner.

Exposure to 1,000 mSv in the thyroid increases the probability of developing thyroid cancer by 0.58% to 1.39% for females and by 0.18% to 0.34% for males.

However, if the thyroid exposure dose is low, it is considered to be difficult to scientifically prove risk increases due to the radiation exposure, as effects of other factors are larger.

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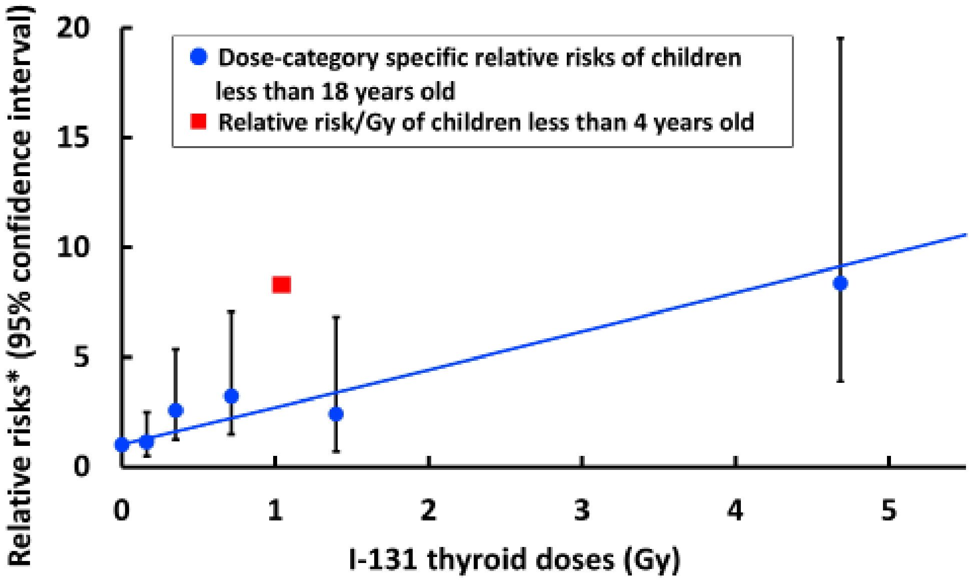
Basic Information on Thyroid

Relationship between Thyroid Cancer and Doses

- Chornobyl NPS Accident -

Dose-effect relationship between thyroid cancer and I-131 doses
(Estimation based on the cohort study on effects of the Chornobyl NPS Accident in Ukraine)



Source: Prepared based on Brenner et al., Environ Health Perspect 119, 933, 2011

* Relative risks indicate how many times larger the cancer risks are among people exposed to radiation when assuming the risks among non-exposed people as 1.

The results of the study on the relationship between internal doses and risks of thyroid cancer among children affected by the Chornobyl NPS Accident are as shown in the figure above.

That is, exposure to 1 Gy in the thyroid increases the probability of developing thyroid cancer by 2.9. This study concludes that the 2.9-fold increase in risks is the average of children less than 18 years old, and for younger children less than 4 years old, the risk increase would be sharper (indicated with ■ in the figure).
(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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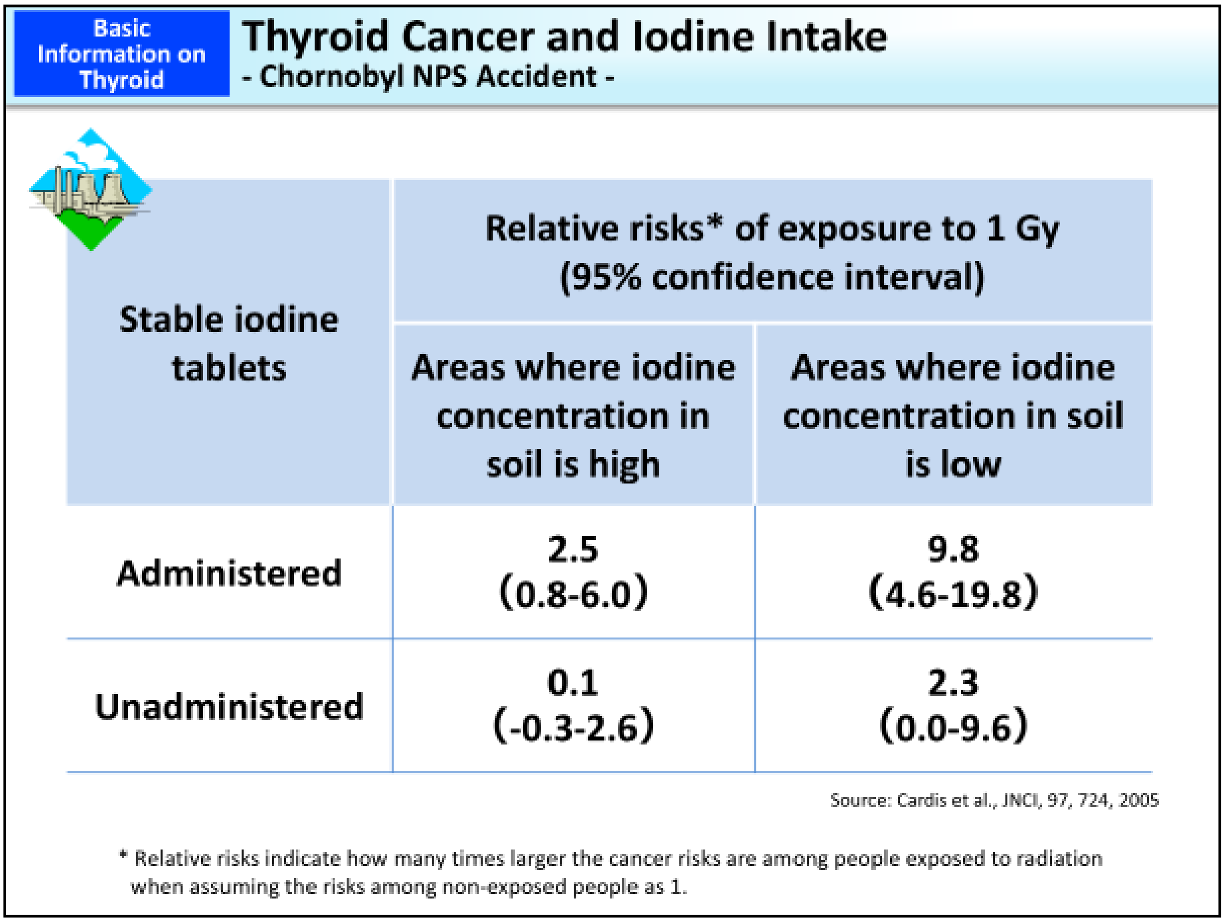

Basic Information on Thyroid

Thyroid Cancer and Iodine Intake

- Chornobyl NPS Accident -

Stable iodine tablets	Relative risks* of exposure to 1 Gy (95% confidence interval)	
	Areas where iodine concentration in soil is high	Areas where iodine concentration in soil is low
Administered	2.5 (0.8-6.0)	9.8 (4.6-19.8)
Unadministered	0.1 (-0.3-2.6)	2.3 (0.0-9.6)

Source: Cardis et al., JNCI, 97, 724, 2005

* Relative risks indicate how many times larger the cancer risks are among people exposed to radiation when assuming the risks among non-exposed people as 1.

As shown in the table, there has been a report that the relative risk of thyroid cancer per gray increases in areas where iodine concentration in soil is low and iodine intake is insufficient. Areas around Chornobyl, where the relevant data was obtained, are located inland away from the sea and iodine concentration in soil is low, and people there do not habitually eat seaweed and salt-water fish that are rich in iodine.

Compared to areas around Chornobyl, iodine concentration in soil is higher in Japan as a whole and iodine intake is also higher than in other countries. Accordingly, such data as obtained in areas around Chornobyl is not necessarily applicable in Japan.
(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks,” and p.128 of Vol. 1, “Iodine”)

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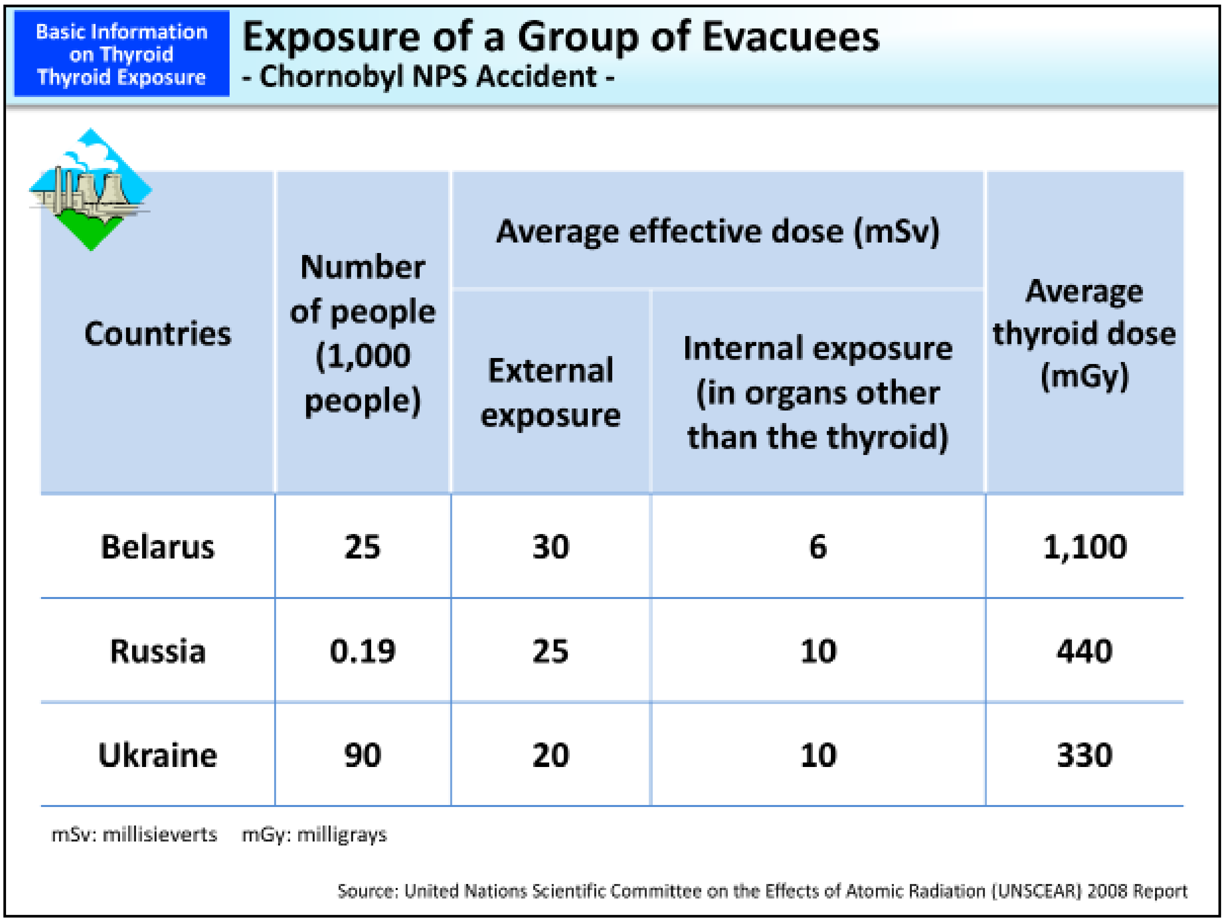

Basic Information on Thyroid
Thyroid Exposure

Exposure of a Group of Evacuees

- Chornobyl NPS Accident -

Countries	Number of people (1,000 people)	Average effective dose (mSv)		Average thyroid dose (mGy)
		External exposure	Internal exposure (in organs other than the thyroid)	
Belarus	25	30	6	1,100
Russia	0.19	25	10	440
Ukraine	90	20	10	330

mSv: millisieverts mGy: milligrays

Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 Report

Thyroid exposure doses are high for people who were forced to evacuate after the Chornobyl NPS Accident and the average is estimated to be approx. 490 mGy, which was far larger than the average thyroid exposure dose for people who resided outside evacuation areas in the former Soviet Union (approx. 20 mGy) and the average for people residing in other European countries (approx. 1 mGy).

The average thyroid exposure dose for children is estimated to be even higher. One of the major causes is that they drank milk contaminated with I-131 for two to three weeks after the accident.

The effective dose from internal exposure in organs other than the thyroid and from external exposure was approx. 31 mSv on average. The average effective dose was approx. 36 mSv in Belarus, approx. 35 mSv in Russia, and approx. 30 mSv in Ukraine. It is known that the average effective dose is larger in Belarus than in Ukraine and Russia as in the case of the average thyroid exposure dose.

(Related to p.138 of Vol. 1, “Time of Developing Childhood Thyroid Cancer - Chornobyl NPS Accident -”)

Included in this reference material on March 31, 2013
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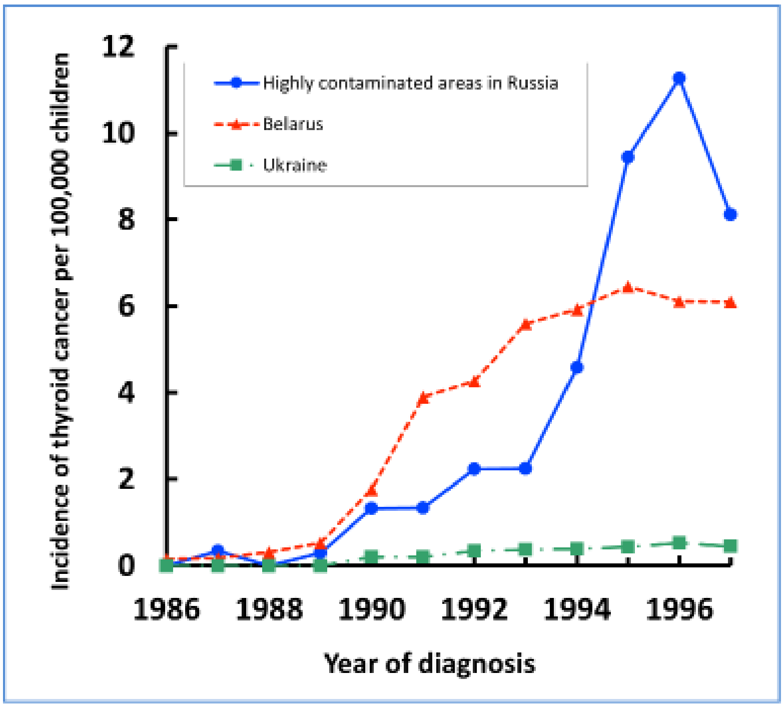
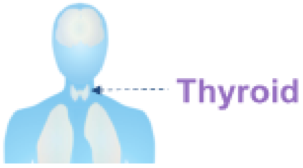
Time of Developing Childhood Thyroid Cancer - Chornobyl NPS Accident -

Childhood thyroid cancer (Chornobyl NPS Accident)





Iodine is a raw material of thyroid hormones.

Childhood thyroid cancer cases started to appear four or five years after the accident, and showed a sharp increase by more than 10 times after the lapse of 10 years.

Source: Prepared based on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report

At the time of the Chornobyl NPS Accident, a large amount of radioactive materials was released and broadly spread out due to the explosion. The major cause of the adverse effects of health is said to be radioactive iodine.

Some of the children who inhaled radioactive iodine that fell onto the ground or consumed the vegetables, milk, and meat contaminated through the food chain later developed childhood thyroid cancer. In particular, the major contributing factor is considered to be internal exposure to I-131 contained in milk.

In Belarus and Ukraine, childhood thyroid cancer cases started to appear four or five years after the accident. The incidence rate of thyroid cancer among children aged 14 or younger increased by 5 to 10 times from 1991 to 1994 than in the preceding five years from 1986 to 1990.

The incidence of childhood thyroid cancer for Belarus and Ukraine is the number per 100,000 children nationwide, while that for Russia is the number per 100,000 children only in specific areas heavily contaminated[1]. In addition, concerning the thyroid cancer cases observed with children and adolescents after the Chornobyl NPS Accident, the UNSCEAR calculated the attributable fraction (p.99 of Vol. 1, “Relative Risks and Attributable Risks”) based on the latest information provided by the three most affected countries (Russia, Ukraine, and Belarus) and estimated that among the thyroid cancer cases that appeared in the population of children or adolescents who were living in the most contaminated areas at the time of the accident, the thyroid cancer cases attributable to radiation exposure accounted for about 25%[2].

(Related to p.127 of Vol. 1, “Thyroid,” and p.137 of Vol. 1, “Exposure of a Group of Evacuees - Chornobyl NPS Accident -”)

1. UNSCEAR 2000 Report, Annex
2. UNSCEAR “Chornobyl 2018 White Paper”

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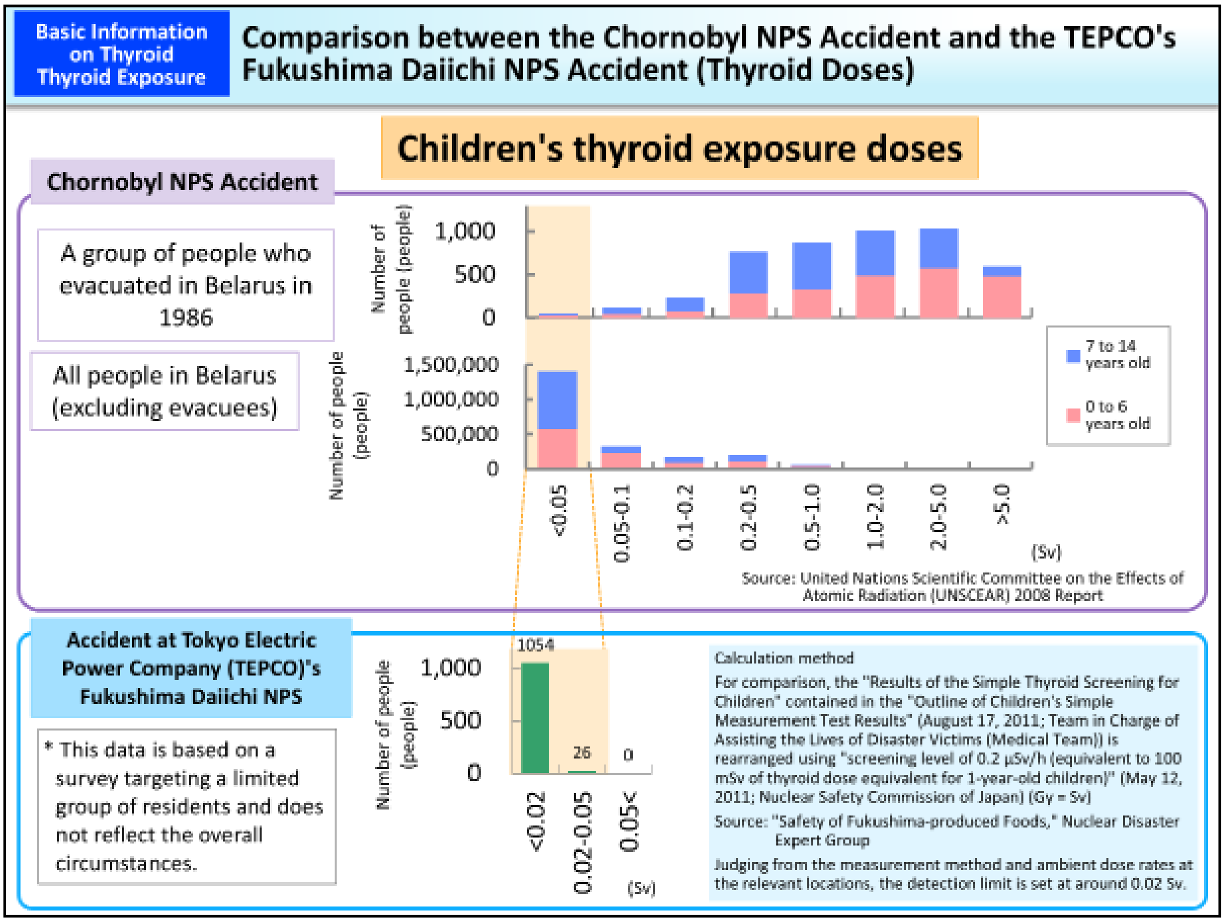

Basic Information on Thyroid Thyroid Exposure

Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Thyroid Doses)

Children's thyroid exposure doses

Chornobyl NPS Accident

A group of people who evacuated in Belarus in 1986

All people in Belarus (excluding evacuees)

Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 Report

Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS

* This data is based on a survey targeting a limited group of residents and does not reflect the overall circumstances.

Calculation method

For comparison, the "Results of the Simple Thyroid Screening for Children" contained in the "Outline of Children's Simple Measurement Test Results" (August 17, 2011; Team in Charge of Assisting the Lives of Disaster Victims (Medical Team)) is rearranged using "screening level of 0.2 μSv/h (equivalent to 100 mSv of thyroid dose equivalent for 1-year-old children)" (May 12, 2011; Nuclear Safety Commission of Japan) (Gy = Sv)

Source: "Safety of Fukushima-produced Foods," Nuclear Disaster Expert Group

Judging from the measurement method and ambient dose rates at the relevant locations, the detection limit is set at around 0.02 Sv.

It is very difficult to accurately assess the level of exposure of children's thyroids to radioactive iodine after the accident at TEPCO's Fukushima Daiichi NPS, but rough estimation is possible using the results of the thyroid screening conducted for children as of approx. two weeks after the accident.

This screening was conducted using survey meters for 1,080 children aged 15 or younger in Kawamata, Iwaki, and Iitate, where children's thyroid doses were suspected to be especially high.

As a result, thyroid doses exceeding the screening level set by the Nuclear Safety Commission of Japan (at that time) were not detected and measured thyroid doses were all below 50 mSv for those children who received the screening.

In the UNSCEAR's analysis of thyroid doses after the Chornobyl NPS Accident, the dose range below 50 mSv is considered to be the lowest dose range. Thyroid exposure doses for children in Belarus, where increased incidences of childhood thyroid cancer were later observed, were 0.2 to 5.0 Sv or over 5.0 Sv among a group of evacuees, showing two-digit larger values than the results of the screening in Fukushima Prefecture.
(Related to p.140 of Vol. 1, "Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Ages at the Time of Radiation Exposure)")

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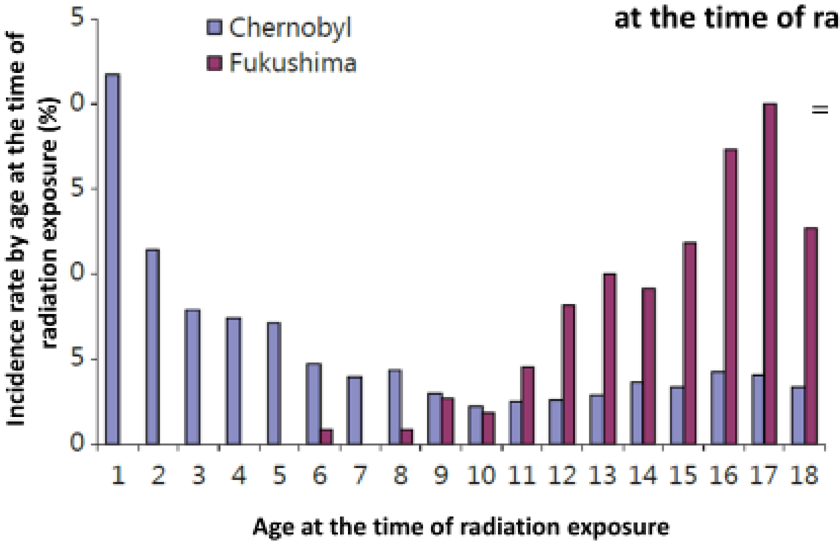
Basic Information on Thyroid Thyroid Exposure

Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Ages at the Time of Radiation Exposure)

- **Distribution of age at the time of radiation exposure of childhood thyroid cancer patients observed in Chornobyl and Fukushima**

(Among the total number of incidence in respective regions)



Incidence rate of thyroid cancer by age at the time of radiation exposure (%)

= **Number of incidence for each age** / **Total number of incidence of thyroid cancer**

(Fukushima: Diagnosed as malignant or suspected)

Source: Prepared based on Williams D, Eur Thyroid J 2015; 4: 164–173

This figure shows the incidence rates of childhood thyroid cancer by age at the time of radiation exposure (aged 18 or younger), in comparison with those after the Chornobyl NPS Accident and those in three years after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (the percentage in the figure shows the ratio by age, i.e., what percentage the incidence for each age accounts for against the total number of incidence of thyroid cancer in respective regions; the sum of all percentages comes to 100%). The figure shows clear difference in age distribution although an accurate comparison is difficult as thyroid cancer screening in Chornobyl has not been conducted in a uniform manner as in Fukushima and such information as the number of examinees and observation period is not clearly indicated.

Generally speaking, risks of radiation-induced thyroid cancer are higher at younger ages (especially 5 years old or younger) (p.121 of Vol. 1, "Oncogenic Risks by Age at the Time of Radiation Exposure"). In Chornobyl, it is observed that people exposed to radiation at younger ages have been more likely to develop thyroid cancer. On the other hand, in Fukushima, incidence rates of thyroid cancer among young children have not increased three years after the accident and incidence rates have only increased in tandem with examinees' ages. This tendency is the same as increases observed in incidence rates of ordinary thyroid cancer (p.129 of Vol. 1, "Characteristics of Thyroid Cancer").

The document by Williams suggests that thyroid cancer detected three years after the accident at Fukushima Daiichi NPS is not attributable to the effects of the radiation exposure due to the accident in light of the facts that daily iodine intake from foods is larger in Japan than in areas around Chornobyl and that the maximum estimated thyroid exposure doses among children is much smaller in Japan (66 mGy in Fukushima and 5,000 mGy in Chornobyl).
(Related to p.139 of Vol. 1, "Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Thyroid Doses)")

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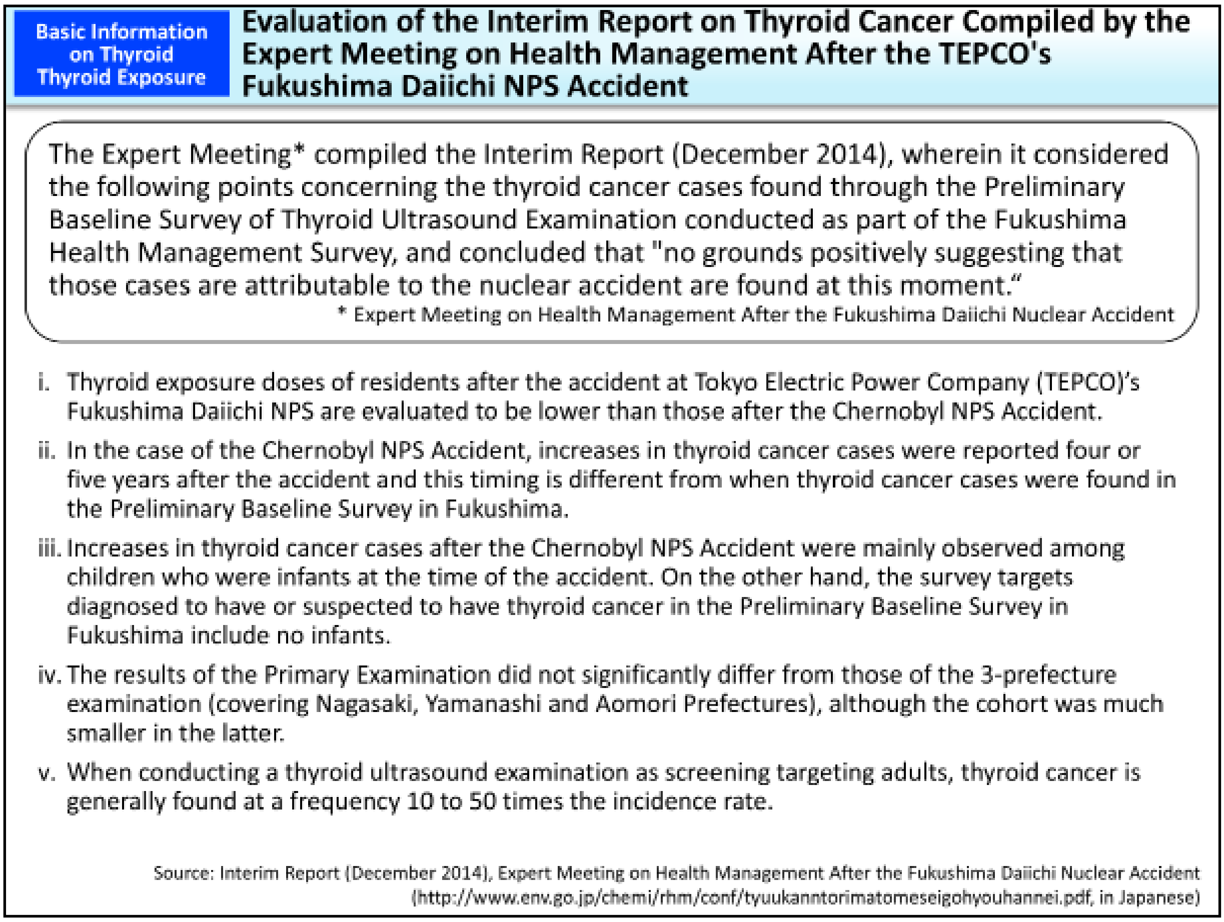

Basic Information on Thyroid Thyroid Exposure

Evaluation of the Interim Report on Thyroid Cancer Compiled by the Expert Meeting on Health Management After the TEPCO's Fukushima Daiichi NPS Accident

The Expert Meeting* compiled the Interim Report (December 2014), wherein it considered the following points concerning the thyroid cancer cases found through the Preliminary Baseline Survey of Thyroid Ultrasound Examination conducted as part of the Fukushima Health Management Survey, and concluded that "no grounds positively suggesting that those cases are attributable to the nuclear accident are found at this moment.“

* Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident

i. Thyroid exposure doses of residents after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS are evaluated to be lower than those after the Chernobyl NPS Accident.
ii. In the case of the Chernobyl NPS Accident, increases in thyroid cancer cases were reported four or five years after the accident and this timing is different from when thyroid cancer cases were found in the Preliminary Baseline Survey in Fukushima.
iii. Increases in thyroid cancer cases after the Chernobyl NPS Accident were mainly observed among children who were infants at the time of the accident. On the other hand, the survey targets diagnosed to have or suspected to have thyroid cancer in the Preliminary Baseline Survey in Fukushima include no infants.
iv. The results of the Primary Examination did not significantly differ from those of the 3-prefecture examination (covering Nagasaki, Yamanashi and Aomori Prefectures), although the cohort was much smaller in the latter.
v. When conducting a thyroid ultrasound examination as screening targeting adults, thyroid cancer is generally found at a frequency 10 to 50 times the incidence rate.

Source: Interim Report (December 2014), Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident
(http://www.env.go.jp/chemi/rhm/conf/tyuukanntorimatomeseigohyouhannei.pdf, in Japanese)

The Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident examines various measures concerning dose evaluation, health management and medical services from an expert perspective.

It publicized the Interim Report in December 2014 and concluded that regarding the thyroid cancer cases found through the Preliminary Baseline Survey of Thyroid Ultrasound Examination conducted as part of the Fukushima Health Management Survey, “no grounds positively suggesting that those cases are attributable to the nuclear accident are found at this moment.”

The Expert Meeting points out the necessity to continue the Thyroid Ultrasound Examination as follows.

- The trend of the incidence of thyroid cancer, which is especially a matter of concern among the residents, needs to be carefully monitored under the recognition that radiation health management requires a mid- to long-term perspective in light of the uncertainties of estimated exposure doses.

(Related to p.150 of Vol. 2, “Thyroid Ultrasound Examination: Remarks on the Results of the Preliminary Baseline Survey”)

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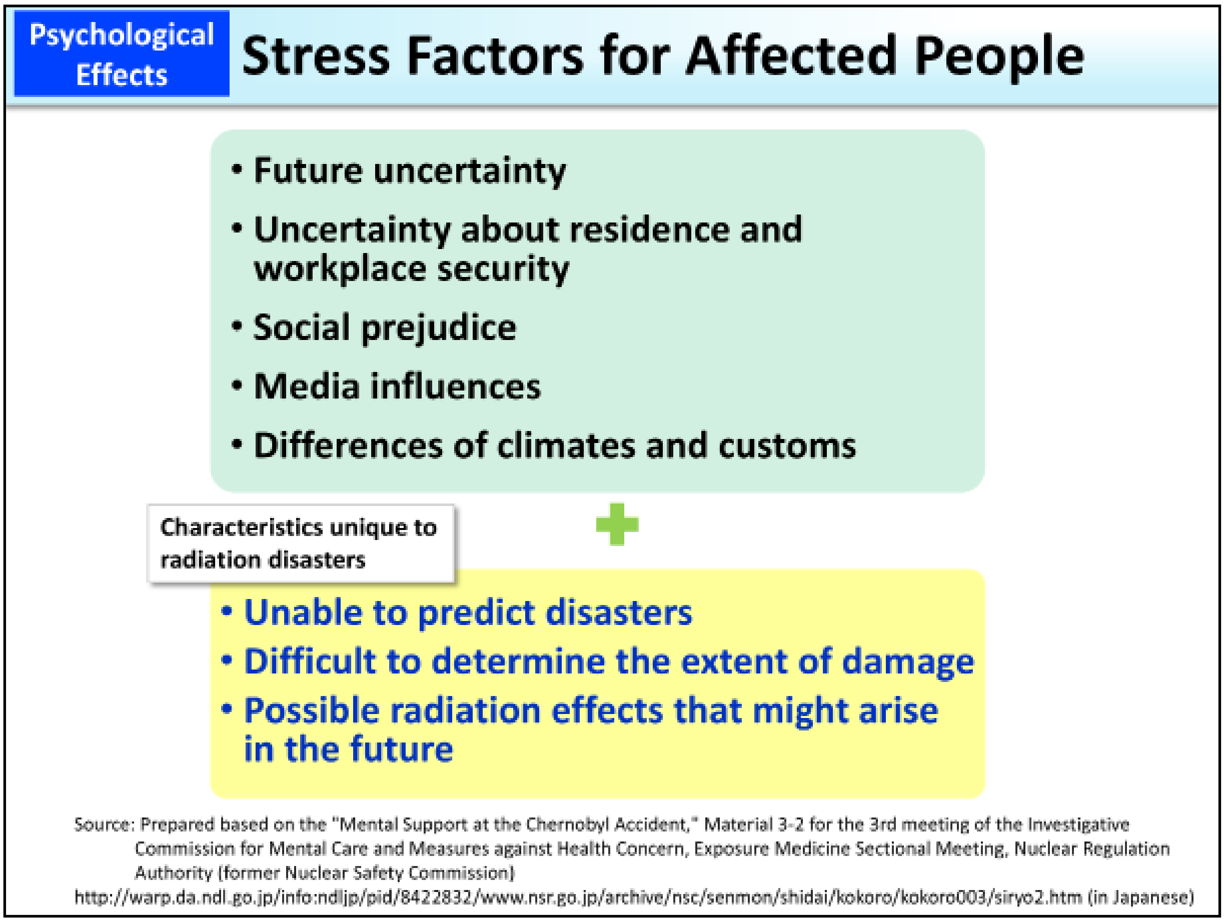

Psychological Effects

Stress Factors for Affected People

- Future uncertainty
- Uncertainty about residence and workplace security
- Social prejudice
- Media influences
- Differences of climates and customs

Characteristics unique to radiation disasters

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- Unable to predict disasters
- Difficult to determine the extent of damage
- Possible radiation effects that might arise in the future

Source: Prepared based on the "Mental Support at the Chernobyl Accident," Material 3-2 for the 3rd meeting of the Investigative Commission for Mental Care and Measures against Health Concern, Exposure Medicine Sectional Meeting, Nuclear Regulation Authority (former Nuclear Safety Commission)
http://warp.da.ndl.go.jp/info:ndljp/pid/8422832/www.nsr.go.jp/archive/nsc/senmon/shidai/kokoro/kokoro003/siryo2.htm (in Japanese)

Generally, factors causing stress to the affected people include future uncertainty, uncertainty about residence and workplace security, social prejudices, media influences, differences of climates and customs, etc. For radiation disasters, there are other stress factors as well, such as being unable to predict disasters, difficulty in determining the extent of damage, and radiation effects that might arise in the future (p.143 of Vol. 1, “Radiation Accidents and Health Concerns”).

In particular, concerns over future radiation effects cause a huge stress as affected people have to be worried for a long time about the possibility that they might someday develop cancer.

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Psychological Effects

Radiation Accidents and Health Concerns

Anxiety caused by radiation accidents

- Anxiety over health effects of radiation
- Anxiety over health effects on children now and in the future

Psychological effects from protracted anxiety

- Possibility that mental health may deteriorate
- Possibility that mothers' anxiety may affect the mental state and growth of children

Factors that increase anxiety

- Unable to acquire reliable information
- Confusion caused by scientifically inaccurate information
- Stigmas and stereotypes

In the event of a radiation accident, people would be worried about the possibility of their exposure to radiation and about the extent of exposure and possible health effects if exposure occurred. Parents in particular would be concerned about the immediate and long-term health effects on their children.

People’s mental health would deteriorate as a result of protracted anxiety over possible future health effects. It has also been pointed out that the anxiety of mothers might affect the mental state and growth of their children (p.106 of Vol. 1, “Effects on Children - Chornobyl NPS Accident -”).

The anxiety could be heightened by being unable to acquire reliable and accurate information about radiation. It has also been reported that unreasonable public stigmas and discriminations (stereotypes) about people affected by contamination or exposure could exacerbate their mental health problems.[1,2]

1. Fukushima Psychological Care Manual, Fukushima Mental Health and Welfare Centre
2. Werner Burkart(Vienna) “Message to our friends affected by the nuclear component of the earthquake/tsunami event of March 2011 (August 26, 2013)”(Werner Burkart :Professor for Radiation Biology at the Faculty of Medicine of the Ludwig Maximilians University in Munich, Former Deputy Director General of the International Atomic Energy Agency (IAEA))
(http://japan.kantei.go.jp/incident/health_and_safety/burkart.html)

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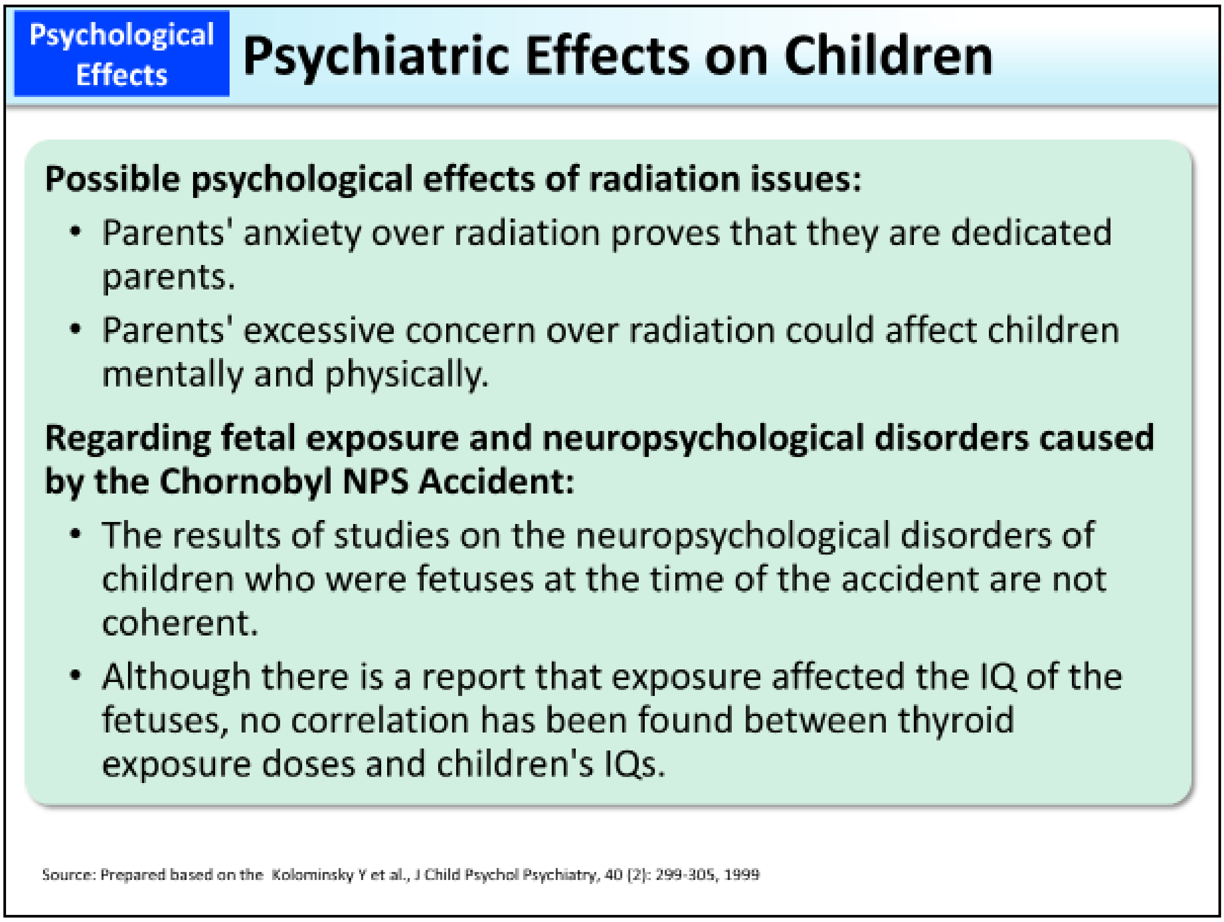

Psychological Effects

Psychiatric Effects on Children

Possible psychological effects of radiation issues:

- Parents' anxiety over radiation proves that they are dedicated parents.
- Parents' excessive concern over radiation could affect children mentally and physically.

Regarding fetal exposure and neuropsychological disorders caused by the Chornobyl NPS Accident:

- The results of studies on the neuropsychological disorders of children who were fetuses at the time of the accident are not coherent.
- Although there is a report that exposure affected the IQ of the fetuses, no correlation has been found between thyroid exposure doses and children's IQs.

Source: Prepared based on the Kolominsky Y et al., J Child Psychol Psychiatry, 40 (2): 299-305, 1999

In some of the studies targeting children who were fetuses at the time of the Chornobyl NPS Accident, investigations on neuropsychological effects were also conducted.

Although the results of the studies are not necessarily coherent, a report that attests to emotional disorders of the children caused by the accident also points out other effects such as parents' anxiety as factors affecting their mental state, rather than merely pointing out radiation exposure as a direct effect (p.106 of Vol. 1, "Effects on Children - Chornobyl NPS Accident -").

(For the results of the survey on children's mental health conducted by Fukushima Prefecture, see p.164 of Vol. 2, "Mental Health and Lifestyle Survey: What Has Become Clear (5/5).")

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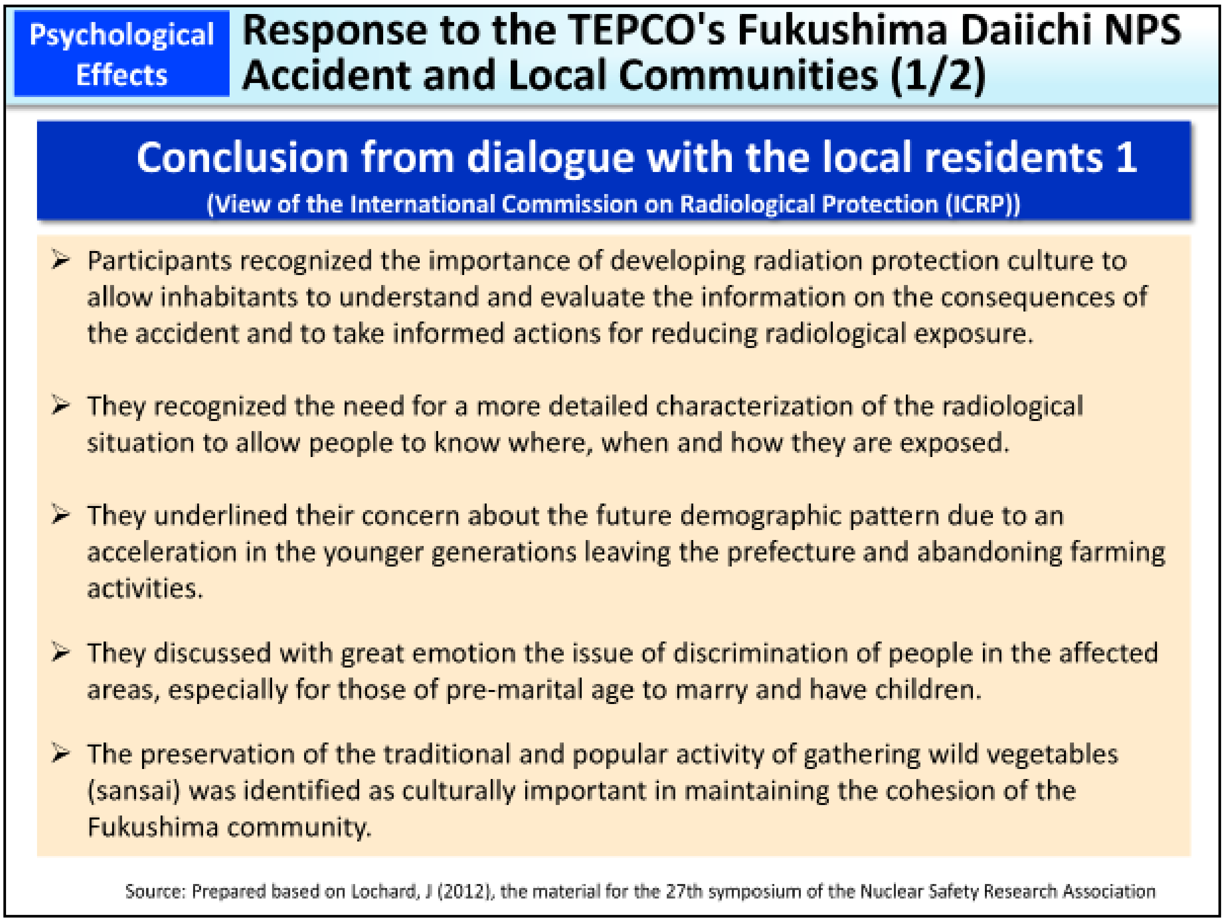

Psychological Effects

Response to the TEPCO's Fukushima Daiichi NPS Accident and Local Communities (1/2)

Conclusion from dialogue with the local residents 1

(View of the International Commission on Radiological Protection (ICRP))

- Participants recognized the importance of developing radiation protection culture to allow inhabitants to understand and evaluate the information on the consequences of the accident and to take informed actions for reducing radiological exposure.
- They recognized the need for a more detailed characterization of the radiological situation to allow people to know where, when and how they are exposed.
- They underlined their concern about the future demographic pattern due to an acceleration in the younger generations leaving the prefecture and abandoning farming activities.
- They discussed with great emotion the issue of discrimination of people in the affected areas, especially for those of pre-marital age to marry and have children.
- The preservation of the traditional and popular activity of gathering wild vegetables (sansai) was identified as culturally important in maintaining the cohesion of the Fukushima community.

Source: Prepared based on Lochard, J (2012), the material for the 27th symposium of the Nuclear Safety Research Association

Providing useful information for helping affected people to solve or deal with real issues has been proven to be an effective means for offering psychological support.

In the event of a nuclear disaster, expert knowledge is required to understand the possible effects of radiation and to come up with measures for radiological protection.

After the Chornobyl NPS Accident, as well as after the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident, experts and local residents had dialogues. If affected people are able to solve radiation issues by themselves with experts' support, that is considered quite effective in reducing their psychological stress.

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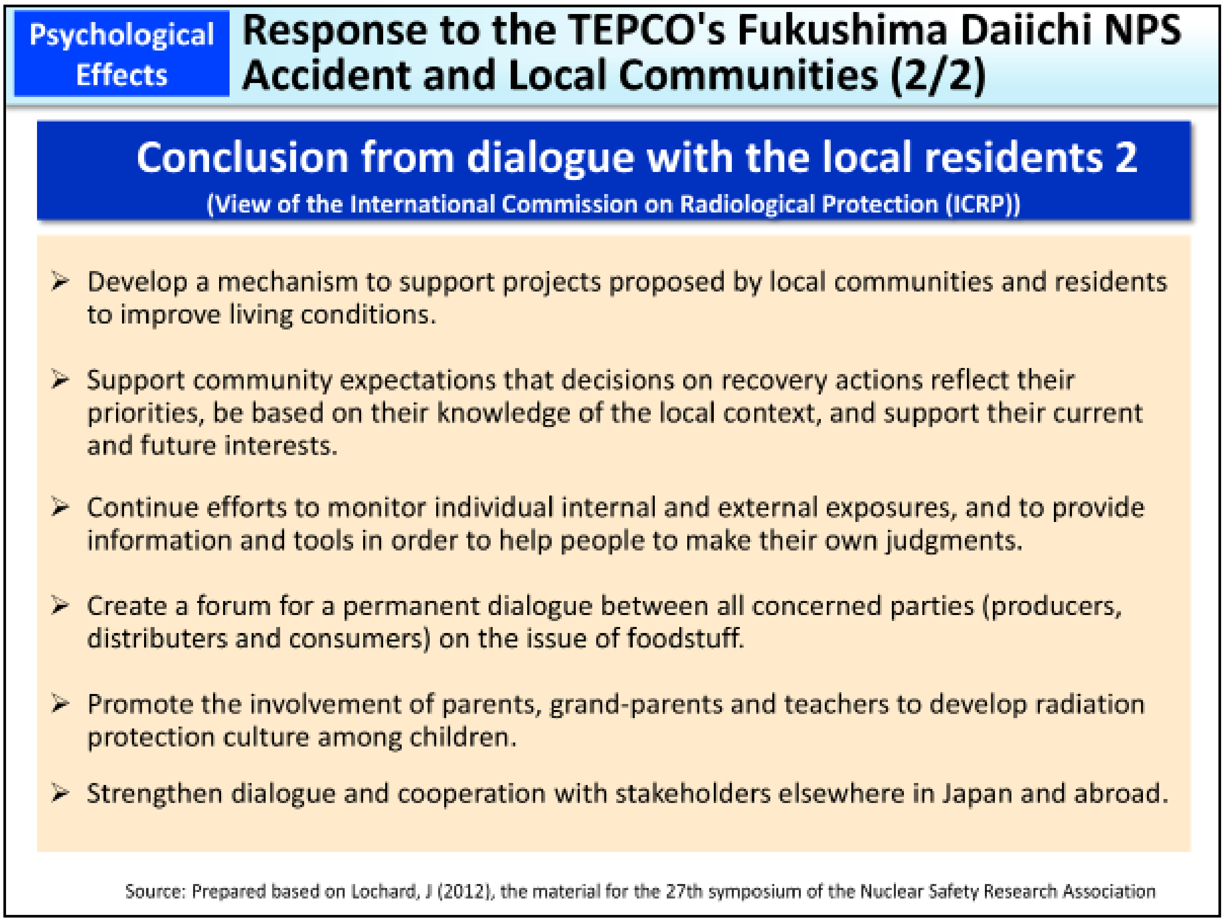

Psychological Effects

Response to the TEPCO's Fukushima Daiichi NPS Accident and Local Communities (2/2)

Conclusion from dialogue with the local residents 2

(View of the International Commission on Radiological Protection (ICRP))

- ➢ Develop a mechanism to support projects proposed by local communities and residents to improve living conditions.
- ➢ Support community expectations that decisions on recovery actions reflect their priorities, be based on their knowledge of the local context, and support their current and future interests.
- ➢ Continue efforts to monitor individual internal and external exposures, and to provide information and tools in order to help people to make their own judgments.
- ➢ Create a forum for a permanent dialogue between all concerned parties (producers, distributers and consumers) on the issue of foodstuff.
- ➢ Promote the involvement of parents, grand-parents and teachers to develop radiation protection culture among children.
- ➢ Strengthen dialogue and cooperation with stakeholders elsewhere in Japan and abroad.

Source: Prepared based on Lochard, J (2012), the material for the 27th symposium of the Nuclear Safety Research Association

The ICRP provided some specific suggestions as a result of the dialogues between experts on radiological protection and the affected people of the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. The suggestions include the necessity to reflect the priorities of local communities, provide tools and information about radiation doses, create a permanent forum on foods, develop radiological protection culture, etc.

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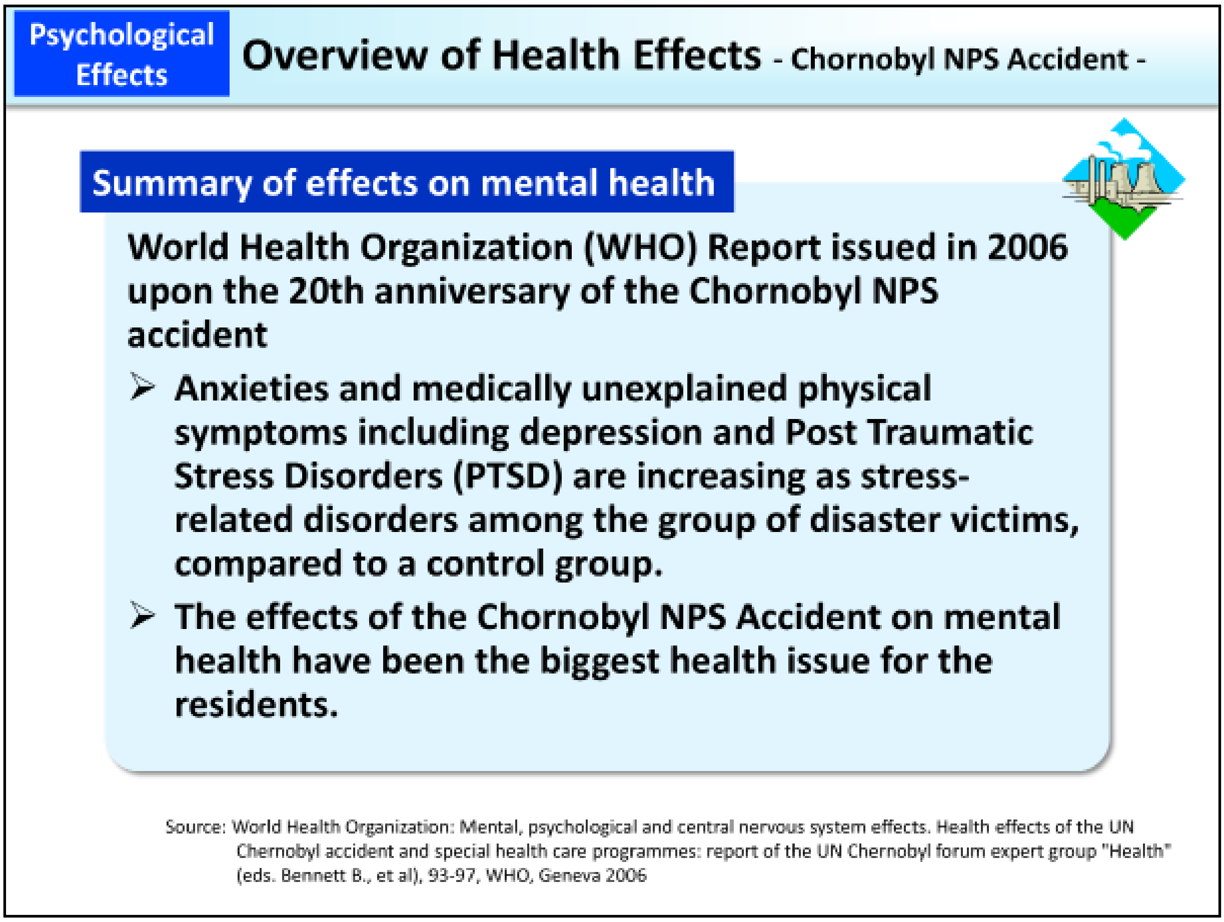

Psychological Effects

Overview of Health Effects - Chornobyl NPS Accident -

Summary of effects on mental health

World Health Organization (WHO) Report issued in 2006 upon the 20th anniversary of the Chornobyl NPS accident

- Anxieties and medically unexplained physical symptoms including depression and Post Traumatic Stress Disorders (PTSD) are increasing as stress-related disorders among the group of disaster victims, compared to a control group.
- The effects of the Chornobyl NPS Accident on mental health have been the biggest health issue for the residents.

Source: World Health Organization: Mental, psychological and central nervous system effects. Health effects of the UN Chernobyl accident and special health care programmes: report of the UN Chernobyl forum expert group "Health" (eds. Bennett B., et al), 93-97, WHO, Geneva 2006

The effects of the Chornobyl NPS Accident are often cited as an example of psychological effects of nuclear disasters.

According to summaries by the International Atomic Energy Agency (IAEA) and WHO, psychological effects surpassed direct health effects of radiation.

After the Chornobyl NPS Accident, many complained about health problems because of mental stress. This was not caused solely by the effects of radiation but is considered to have resulted from a complex combination of multiple factors including social and economic instability brought about by the collapse of the USSR at the time, which caused a great deal of mental stress to people.

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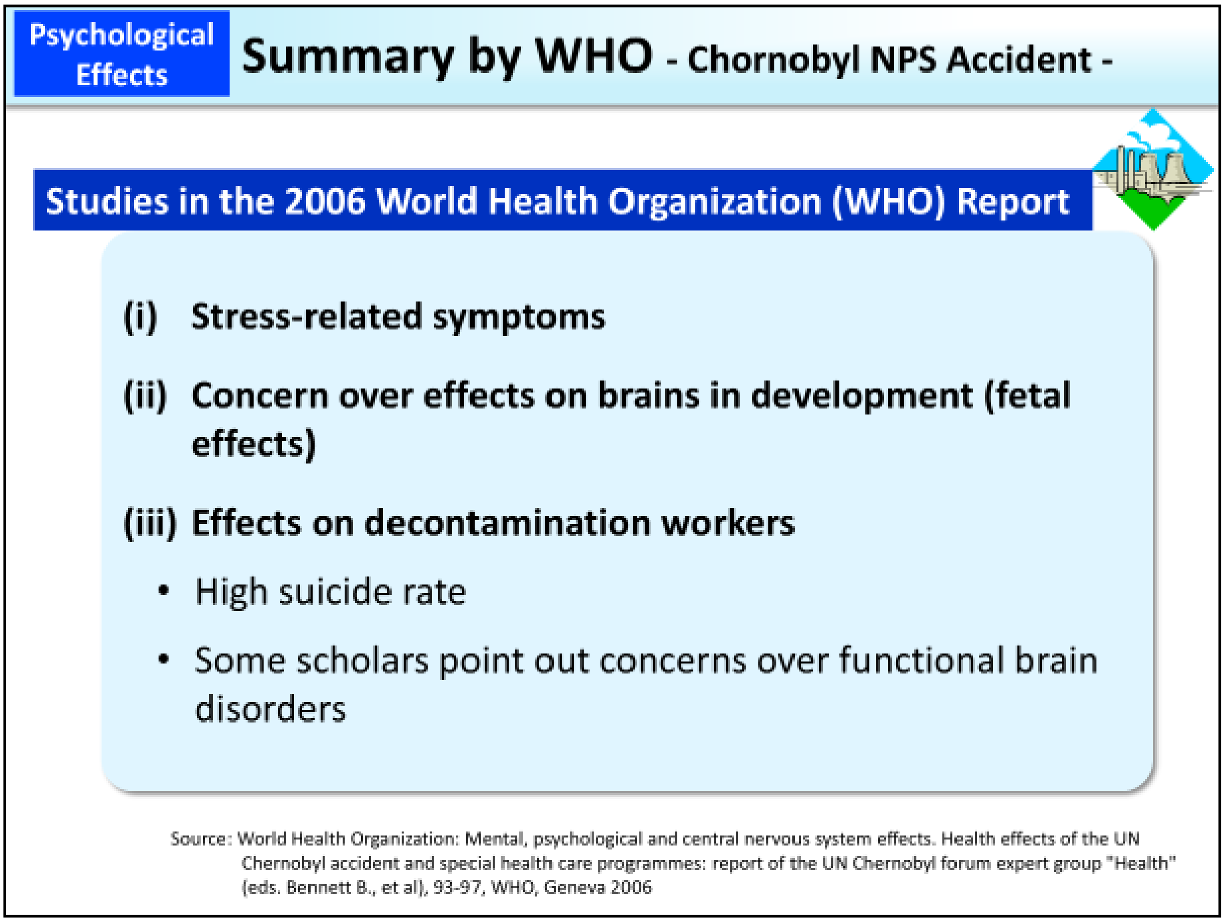

Psychological Effects

Summary by WHO - Chornobyl NPS Accident -

Studies in the 2006 World Health Organization (WHO) Report

(i) Stress-related symptoms

(ii) Concern over effects on brains in development (fetal effects)

(iii) Effects on decontamination workers

- High suicide rate
- Some scholars point out concerns over functional brain disorders

Source: World Health Organization: Mental, psychological and central nervous system effects. Health effects of the UN Chernobyl accident and special health care programmes: report of the UN Chernobyl forum expert group "Health" (eds. Bennett B., et al), 93-97, WHO, Geneva 2006

The WHO Report summarizes psychiatric consequences of stress from the nuclear disaster, pointing out the following four points:

The first is about stress-related symptoms. The study reports that the percentage of those claiming unexplainable physical symptoms or health problems based on self-assessment in a group of exposed people was 3 to 4 times larger than that in a control group.

Secondly, it was found that mothers who were pregnant when the accident happened have been deeply concerned about radiation effects on the brain functions of their children. For example, to a questionnaire question such as “if they believe their children have problems with their memory,” 31% of mothers in mandatory evacuation areas answered yes, which is 4 times larger than the percentage (7%) of mothers in uncontaminated areas who answered yes.

The third and fourth points are radiation effects observed in decontamination workers.

A follow-up study on 4,742 Estonians who participated in decontamination operations found that 144 of them had been confirmed dead by 1993, with 19.4% of them dying by suicide, although no increases were seen in cancer incidence and mortality rates.

Additionally, there was a study report that functional brain disorders were found in decontamination workers with the highest exposure doses. However, such findings are criticized for a lack of scientific correctness as alleged by some researchers and are not confirmed individually.

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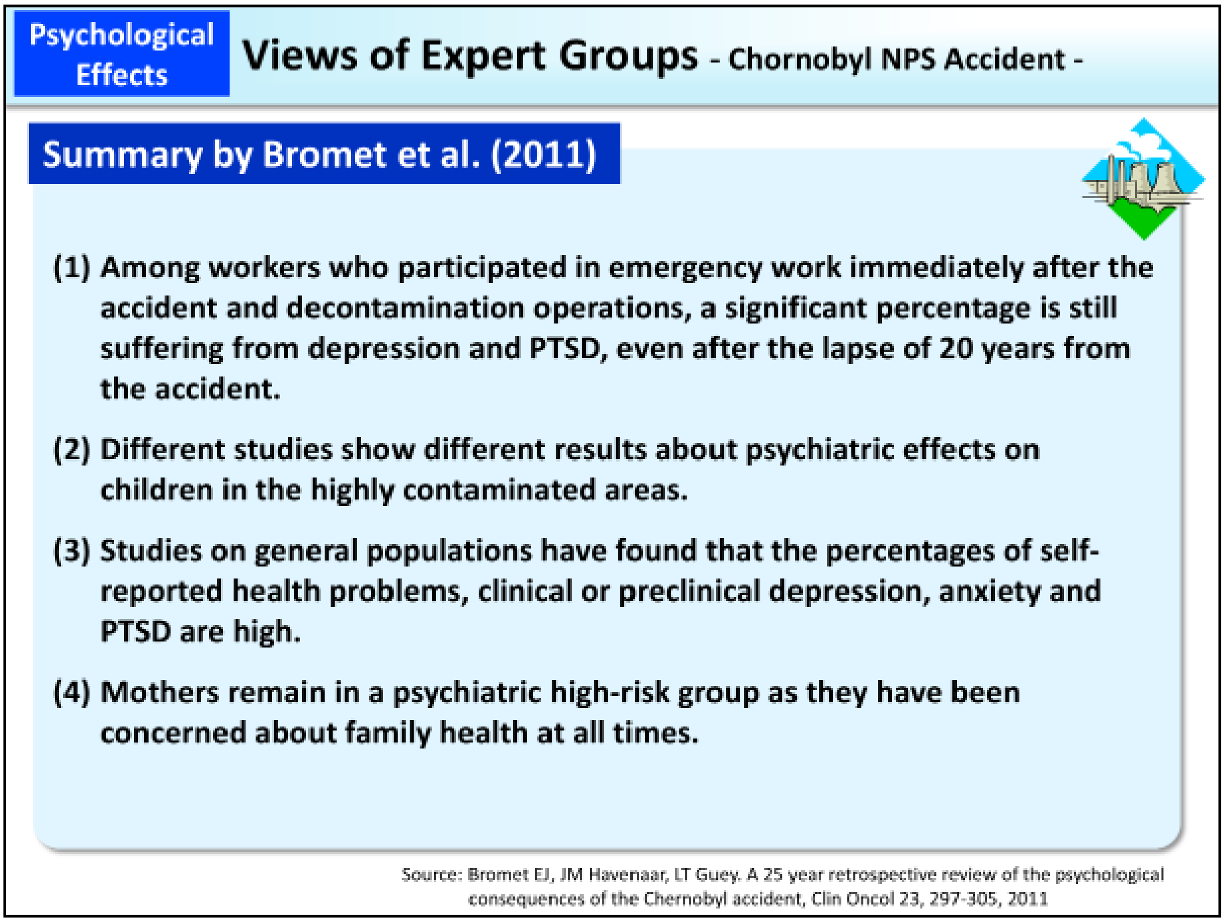


Psychological Effects

Views of Expert Groups - Chornobyl NPS Accident -

Summary by Bromet et al. (2011)

(1) Among workers who participated in emergency work immediately after the accident and decontamination operations, a significant percentage is still suffering from depression and PTSD, even after the lapse of 20 years from the accident.

(2) Different studies show different results about psychiatric effects on children in the highly contaminated areas.

(3) Studies on general populations have found that the percentages of self-reported health problems, clinical or preclinical depression, anxiety and PTSD are high.

(4) Mothers remain in a psychiatric high-risk group as they have been concerned about family health at all times.

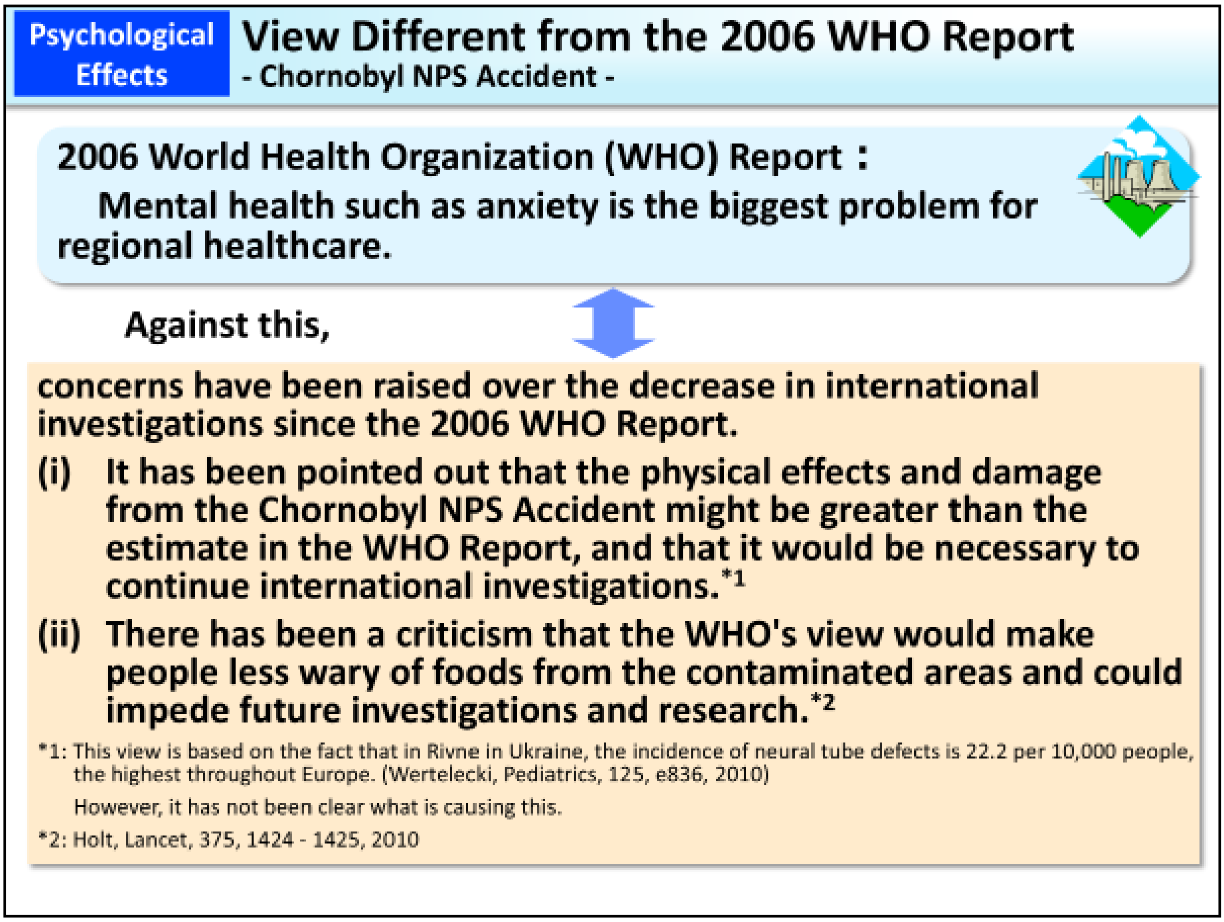
Source: Bromet EJ, JM Havenaar, LT Guey. A 25 year retrospective review of the psychological consequences of the Chernobyl accident, Clin Oncol 23, 297-305, 2011

In 2011, a research group specialized in psychiatry and preventive medicine published a paper detailing what psychiatric effects of the Chornobyl NPS Accident were observed.

It has been found that among a group of workers who worked at the site immediately after the accident and who were exposed to high levels of radiation, a significant percentage is still suffering from depression and PTSD, even after the lapse of 20 years from the accident. Different studies show different results concerning radiation effects on toddlers and fetuses who lived around the plant or in the highly contaminated areas at the time of the accident. For example, studies conducted in Kiev, Norway and Finland on children who were exposed to radiation in their mothers' wombs suggest that they had specific psychiatric and psychological disorders, but other studies do not observe such health problems. Studies on general populations have found that the percentages of self-reported health problems, clinical or preclinical depression, anxiety and PTSD are high. Mothers remain in a high-risk group from a psychiatric viewpoint as they have been concerned about family health at all times.

In the case of the Chornobyl NPS Accident, all such symptoms are not attributed solely to concern over radiation. Distrust of the government, inappropriate communications, the collapse of the USSR, economic issues, and other factors would also have had some relevance and some of them would have had a combined effect, rather than one factor being the sole culprit.

Included in this reference material on March 31, 2013
Updated on March 31, 2024



Psychological Effects

View Different from the 2006 WHO Report

- Chornobyl NPS Accident -

2006 World Health Organization (WHO) Report：
Mental health such as anxiety is the biggest problem for regional healthcare.

Against this,

concerns have been raised over the decrease in international investigations since the 2006 WHO Report.

(i) It has been pointed out that the physical effects and damage from the Chornobyl NPS Accident might be greater than the estimate in the WHO Report, and that it would be necessary to continue international investigations.[*1]

(ii) There has been a criticism that the WHO's view would make people less wary of foods from the contaminated areas and could impede future investigations and research.[*2]

*1: This view is based on the fact that in Rivne in Ukraine, the incidence of neural tube defects is 22.2 per 10,000 people, the highest throughout Europe. (Wertelecki, Pediatrics, 125, e836, 2010)
However, it has not been clear what is causing this.

*2: Holt, Lancet, 375, 1424 - 1425, 2010

There are also reports arguing that the WHO Report overestimates mental health aspects such as anxiety and underestimates physical effects.

These reports rely primarily on a report that people living as an isolated Polish community in the Rivne province of Ukraine, called “Polishchuks,” have a high incidence of neural tube defects. Because the effects of consanguineous marriage are also suspected and neural tube defects could be also caused by folate deprivation and maternal alcohol use, it is unclear whether the high incidence of neural tube defects in the Rivne province has been caused by radiation from the Chornobyl NPS Accident or other effects, or their combinations.
(Related to p.107 of Vol. 1, “Knowledge on Malformation Induction - Chornobyl NPS Accident -”)

Included in this reference material on March 31, 2013
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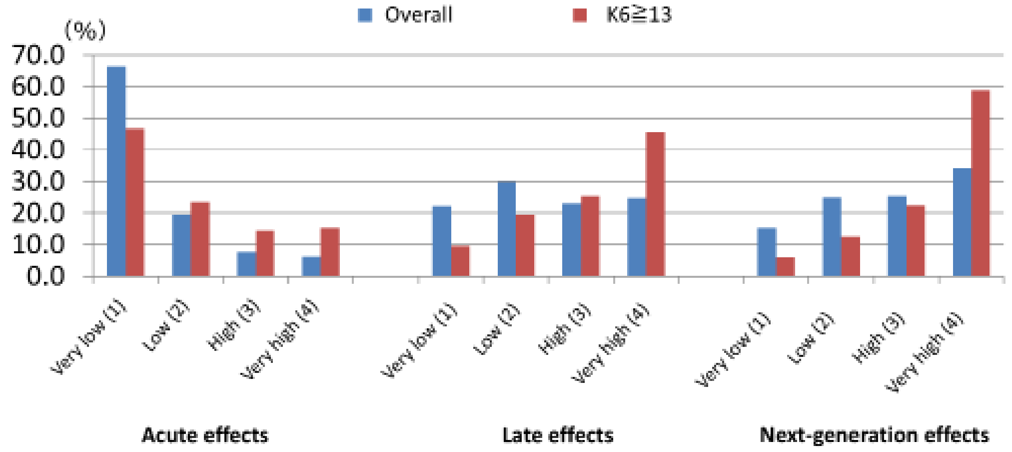
Psychological Effects

Relationship between Mental Health and Perception of Risks Concerning Health Effects of Radiation

Results of the Mental Health and Lifestyle Survey of the FY2011 Fukushima Health Management Survey



*K6 is a self-recording scale to measure general levels of mental health. Scores exceeding 13 show strong depression and anxiety symptoms.

- **Overall trend**
  The majority answered that the possibility of acute effects is very low. Opinions vary with regard to late effects. The largest number of respondents chose the option "very high" for next-generation effects.
- **Among people with mental disorders**
  The percentages of respondents who chose the option "very high" were large for all three types of effects.

Source: Prepared based on Suzuki Y, et. al., Bull World Health Organ, 2015 (http://dx.doi.org/10.2471/BLT.14.146498)

As part of the Fukushima Health Management Survey, Fukushima Prefecture conducts the Mental Health and Lifestyle Survey targeting residents of evacuation areas, etc. every year (see Vol. 2, “10.5 Mental Health and Lifestyle” for details). The 2011 survey asked about the perception of (i) acute effects (hair loss and bleeding), (ii) late effects (thyroid cancer and leukemia), and (iii) any next-generation effects of radiation. As a result, the following were found.

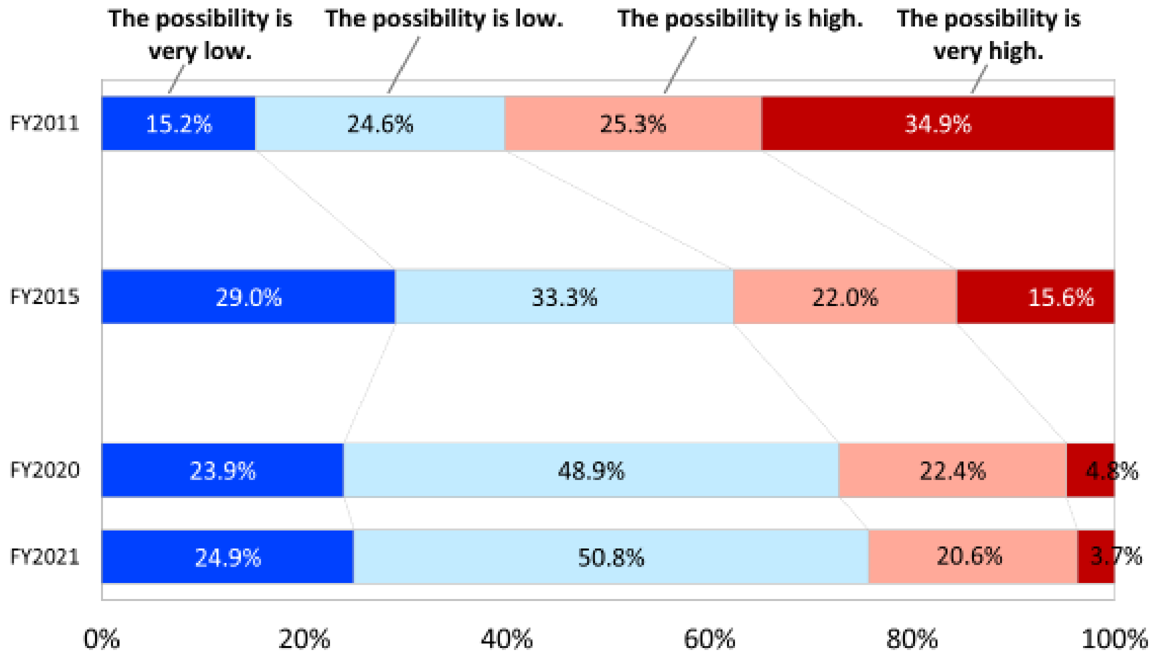
- There are very few people worrying about acute exposure, but the majority have concerns over late effects and next-generation effects.
- Those worrying about radiation effects as indicated in their responses to all three questions clearly show worse mental health conditions and have depression and anxiety symptoms.

Given these, it can be said that people who are apt to have negative perception of risks are highly likely to have strong depression and anxiety symptoms as well.

Included in this reference material on February 28, 2018
Updated on March 31, 2022

Psychological Effects

Changes in Perception of Radiation Risks (Next-generation Effects)



Source: Prepared based on the materials of the 45th and 48th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey

As shown on p.151 of Vol. 1, “Relationship between Mental Health and Perception of Risks Concerning Health Effects of Radiation,” the Fukushima Health Management Survey examines perception of risks concerning health effects of radiation (late effects and next-generation effects) every year. The percentages of respondents answering that the possibility is high are gradually decreasing for both questions. However, what should be noted is the fact that a larger number of people every year worry about next-generation effects rather than late effects. The figure shows changes over the years in responses to questions about next-generation effects. The percentage of people worrying about next-generation effects is decreasing gradually but still remains at around 30% as of FY2021.

Such worries over next-generation effects of radiation tend to cause discrimination and prejudice and doubt about future chances of getting married or having children. If affected people themselves feel in this manner or have self-stigmas (self-prejudice), their confidence and identity may be shaken significantly and their future life plans may be affected accordingly. It is necessary to note the sensitiveness of such worries and prejudice for affected people (p.143 of Vol. 1, “Radiation Accidents and Health Concerns”).

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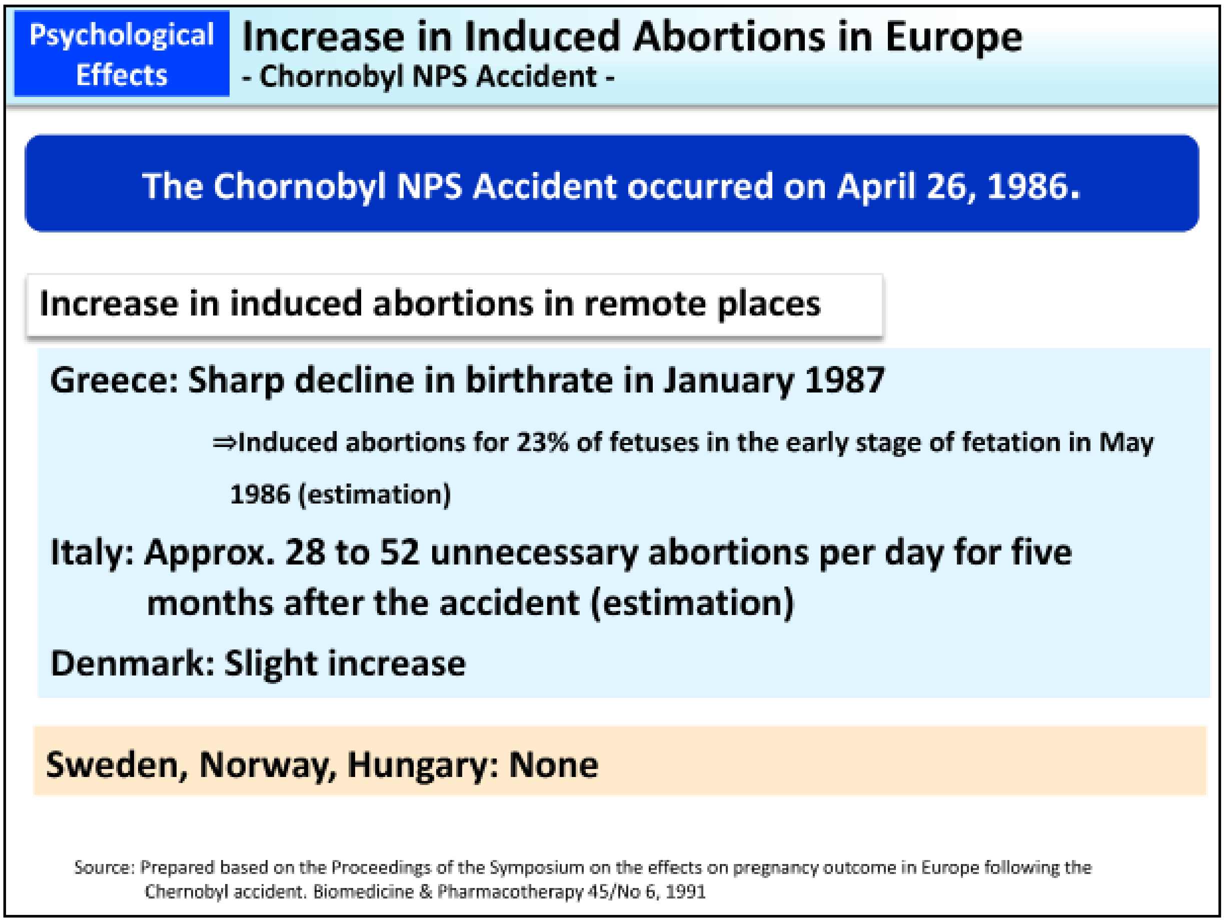

Psychological Effects

Increase in Induced Abortions in Europe

- Chornobyl NPS Accident -

The Chornobyl NPS Accident occurred on April 26, 1986.

Increase in induced abortions in remote places

Greece: Sharp decline in birthrate in January 1987

⇒Induced abortions for 23% of fetuses in the early stage of fetation in May 1986 (estimation)

Italy: Approx. 28 to 52 unnecessary abortions per day for five months after the accident (estimation)

Denmark: Slight increase

Sweden, Norway, Hungary: None

Source: Prepared based on the Proceedings of the Symposium on the effects on pregnancy outcome in Europe following the Chernobyl accident. Biomedicine & Pharmacotherapy 45/No 6, 1991

Excessive concern over the health effects of radiation could be harmful both physically and mentally.

For example, resulting suicide attempts and alcohol addiction are harmful to the body.

There is a report that spontaneous abortions increased because of stress after the Chornobyl NPS Accident. There is also a report that induced abortions increased even in areas remote from the Chornobyl NPS. In Greece, the effect of the Chornobyl NPS Accident was minor within the level below 1 mSv, but the number of pregnant women who chose abortion increased in the next month after the accident and the number of births sharply declined in January of the next year. Based on the birth rate, it is estimated that 23% of fetuses in the early stage of fetation were aborted. On the other hand, in such countries as Hungary, where abortion is not allowed unless fetal exposure dose exceeds 100 mSv, no abortions were performed.

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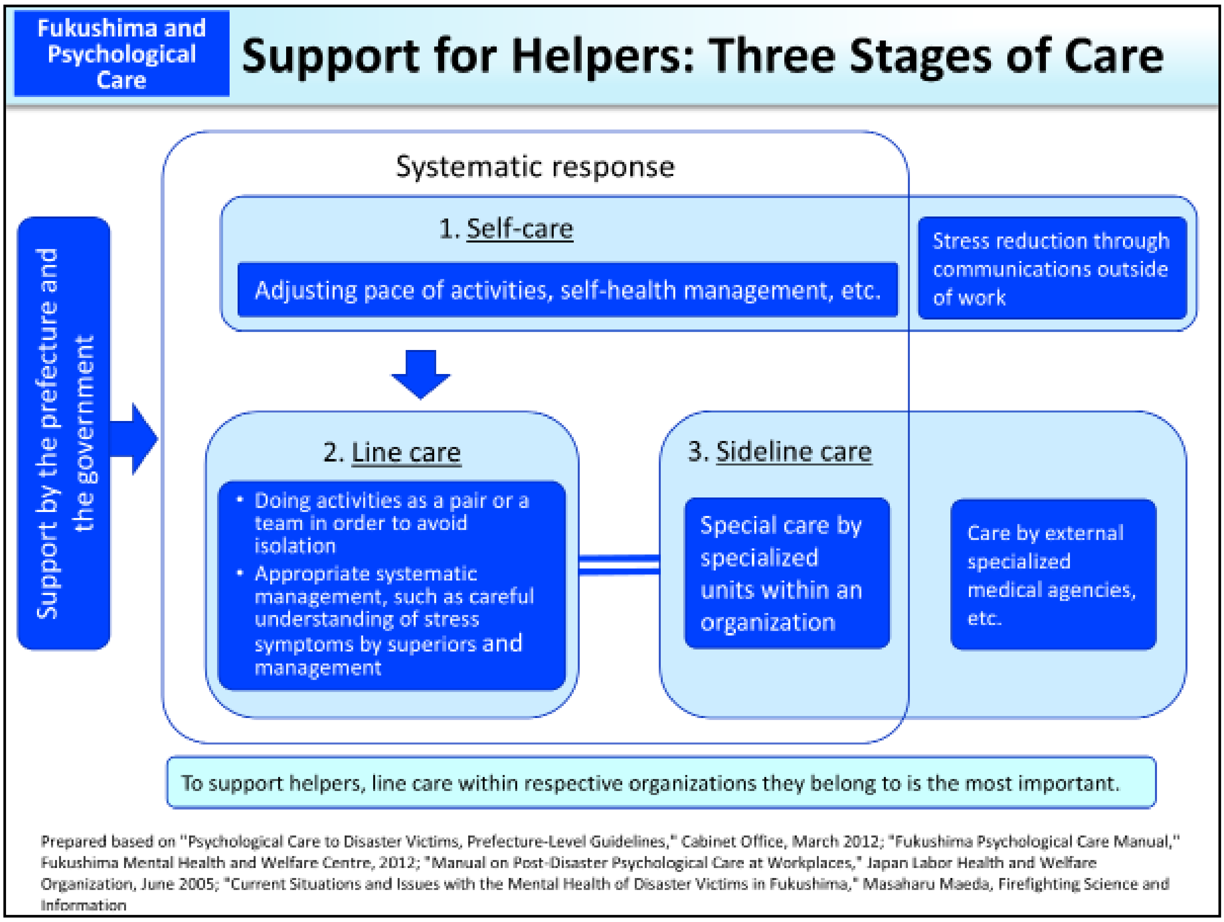


Fukushima and Psychological Care

Support for Helpers: Three Stages of Care

Support by the prefecture and the government

Systematic response

1. Self-care

Adjusting pace of activities, self-health management, etc.

Stress reduction through communications outside of work

2. Line care

- Doing activities as a pair or a team in order to avoid isolation
- Appropriate systematic management, such as careful understanding of stress symptoms by superiors and management

3. Sideline care

Special care by specialized units within an organization

Care by external specialized medical agencies, etc.

To support helpers, line care within respective organizations they belong to is the most important.

Prepared based on "Psychological Care to Disaster Victims, Prefecture-Level Guidelines," Cabinet Office, March 2012; "Fukushima Psychological Care Manual," Fukushima Mental Health and Welfare Centre, 2012; "Manual on Post-Disaster Psychological Care at Workplaces," Japan Labor Health and Welfare Organization, June 2005; "Current Situations and Issues with the Mental Health of Disaster Victims in Fukushima," Masaharu Maeda, Firefighting Science and Information

Support service providers to affected people, such as civil servants and medical personnel, are often in positions to closely witness the agony of the affected people and tend to feel helpless or guilty as no immediate solutions are available.

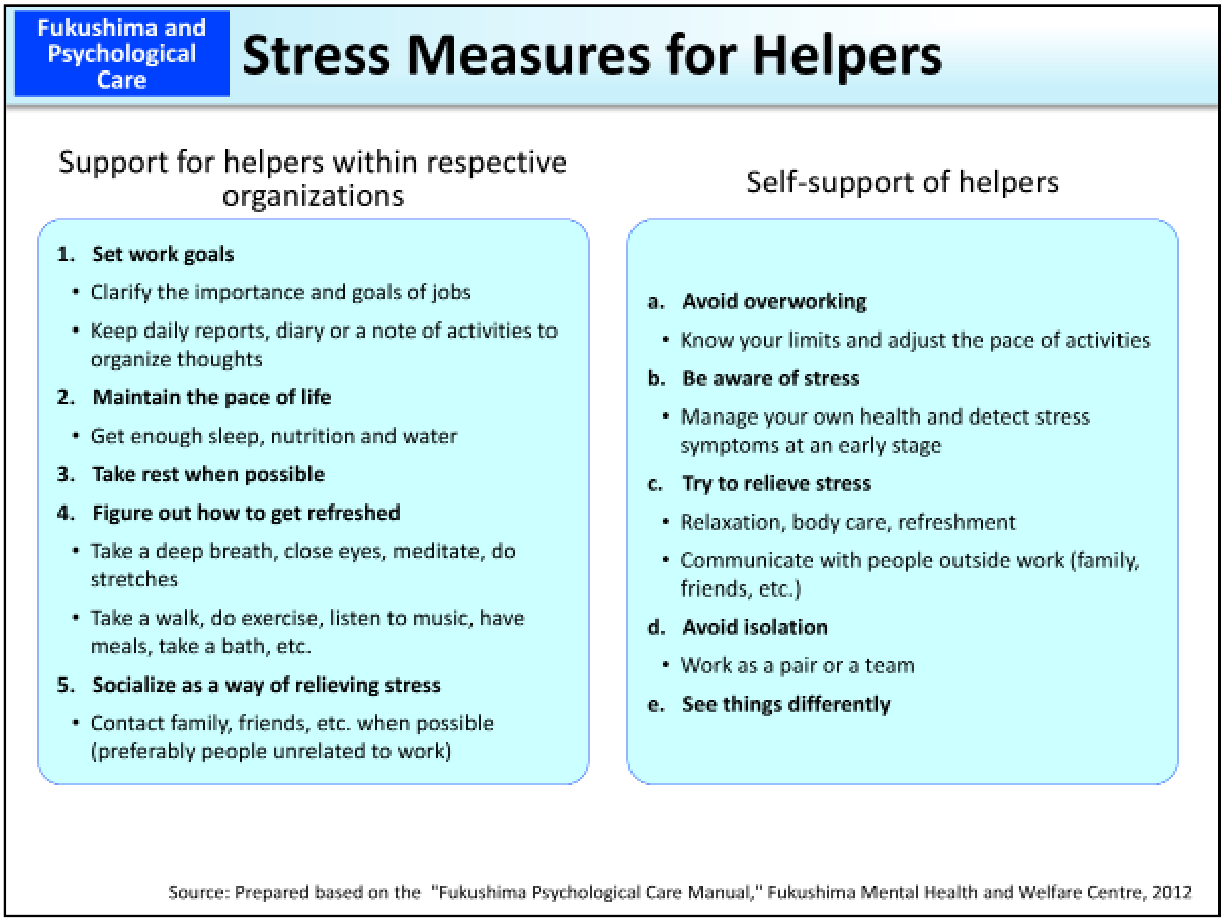
To provide psychological care to them, support within respective organizations they belong to is the most important and such support would help maintain the stability and constancy of the organizations. However, in Fukushima Prefecture, issues to be handled are too wide-ranging, long-term, and complex to find goals or processes for their solutions, so it is difficult to provide support solely by respective organizations.

It is important for such helpers to care for themselves by being aware of their difficult situation and trying to relieve stress by themselves in the first place. Secondly, it is also important for superiors, management or coworkers to detect any problematic symptoms at an early stage and provide care within respective organizations. Furthermore, establishing a specialized unit outside the organization that offers support would be one option. In order to construct such a support system, psychological education and awareness-raising activities targeting managers (also for their own sake) would be very important.

Fukushima Prefecture and the government are providing support for psychological care to the affected people directly and indirectly through psychological care support projects for the affected people, etc.

(Related to p.155 of Vol. 1, “Stress Measures for Helpers”)

Included in this reference material on March 31, 2016



Fukushima and Psychological Care

Stress Measures for Helpers

Support for helpers within respective organizations

1. **Set work goals**
   - Clarify the importance and goals of jobs
   - Keep daily reports, diary or a note of activities to organize thoughts
2. **Maintain the pace of life**
   - Get enough sleep, nutrition and water
3. **Take rest when possible**
4. **Figure out how to get refreshed**
   - Take a deep breath, close eyes, meditate, do stretches
   - Take a walk, do exercise, listen to music, have meals, take a bath, etc.
5. **Socialize as a way of relieving stress**
   - Contact family, friends, etc. when possible (preferably people unrelated to work)

Self-support of helpers

a. **Avoid overworking**
   - Know your limits and adjust the pace of activities

b. **Be aware of stress**
   - Manage your own health and detect stress symptoms at an early stage

c. **Try to relieve stress**
   - Relaxation, body care, refreshment
   - Communicate with people outside work (family, friends, etc.)

d. **Avoid isolation**
   - Work as a pair or a team

e. **See things differently**

Source: Prepared based on the "Fukushima Psychological Care Manual," Fukushima Mental Health and Welfare Centre, 2012

“Fukushima Psychological Care Manual” by the Fukushima Mental Health and Welfare Centre provides guidelines regarding stress measures for helpers.

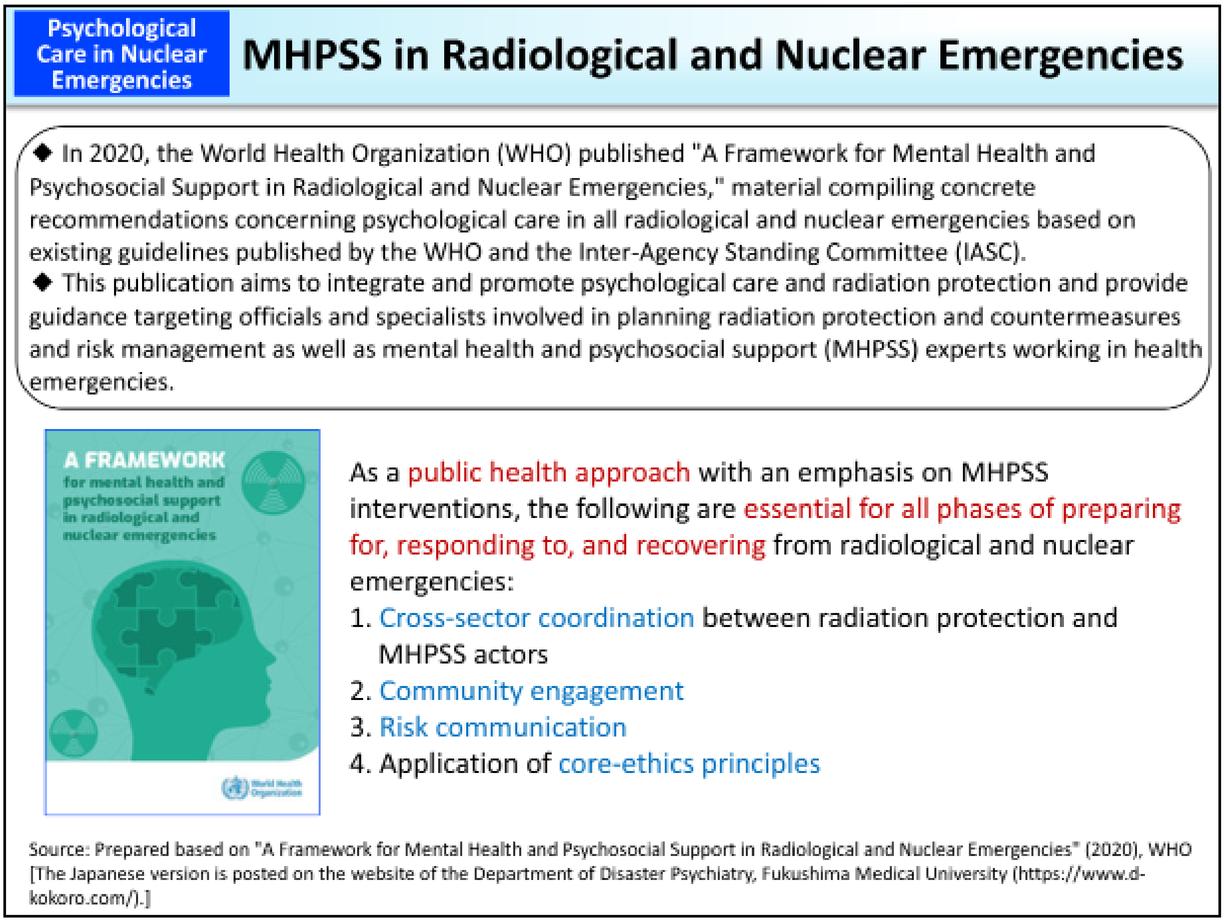
Helpers’ self-support efforts include avoiding overworking and being aware of their own stress, etc. It might be difficult to avoid overworking given the situation they are in, but it is important for individuals to know their own limits so that they can adjust the pace of activities and to hand off work to someone else in order to avoid meeting too many affected people in a day. Having stress symptoms is not something to be ashamed of but an important clue for self-health checks. It is necessary to manage health by oneself and notice any symptoms at an early stage. Relaxation, body care, refreshment, and communication with people outside work (family, friends, etc.) are effective in relieving stress. Isolation should be avoided as much as possible in a situation where one can easily become stressed out, so it would be necessary to work as a pair or a team and to have opportunity to share experience (disaster situations individual helpers witnessed and their feelings) with coworkers on a periodic basis or to be given instructions from senior workers, etc. It is natural that individuals cannot change everything on their own, especially in difficult situations after disasters, so it is better to rate one’s own activities positively and there is no need at all to have negative thoughts considering not being fit or competent for the job.

The manual also cites some concrete ways to provide care for helpers within respective organizations.

- Feeling guilty about taking a rest alone while others are working is a sign of stress.
- When noticing any physical or psychological symptoms, consult with a superior or coworkers at an early stage.
- Exchange words with coworkers as often as possible to encourage each other.
- Be careful about one’s own health and coworkers’ health and tell the relevant person and the supervisor if someone has too much workload.

(Related to p.154 of Vol. 1, “Support for Helpers: Three Stages of Care”)

Included in this reference material on March 31, 2016



Psychological Care in Nuclear Emergencies

MHPSS in Radiological and Nuclear Emergencies

◆ In 2020, the World Health Organization (WHO) published "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies," material compiling concrete recommendations concerning psychological care in all radiological and nuclear emergencies based on existing guidelines published by the WHO and the Inter-Agency Standing Committee (IASC).

◆ This publication aims to integrate and promote psychological care and radiation protection and provide guidance targeting officials and specialists involved in planning radiation protection and countermeasures and risk management as well as mental health and psychosocial support (MHPSS) experts working in health emergencies.

A FRAMEWORK for mental health and psychosocial support in radiological and nuclear emergencies

As a public health approach with an emphasis on MHPSS interventions, the following are essential for all phases of preparing for, responding to, and recovering from radiological and nuclear emergencies:

1. Cross-sector coordination between radiation protection and MHPSS actors
2. Community engagement
3. Risk communication
4. Application of core-ethics principles

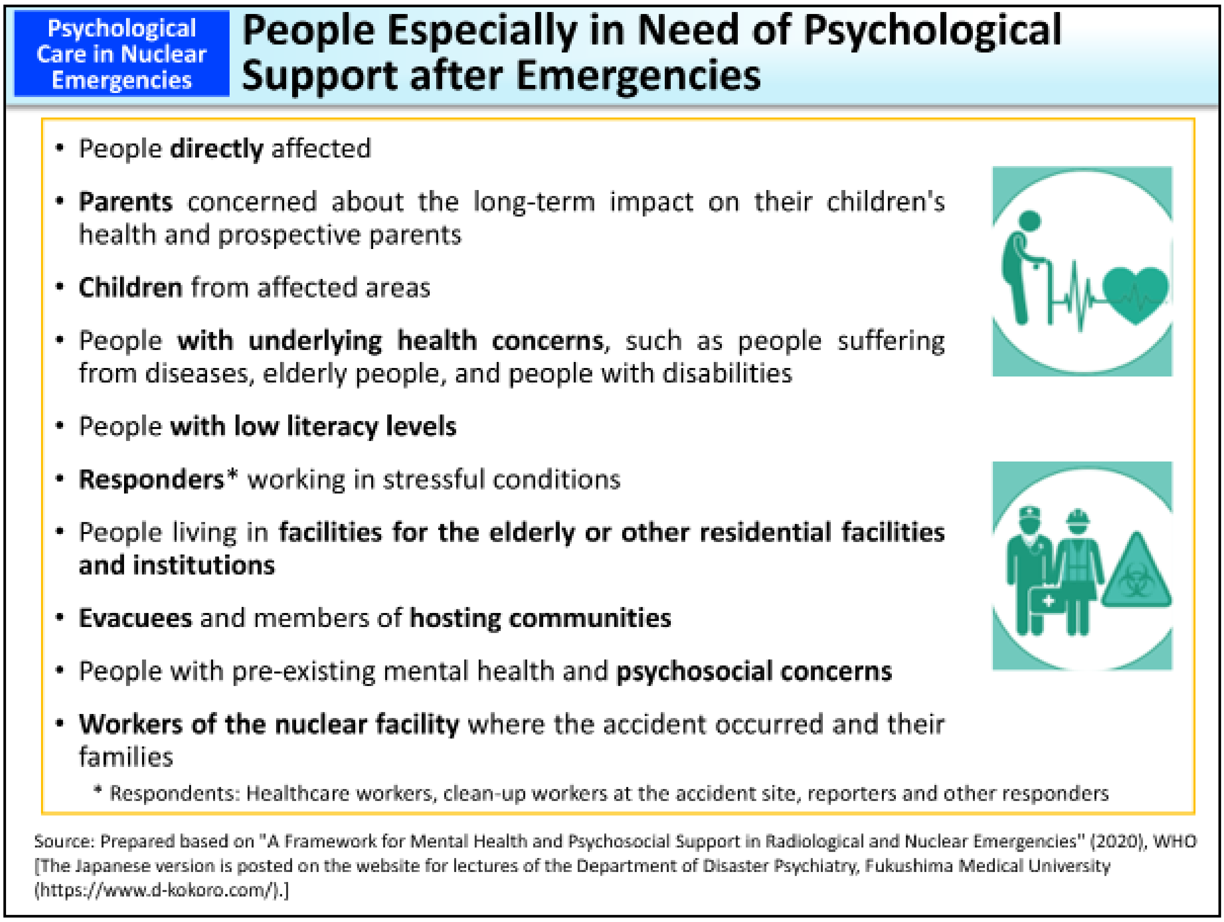
Source: Prepared based on "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" (2020), WHO [The Japanese version is posted on the website of the Department of Disaster Psychiatry, Fukushima Medical University (https://www.d-kokoro.com/).]

“A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies” published by the WHO in 2020 states that psychological care is indispensable at all phases of preparing (planning) for, responding to, and recovering from radiological and nuclear emergencies. Additionally, the significance of cross-sector coordination for bringing about successful recovery is emphasized.

For achieving timely and proper MHPSS interventions, the following are specifically recommended: General health and mental health professionals should advocate and work in partnership with other sectors (for instance, communication, education, community development, disaster coordination, child protection, police); A community-based approach should be adopted to encourage risk communication and community engagement so that affected people can play positive roles in activities for improving their own wellbeing.

This publication also explains key measures at the phases of planning and making responses concretely, such as the need to ensure consistency in messages and information provided by public organizations, to prepare messages regarding health risks and prediction thereof, protective measures and preventive measures that are clear and easy to understand for affected people, and to provide psychosocial support intensively to at-risk groups and to people having psychological distress. Additionally, core ethical considerations necessary for all people involved in the provision of psychological care are also explained.

Included in this reference material on March 31, 2022



Psychological Care in Nuclear Emergencies

People Especially in Need of Psychological Support after Emergencies

- People **directly** affected
- **Parents** concerned about the long-term impact on their children's health and prospective parents
- **Children** from affected areas
- People **with underlying health concerns**, such as people suffering from diseases, elderly people, and people with disabilities
- People **with low literacy levels**
- **Responders*** working in stressful conditions
- People living in **facilities for the elderly or other residential facilities and institutions**
- **Evacuees** and members of **hosting communities**
- People with pre-existing mental health and **psychosocial concerns**
- **Workers of the nuclear facility** where the accident occurred and their families

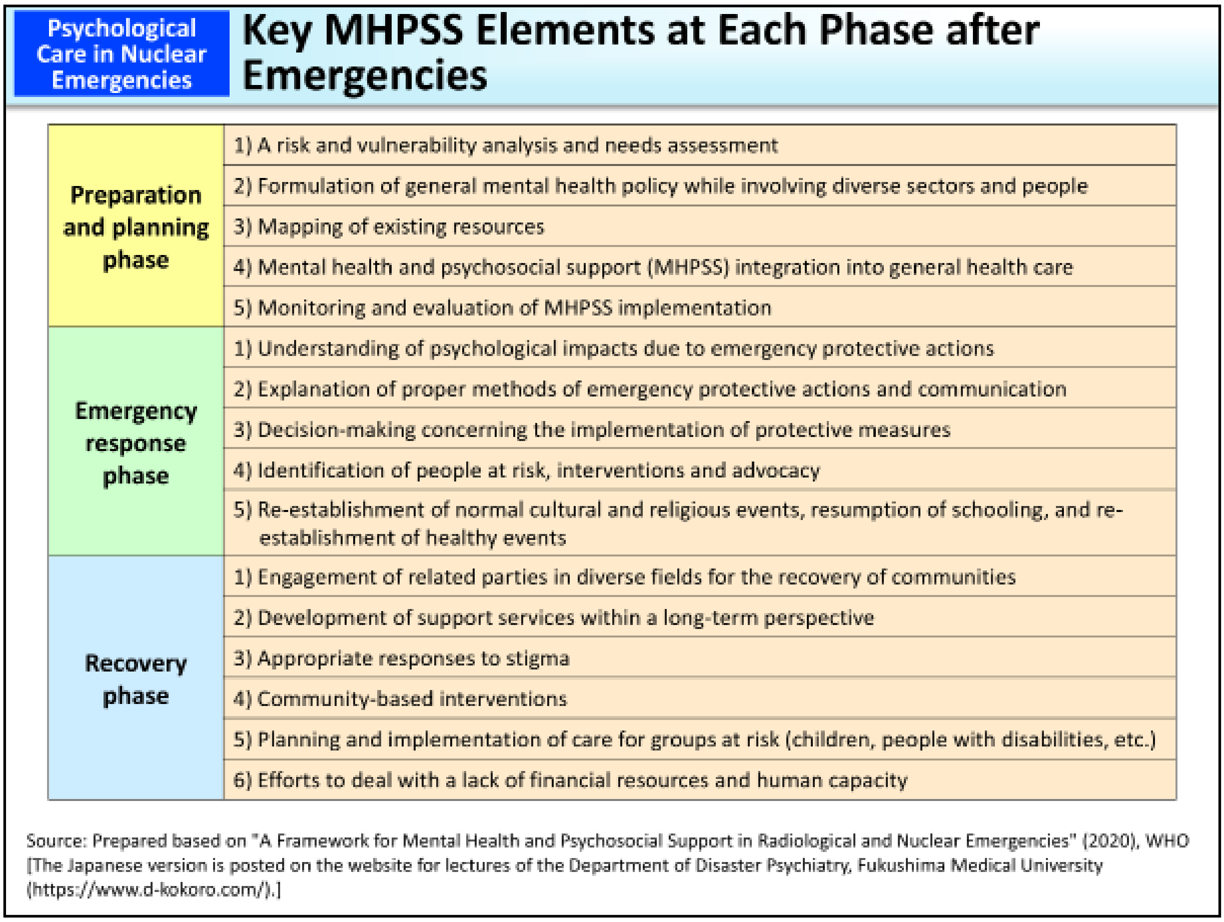
* Respondents: Healthcare workers, clean-up workers at the accident site, reporters and other responders

Source: Prepared based on "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" (2020), WHO [The Japanese version is posted on the website for lectures of the Department of Disaster Psychiatry, Fukushima Medical University (https://www.d-kokoro.com/).]

"A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" published by the WHO in 2020 states that even in the case of a nuclear disaster, many people show resilience, meaning they are able to cope relatively well in adverse situations, and not everyone has significant psychological problems or develops depression, anxiety disorders or PTSD. However, it also calls for attention to the fact that risks for psychosocial problems may increase among specific groups of people depending on the circumstances of an emergency.

This framework points out, as responses to people particularly at risk, the significance of providing psychological care covering affected people as a whole and at the same time formulating good programs suited to individual groups, based on the understanding that those with higher risks also have resilience.

Included in this reference material on March 31, 2022



Psychological Care in Nuclear Emergencies

Key MHPSS Elements at Each Phase after Emergencies

Preparation and planning phase	1) A risk and vulnerability analysis and needs assessment
	2) Formulation of general mental health policy while involving diverse sectors and people
	3) Mapping of existing resources
	4) Mental health and psychosocial support (MHPSS) integration into general health care
	5) Monitoring and evaluation of MHPSS implementation
Emergency response phase	1) Understanding of psychological impacts due to emergency protective actions
	2) Explanation of proper methods of emergency protective actions and communication
	3) Decision-making concerning the implementation of protective measures
	4) Identification of people at risk, interventions and advocacy
	5) Re-establishment of normal cultural and religious events, resumption of schooling, and re-establishment of healthy events
Recovery phase	1) Engagement of related parties in diverse fields for the recovery of communities
	2) Development of support services within a long-term perspective
	3) Appropriate responses to stigma
	4) Community-based interventions
	5) Planning and implementation of care for groups at risk (children, people with disabilities, etc.)
	6) Efforts to deal with a lack of financial resources and human capacity

Source: Prepared based on "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" (2020), WHO
[The Japanese version is posted on the website for lectures of the Department of Disaster Psychiatry, Fukushima Medical University (https://www.d-kokoro.com/).]

"A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" published by the WHO in 2020 compiles key MHPSS elements at the planning, response, and recovery phases after emergencies respectively by separating chapters.

Throughout all chapters, it is emphasized that MHPSS should never jeopardize the implementation of protective actions to reduce people's exposure to radiation at any phase, and for that purpose, radiation protection and MHPSS should be well-balanced with the involvement of individual communities.

At the preparation and planning phase, the assessment of actual radiation hazards and risks as well as mapping (positioning and description) of resources should be conducted to set priorities in MHPSS methods for individual protective actions, and plans for MHPSS integrating into general health care should be formulated. At the response phase, training should be provided to responders so that they can understand psychological impacts due to protective measures and can provide explanations focused on health regarding reasons why protective actions are necessary and offer support for decision-making. At the recovery phase, it is important to develop support services from a long-term perspective, while focusing on medium- and long-term development of community, and on evidence-based mental health services and psychosocial interventions, and conduct care for groups at risk and countermeasures against stigma on an ongoing basis.

Included in this reference material on March 31, 2022
Updated on March 31, 2023

Chapter 4

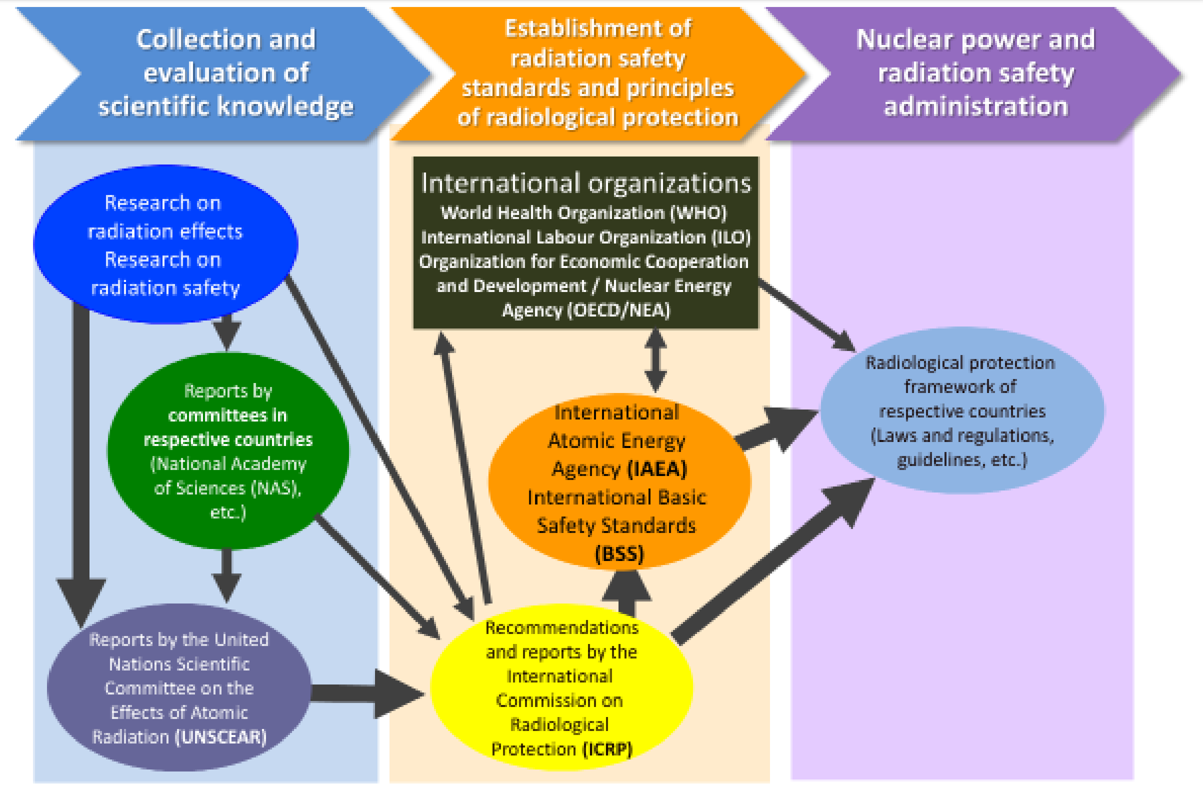
Concept of Radiological Protection

Chapter 4 explains the framework of radiological protection, dose limits and dose reduction.

You can obtain knowledge on principles for protecting human health against radiation effects and methods for reducing exposure doses. Please refer to this chapter when you want to understand the concept of dose limits that served as the basis for standards for distribution restrictions for foods and designation of Areas under Evacuation Orders after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS or the concept of radiological protection.

Principles of Radiological Protection

International Framework Relating to Radiological Protection



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) consists of experts in the scientific field appointed by 31 member countries, including Japan, and is tasked with reviewing and assessing the levels, influences and risks of exposure to ionizing radiation of people and the surrounding environment, and reporting those assessment results. The 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 and other information on radiological protection. 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.

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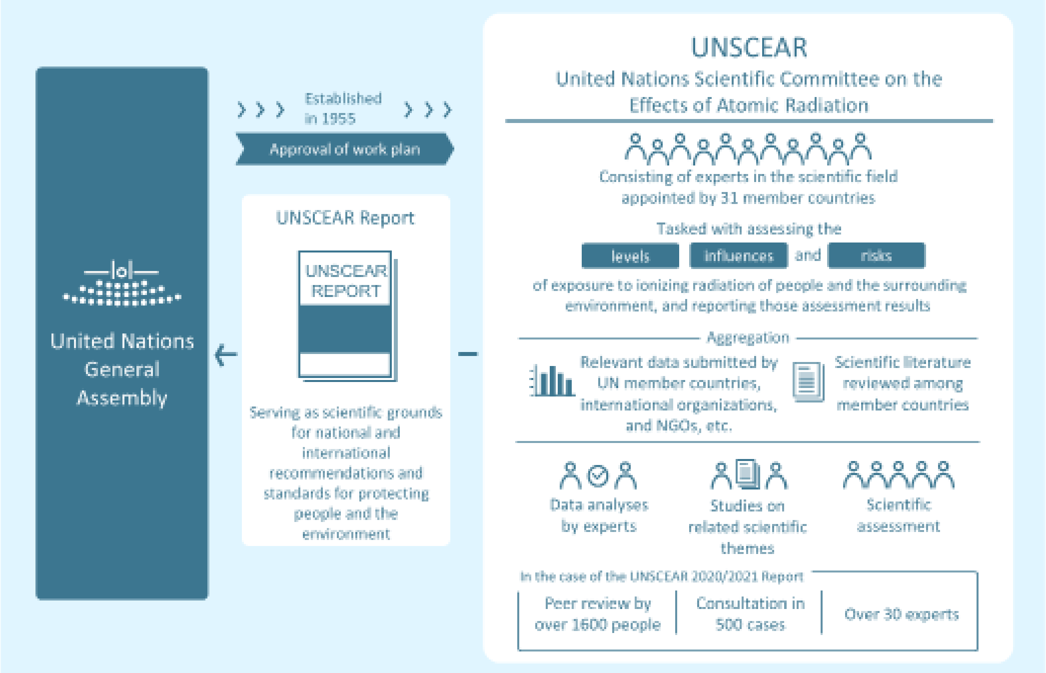
Principles of Radiological Protection

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)



United Nations General Assembly

Established in 1955

Approval of work plan

UNSCEAR Report

Serving as scientific grounds for national and international recommendations and standards for protecting people and the environment

UNSCEAR
United Nations Scientific Committee on the Effects of Atomic Radiation

Consisting of experts in the scientific field appointed by 31 member countries

Tasked with assessing the levels, influences and risks of exposure to ionizing radiation of people and the surrounding environment, and reporting those assessment results

Aggregation

Relevant data submitted by UN member countries, international organizations, and NGOs, etc.

Scientific literature reviewed among member countries

Data analyses by experts

Studies on related scientific themes

Scientific assessment

In the case of the UNSCEAR 2020/2021 Report

Peer review by over 1600 people

Consultation in 500 cases

Over 30 experts

Source: Prepared based on the Fact Sheet in the UNSCEAR 2020/2021 Report, "UNSCEAR 2020 Report on Radiological Consequences from the Fukushima Accident – 10 years later –" (2022)
(https://www.unscear.org/unscear/en/areas-of-work/fukushima.html)

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is a UN Committee established at the General Assembly in 1955. It consists of experts appointed by 31 member countries, including Japan, and is tasked with assessing the levels, influences and risks of exposure to ionizing radiation of people and the surrounding environment, and reporting those assessment results. The 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. Governments, organizations and organs worldwide utilize the UNSCEAR's analysis results as scientific grounds for assessing radiation risks and deciding on radiological protection measures.

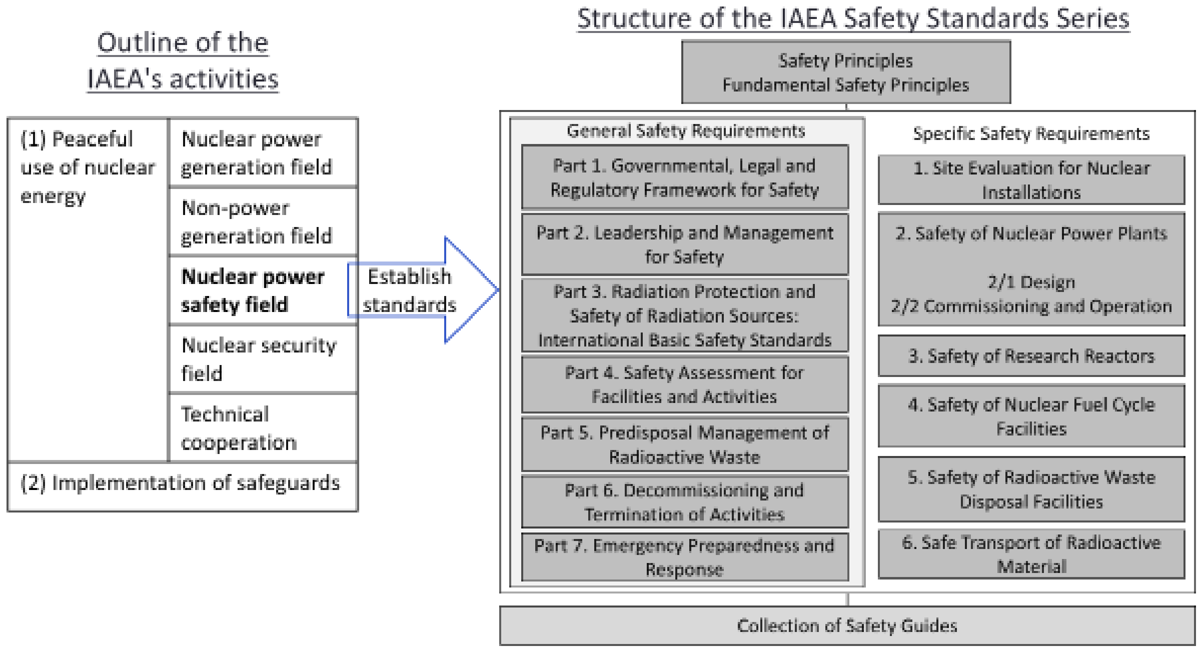
After the accident at Tokyo Electric Power Company's Fukushima Daiichi NPS, the UNSCEAR published white papers and reports concerning the results of the assessment of exposure doses due to the accident and their influence on people's health (p.191 of Vol. 1, "Changes in International Organizations' Assessments").

Included in this reference material on March 31, 2024

Principles of Radiological Protection

International Atomic Energy Agency (IAEA)

Objective: To promote peaceful use of nuclear energy and prevent nuclear energy for peaceful purposes from being used for military purposes



Outline of the IAEA's activities

(1) Peaceful use of nuclear energy	Nuclear power generation field
	Non-power generation field
	Nuclear power safety field
	Nuclear security field
	Technical cooperation
(2) Implementation of safeguards	

Establish standards

Structure of the IAEA Safety Standards Series

Safety Principles
Fundamental Safety Principles

General Safety Requirements
- Part 1. Governmental, Legal and Regulatory Framework for Safety
- Part 2. Leadership and Management for Safety
- Part 3. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards
- Part 4. Safety Assessment for Facilities and Activities
- Part 5. Predisposal Management of Radioactive Waste
- Part 6. Decommissioning and Termination of Activities
- Part 7. Emergency Preparedness and Response

Specific Safety Requirements
- 1. Site Evaluation for Nuclear Installations
- 2. Safety of Nuclear Power Plants
  - 2/1 Design
  - 2/2 Commissioning and Operation
- 3. Safety of Research Reactors
- 4. Safety of Nuclear Fuel Cycle Facilities
- 5. Safety of Radioactive Waste Disposal Facilities
- 6. Safe Transport of Radioactive Material

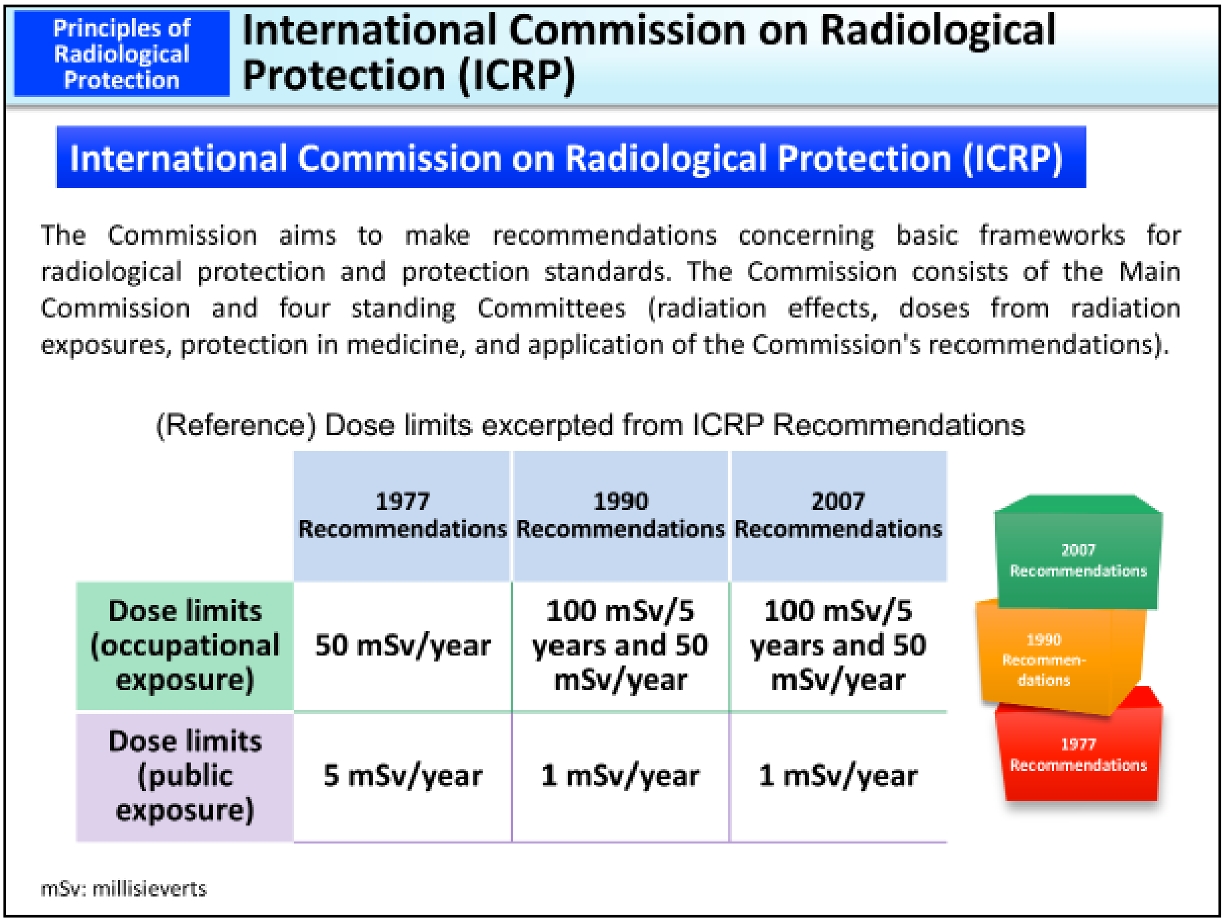
Collection of Safety Guides

Source: Prepared based on "Outline of the International Atomic Energy Agency (IAEA)" on the website of the Ministry of Foreign Affairs and "GSR Part 3 Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards" on the website of International Atomic Energy Agency

The International Atomic Energy Agency (IAEA) was established in 1957 with the objective of promoting peaceful use of nuclear energy and preventing nuclear energy for peaceful purposes from being used for military purposes. The IAEA consists of 178 member countries including Japan (as of September 2023) and its major activities are roughly divided into two: the promotion of peaceful use of nuclear energy and the implementation of safeguards.

In the field of nuclear safety for peaceful use of nuclear power, the IAEA is authorized to establish safety standards as an international organization for the purpose of protecting good health and minimizing risks to the lives and property of all people, and has been contributing to the establishment and dissemination of various international safety standards and guides. The IAEA's safety standards and guides are comprised of three layers: Fundamentals, Requirements, and Guides. In particular, the Basic Safety Standards (BSS) categorized in the Requirements have been used as the guidelines and the basic numerical standards by individual countries for incorporating them in their domestic laws. The Basic Safety Standards (BSS) reflect the details of the ICPR recommendations, knowledge compiled by the UNSCEAR, and IAEA Guides, etc. and are formulated jointly by experts dispatched from IAEA member countries and relevant organizations, including the World Health Organization (WHO), the International Labour Organization (ILO), the Nuclear Energy Agency (NEA) within the Organization for Economic Cooperation and Development (OECD/NEA), etc.

Included in this reference material on March 31, 2024



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

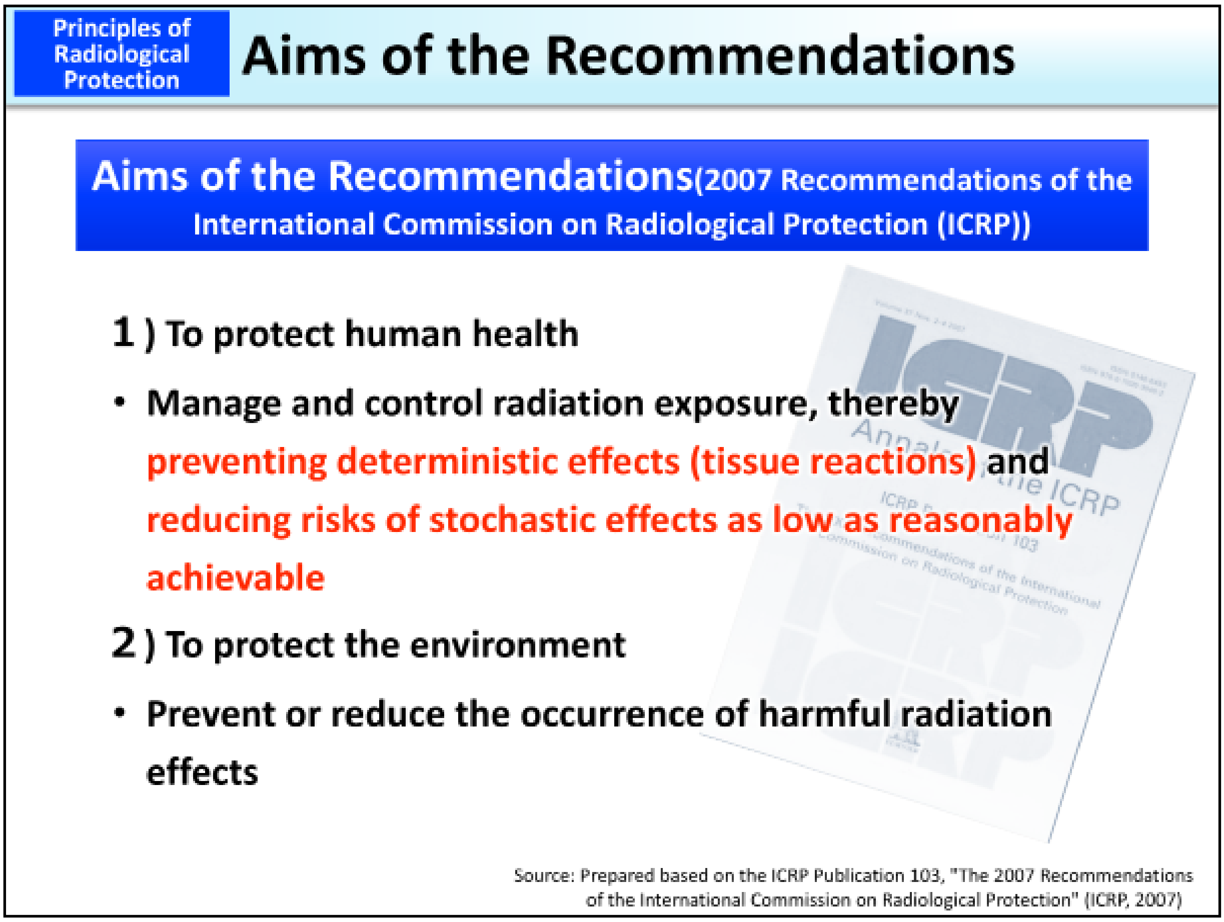
	1977 Recommendations	1990 Recommendations	2007 Recommendations
Dose limits (occupational exposure)	50 mSv/year	100 mSv/5 years and 50 mSv/year	100 mSv/5 years and 50 mSv/year
Dose limits (public exposure)	5 mSv/year	1 mSv/year	1 mSv/year

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.163 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.173 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2021



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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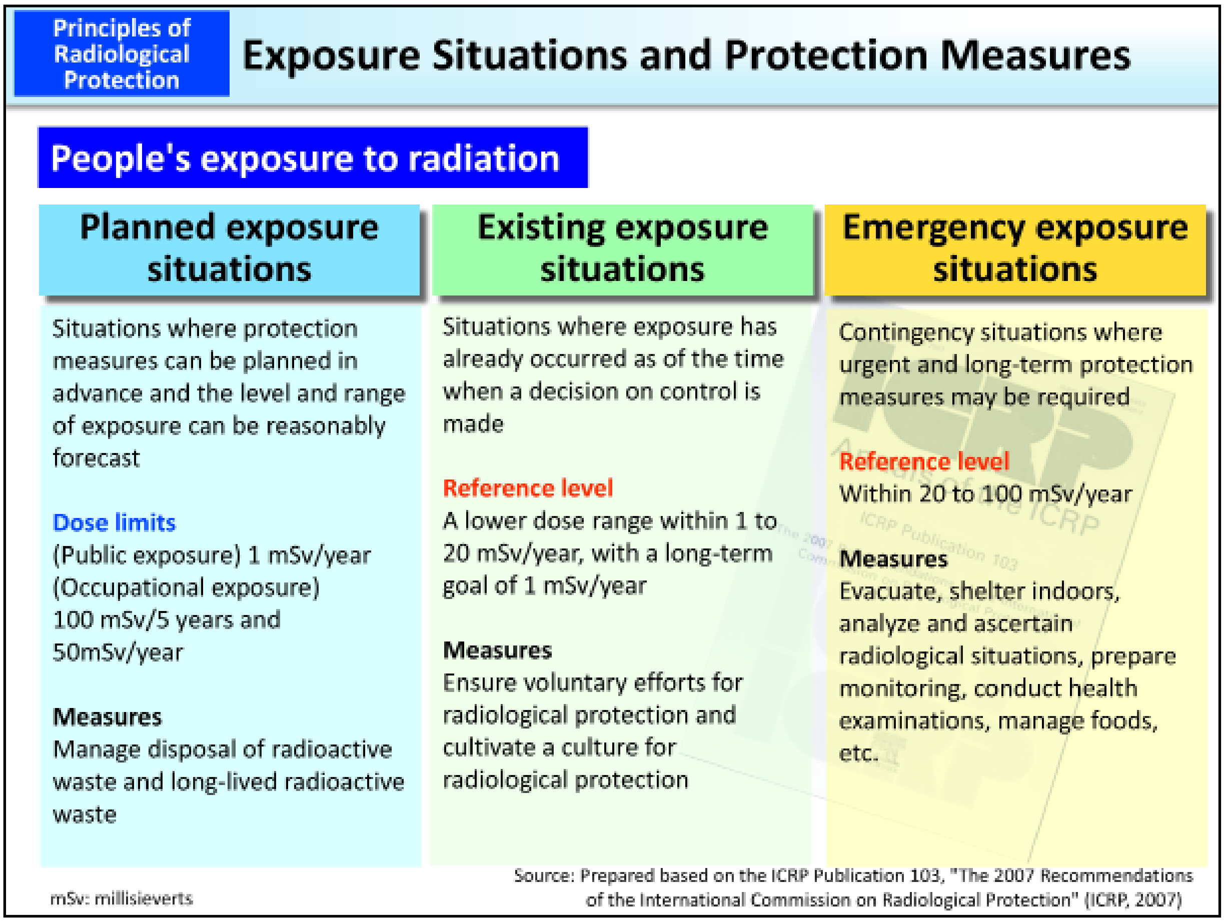

Principles of Radiological Protection

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.173 of Vol. 1, “ICRP Recommendations and Responses of the Japanese Government”)

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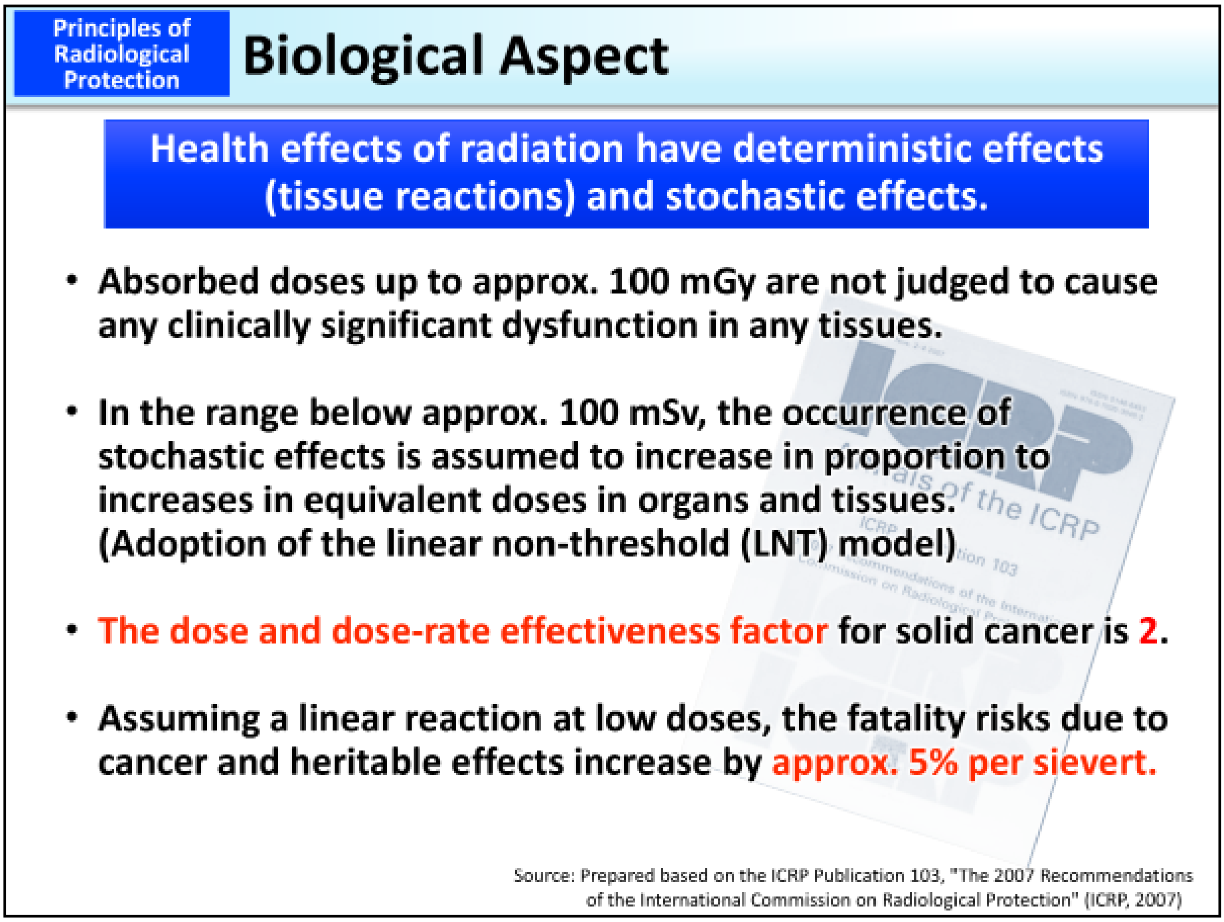

Principles of Radiological Protection

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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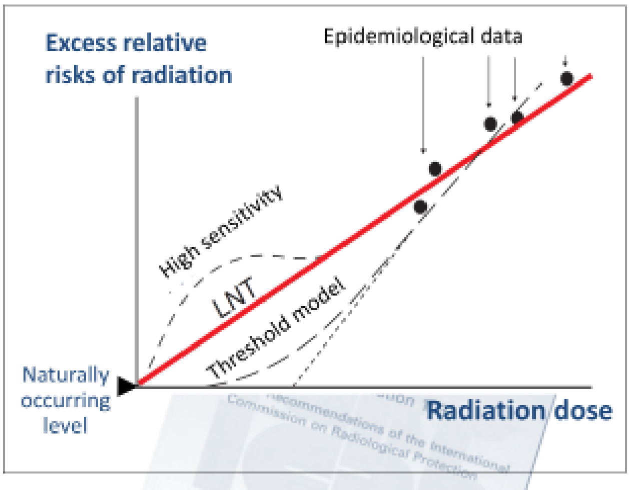
Principles of Radiological Protection

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. The National Council on Radiation Protection and Measurements (NCRP) states that available epidemiological data broadly support the LNT model in its comment in 2018.[1] 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[2,3] and one stating that it is impossible to rule out threshold models.[2]

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.

In the ICRP Recommendations, risks are calculated by applying the linear model. Risks in a low-dose region are close to zero, but it is not certain whether there is any threshold of doses above which risks increase. Accordingly, 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. The WHO and the UNSCEAR calculate risks by applying the linear-quadratic dose response model.
(Related to p.86 of Vol. 1, "Deterministic Effects (Tissue Reactions) and Stochastic Effects")

1. NCRP Commentary No.27:Implications of Recent Epidemiologic Studies for the Linear-Nonthreshold Model and Radiation Protection, 2018.
2. Lubin et al.: J. Clin. Endocrinol Metab. 102(7): 2575-2583, 2017.
3. 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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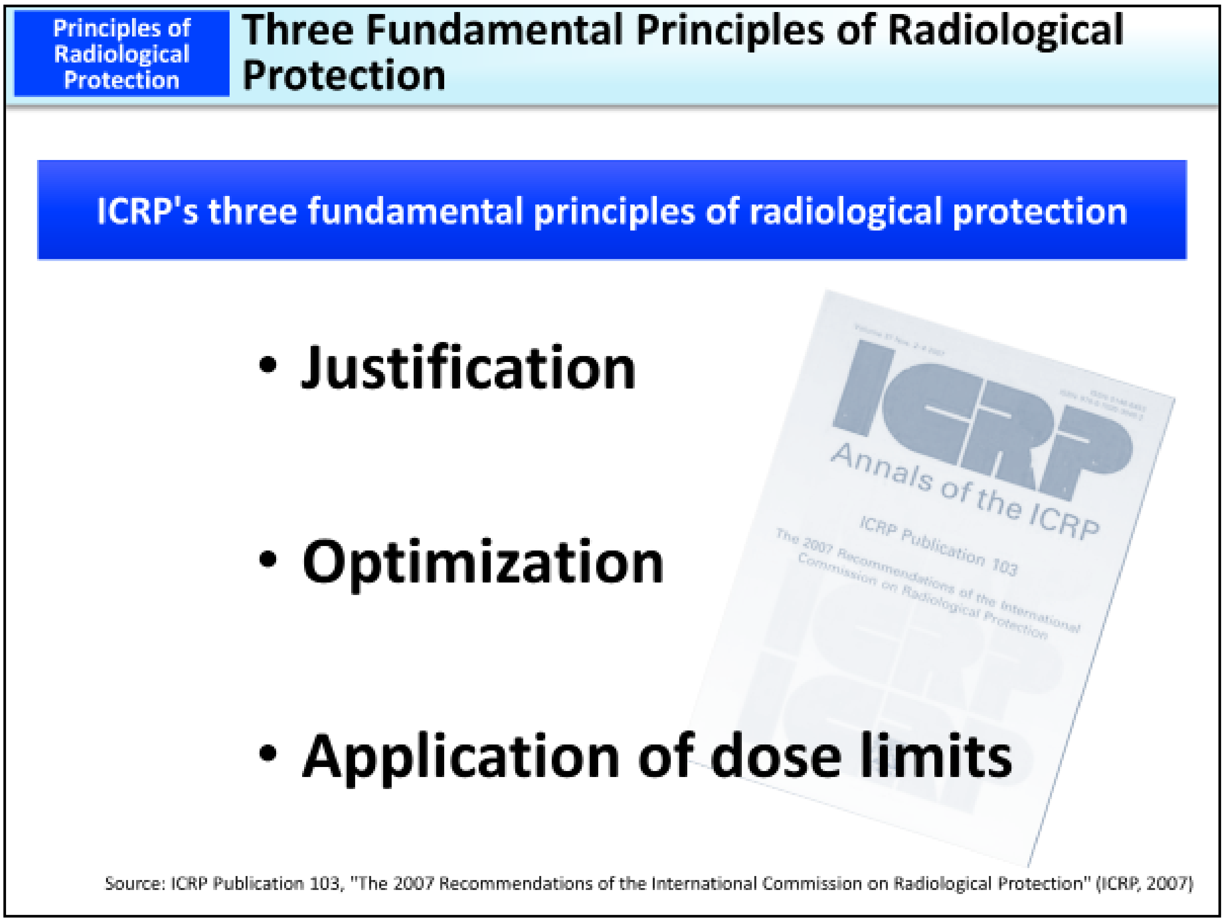

Principles of Radiological Protection

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.166 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.168 of Vol. 1, “Justification of Radiological Protection,” p.169 of Vol. 1, “Optimization of Radiological Protection,” and p.171 of Vol. 1, “Application of Dose Limits”).

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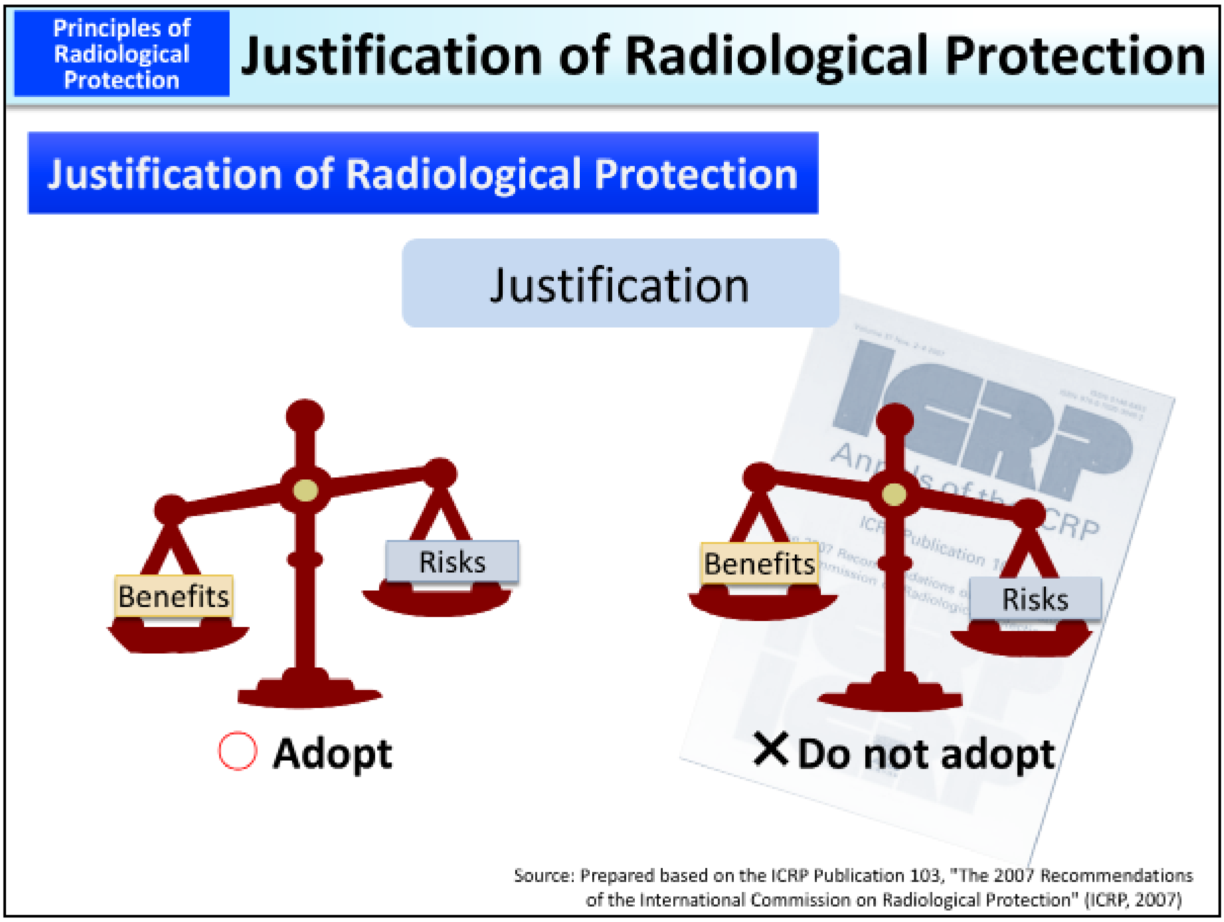
Updated on March 31, 2015



Principles of Radiological Protection

Justification of Radiological Protection

Justification of Radiological Protection

Justification

Benefits

Risks

○ Adopt

Benefits

Risks

✕ Do not adopt

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

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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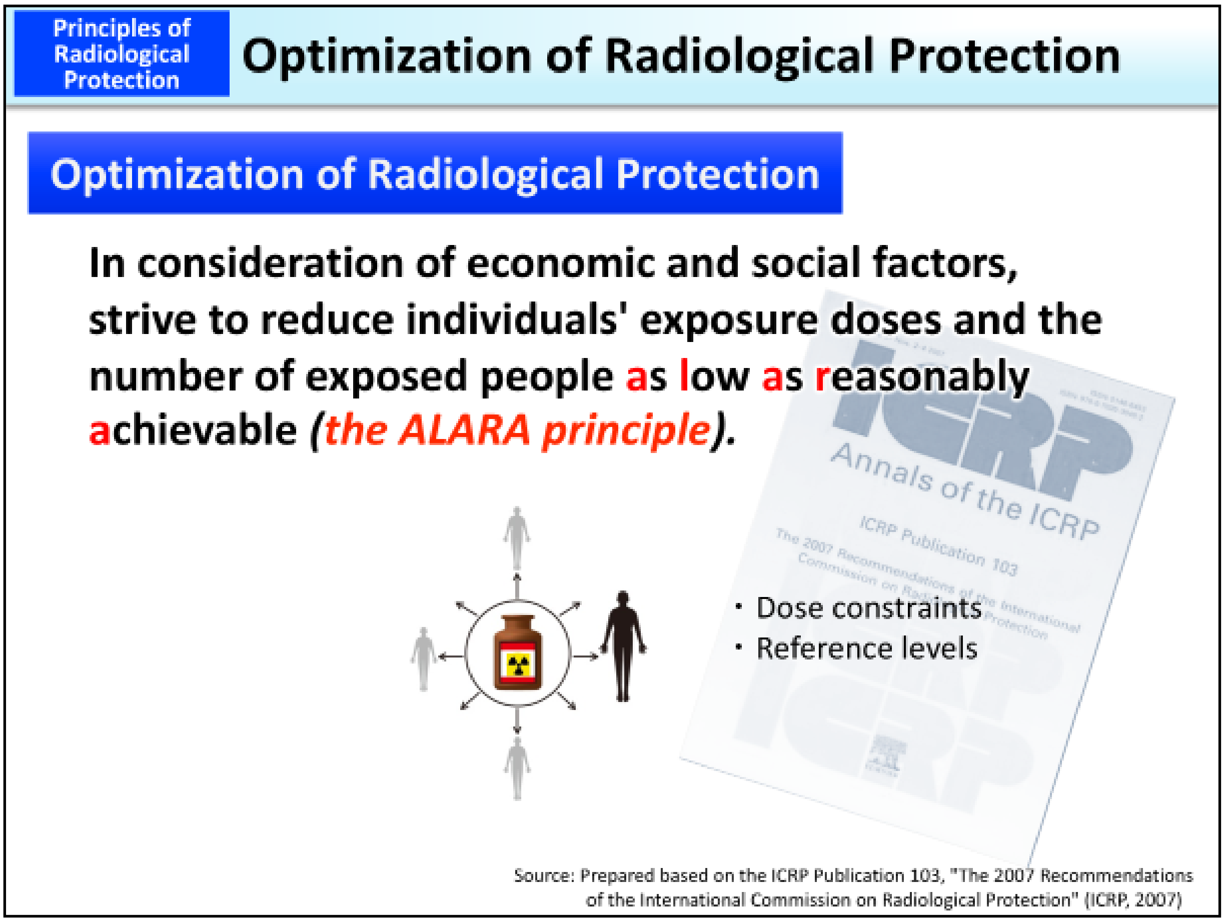

Principles of Radiological Protection

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)*.

- Dose constraints
- Reference levels

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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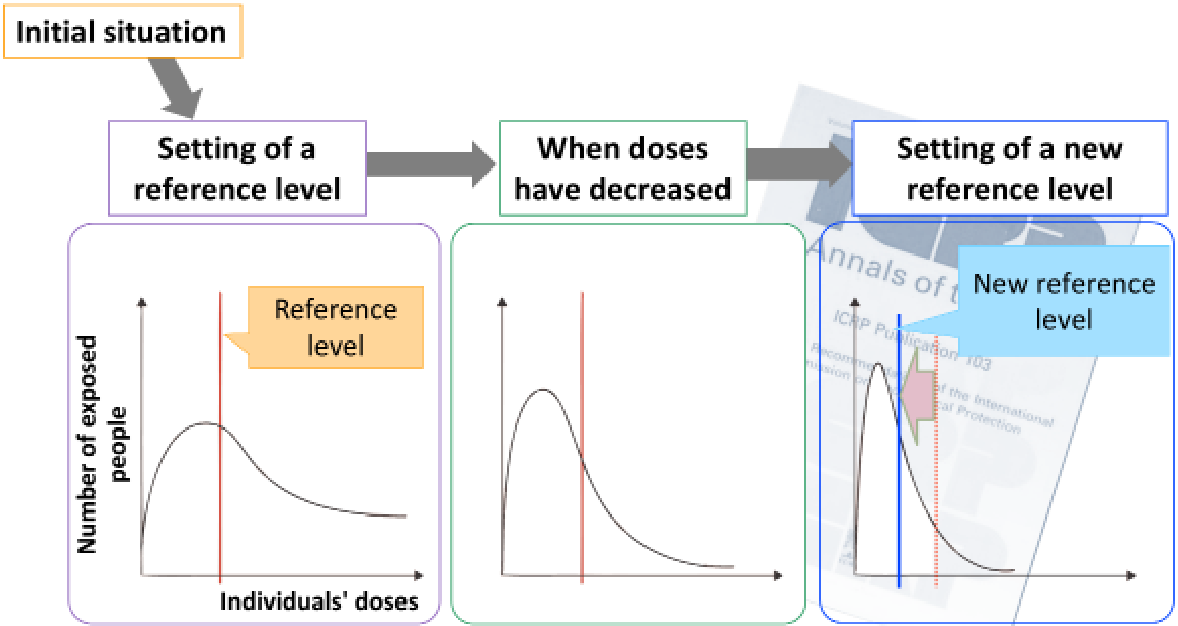
Principles of Radiological Protection

Optimization of Radiological Protection Using Reference Levels

Flow of optimization using reference levels



Initial situation

Setting of a reference level

When doses have decreased

Setting of a new reference level

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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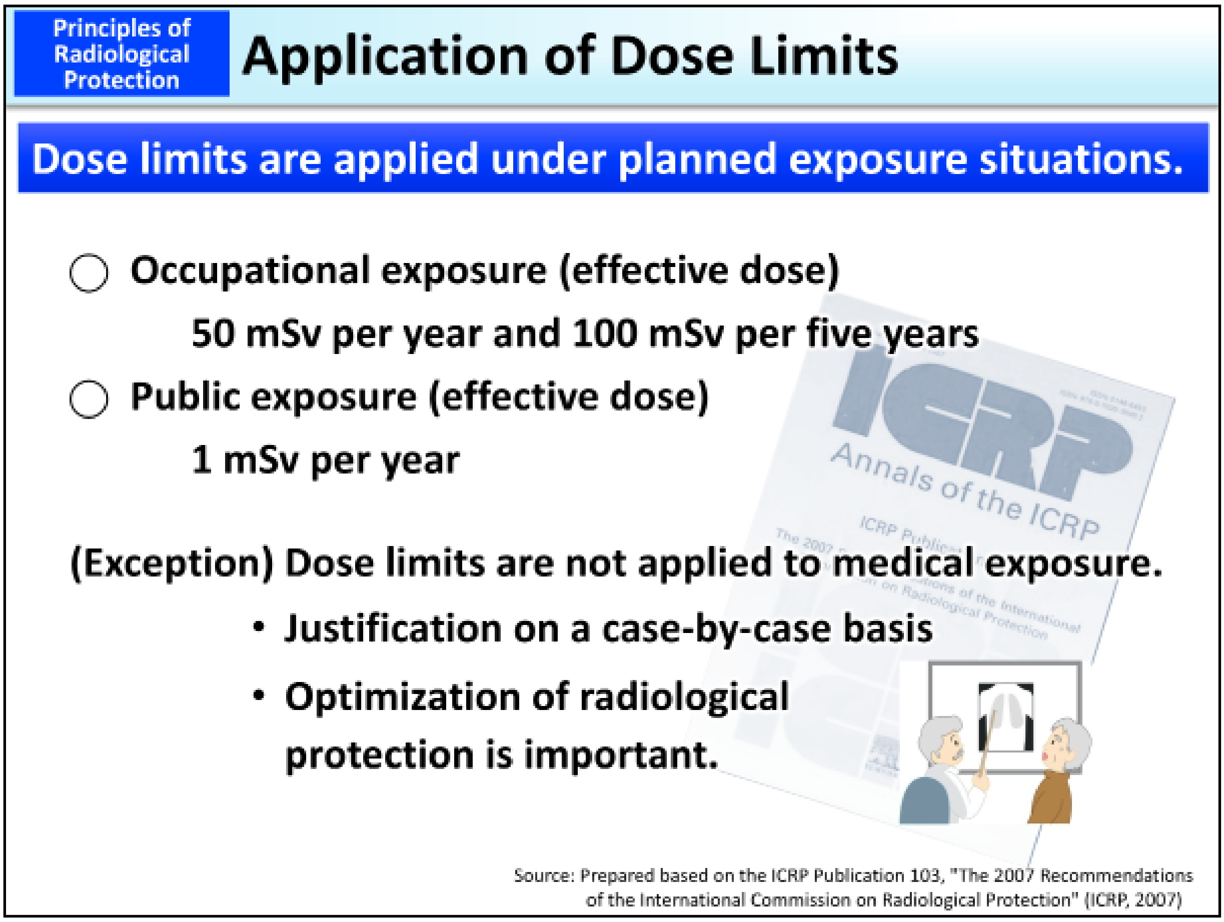

Principles of Radiological Protection

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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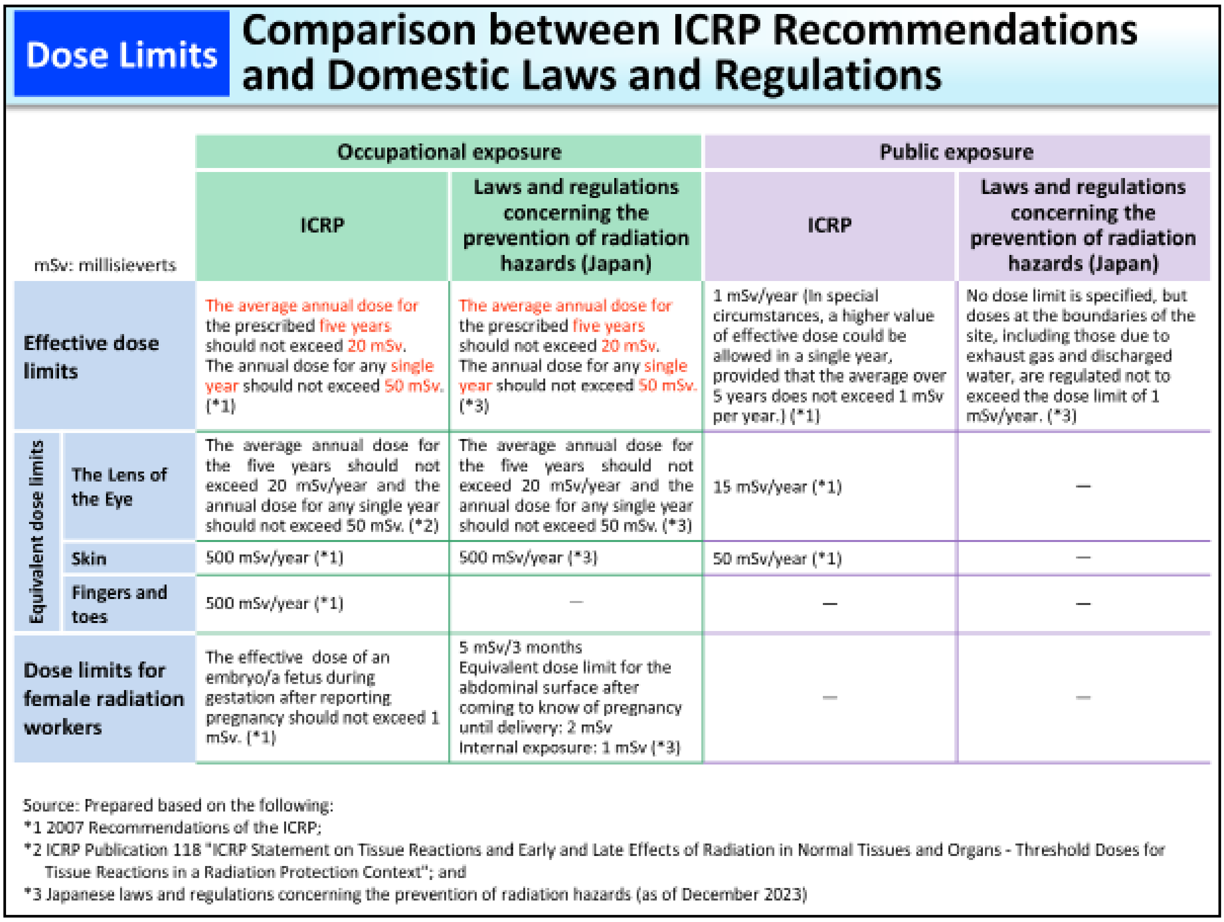

Dose Limits Comparison between ICRP Recommendations and Domestic Laws and Regulations

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 2023)

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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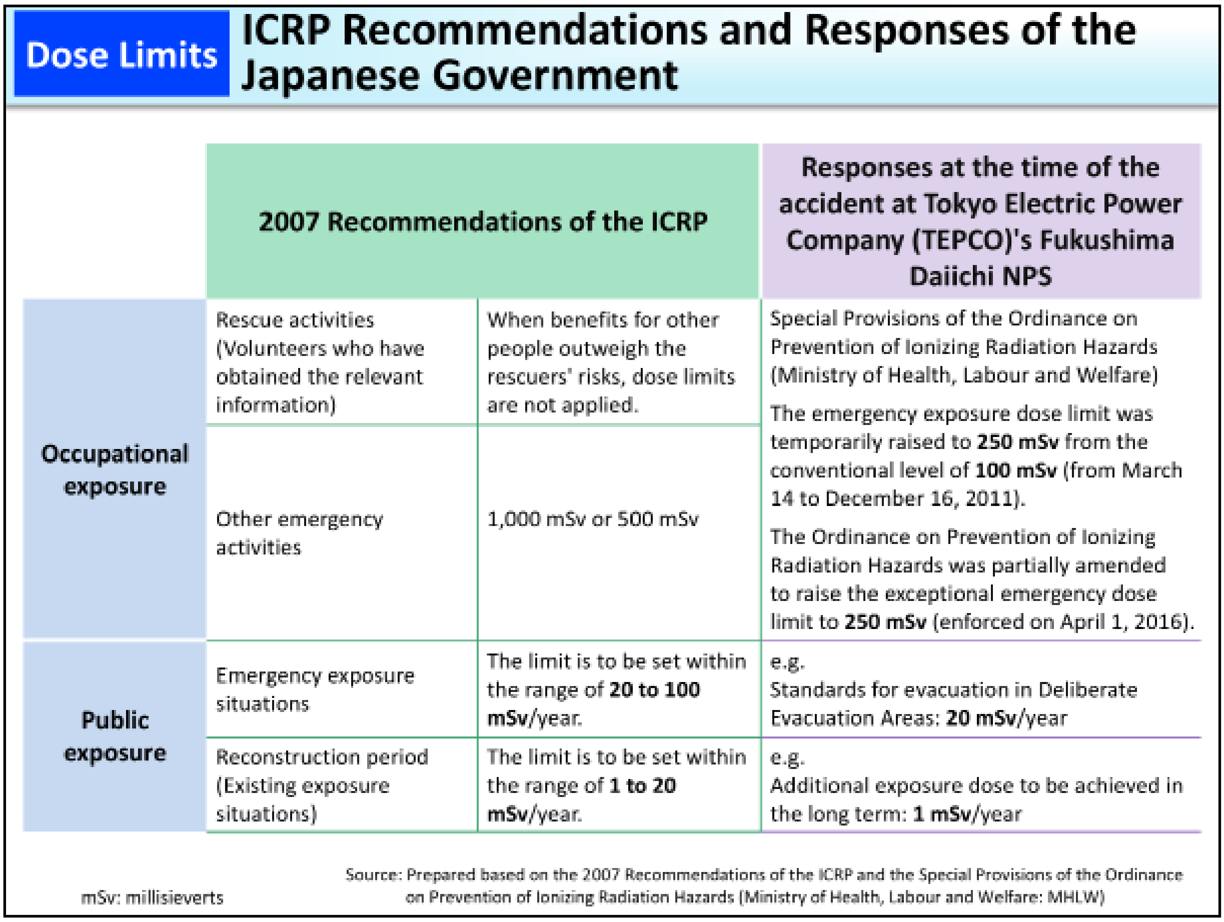
Dose Limits ICRP Recommendations and Responses of the Japanese Government



	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.170 of Vol. 1, "Optimization of Radiological Protection Using Reference Levels")

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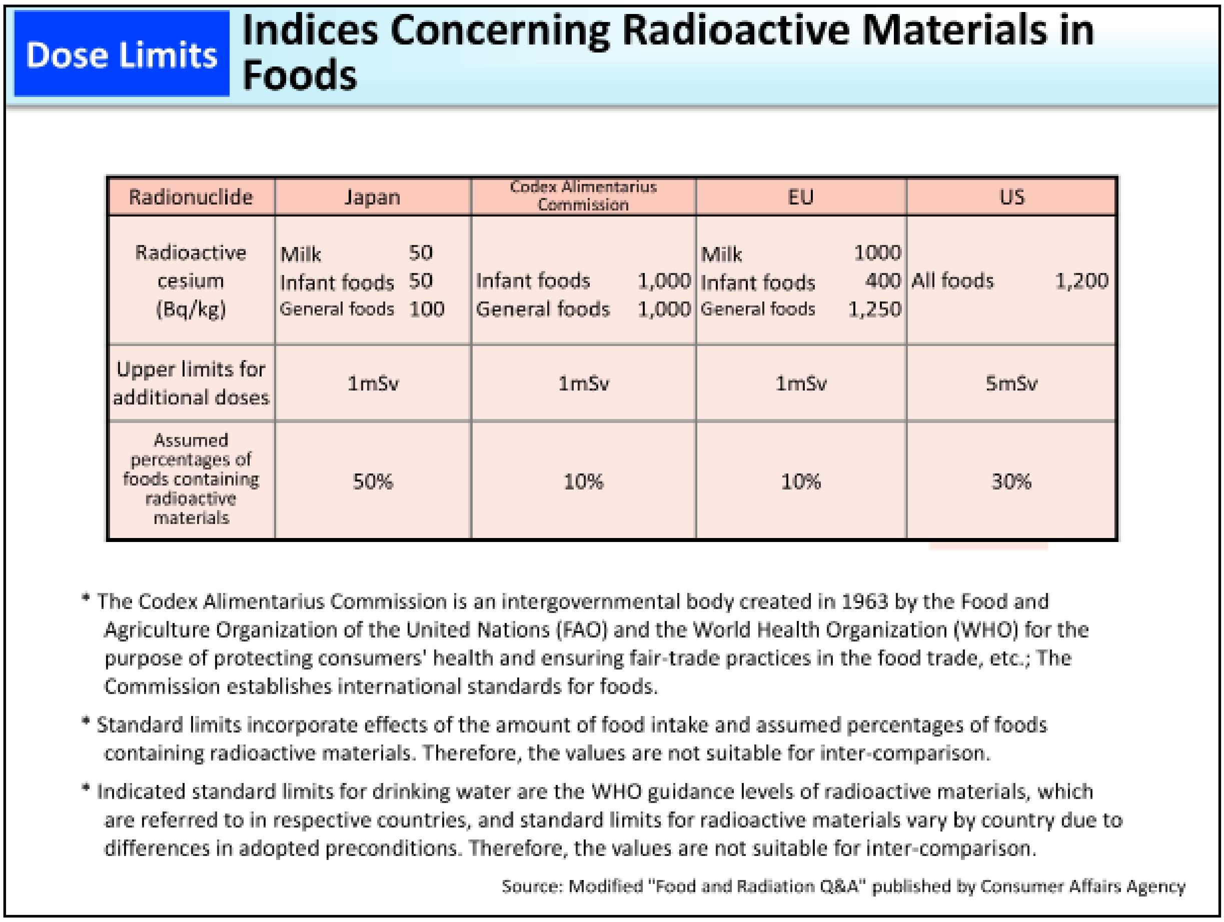

Dose Limits

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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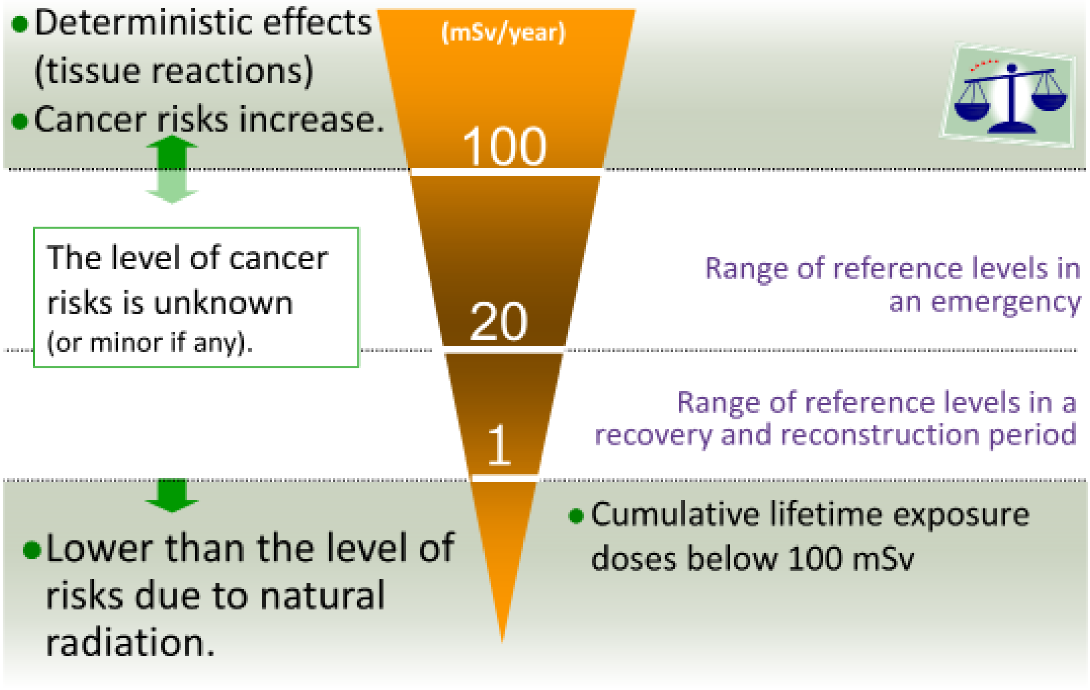
Dose Limits

Relation between Exposure Doses and Health Risks



- Deterministic effects (tissue reactions)
- Cancer risks increase.

The level of cancer risks is unknown (or minor if any).

Range of reference levels in an emergency

Range of reference levels in a recovery and reconstruction period

- Lower than the level of risks due to natural radiation.

- Cumulative lifetime exposure doses below 100 mSv

Source: Prepared based on the 2007 Recommendations of the ICRP

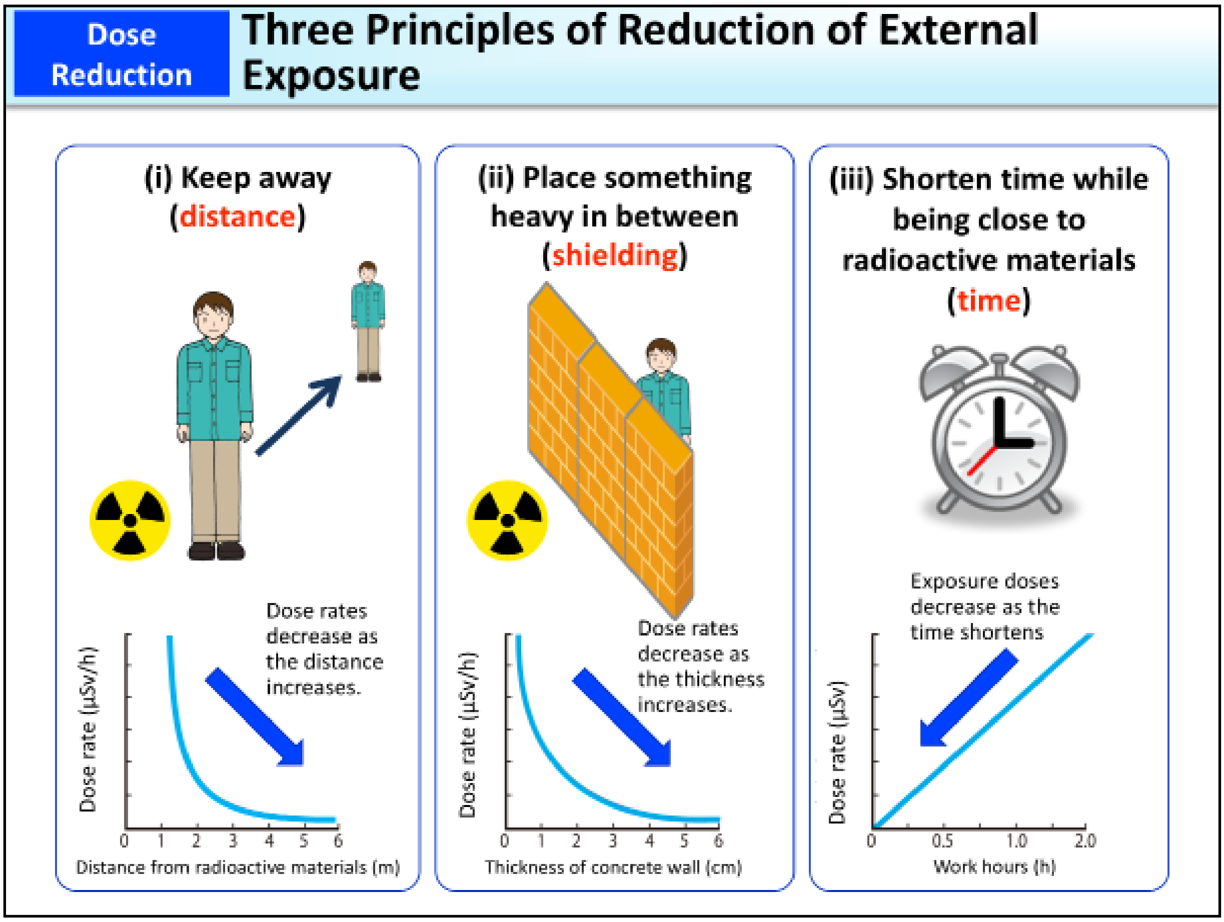
There is scientific evidence for the fact that radiation doses of 100 to 200 mSv or over in a relatively short time increase deterministic effects (tissue reactions) and cancer risks. Therefore, in an emergency due to a radiation accident, the initial reference level is set to avoid annual exposure doses 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.164 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”)

Included in this reference material on March 31, 2013
Updated on March 31, 2021



Dose Reduction

Three Principles of Reduction of External Exposure

(i) Keep away (distance)

Dose rates decrease as the distance increases.

(ii) Place something heavy in between (shielding)

Dose rates decrease as the thickness increases.

(iii) Shorten time while being close to radioactive materials (time)

Exposure doses decrease as the time shortens

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”)

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

Dose Reduction

Reduction of Internal Exposure

○ Be careful so that radioactive materials do not enter the body through the mouth, nose or wounds, in principle.

○ Wash off soil immediately from the body, shoes and clothes.

○ Exercise adequate care in eating wild mountain vegetables or mushrooms.

○ 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.

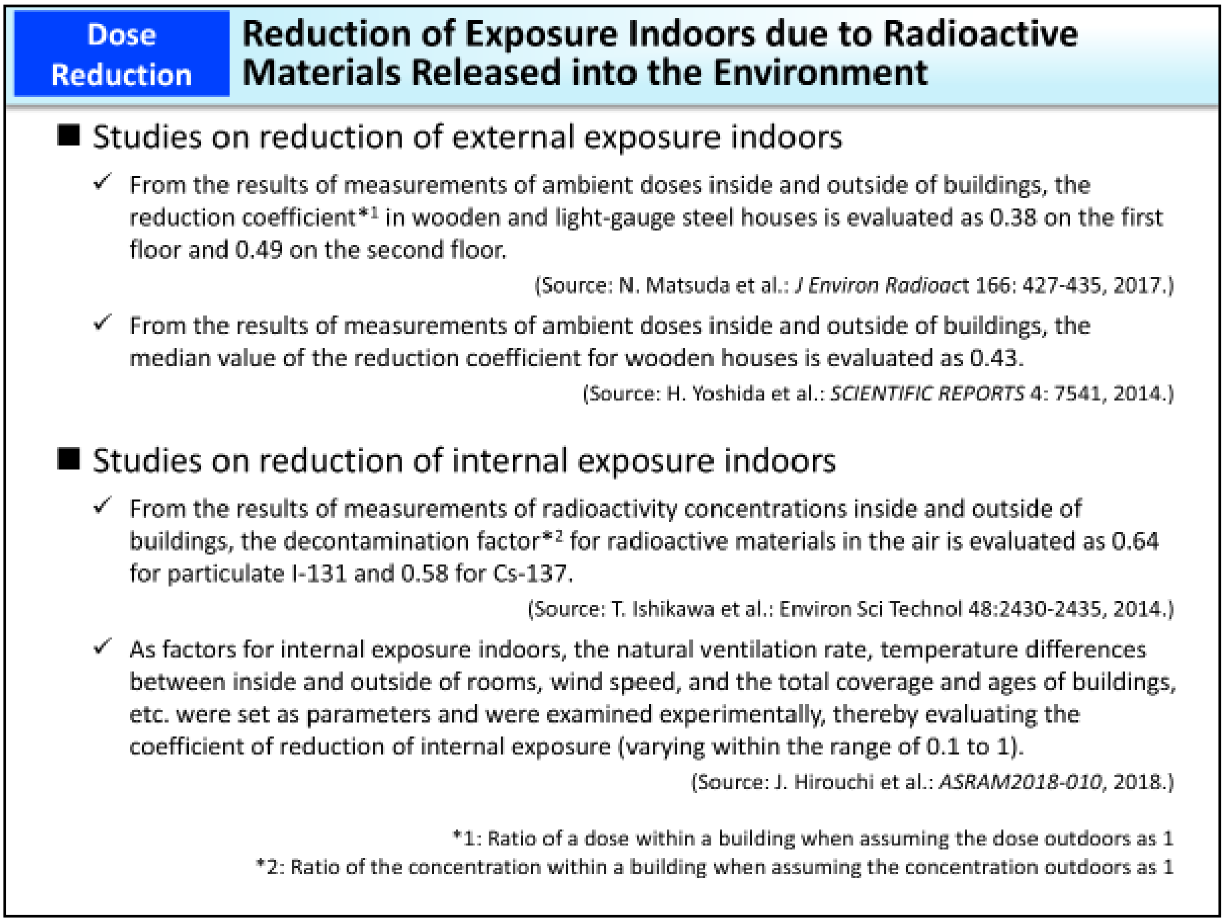
As causes of internal exposure, both intake through inhalation and oral intake through ingestion of foods and drinks need to be taken into consideration. After a nuclear disaster, radioactive materials remaining on the ground pose a problem, but little resuspended radioactive materials exist even immediately after the accident, and become further less over time.[1,2,3] Therefore, intake through inhalation of resuspended radioactive materials is scarce.[4] Proper daily hygienic control (such as washing hands and taking a bath, etc.) is also effective in reducing internal exposure.

In the meantime, attention needs to be paid to wild foods from which radioactive cesium is detected at high levels. In particular, special attention is required for wild mountain vegetables and mushrooms, which tend to contain cesium at high concentrations. In the aftermath of a nuclear disaster, radioactivity concentrations in foods are inspected by individual prefectures based on inspection plans they formulated 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”).

Regarding internal exposure due to radioactive cesium, simple measurement services are available for residents to measure radioactive cesium concentrations in wild mountain vegetables and mushrooms and for home-grown vegetables. Residents can also measure internal exposures using a whole-body counter (WBC).

1. IAEA-TECDOC-1162 “Generic procedures for assessment and response during a radiological emergency” (2000)
2. K. Akimoto: Jpn. J. Health Phys., 49(1): 17-28, 2014.
3. K. Akimoto: Health Phys., 108(1): 32-38, 2015.
4. UNSCEAR 2020/2021 Report

Included in this reference material on March 31, 2013
Updated on March 31, 2024



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

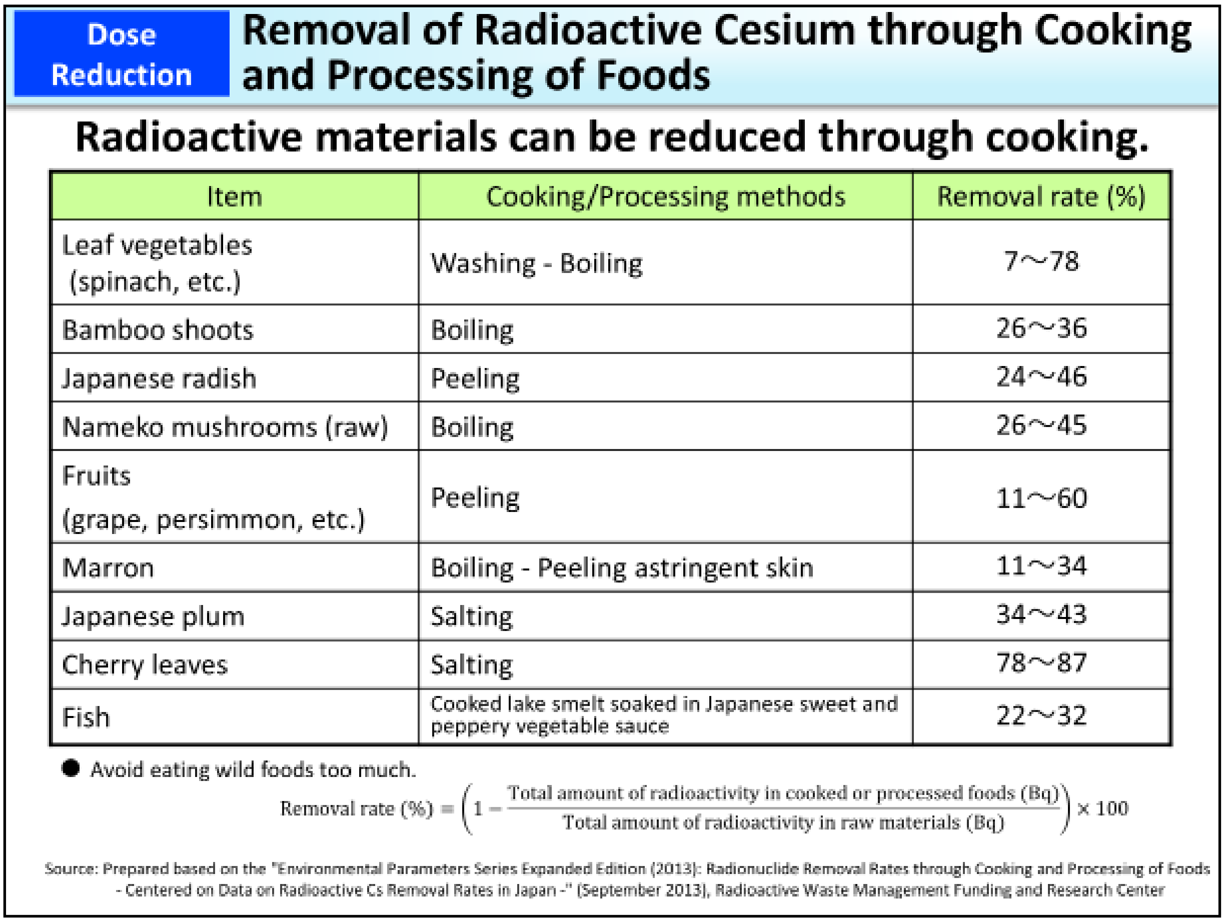
When being indoors, radiation from radioactive materials released into the environment that are suspended in outdoor air or deposited on the ground surface, etc. is shielded by the building and the external exposure dose decreases. Additionally, the concentration of radioactive materials suspended in 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.

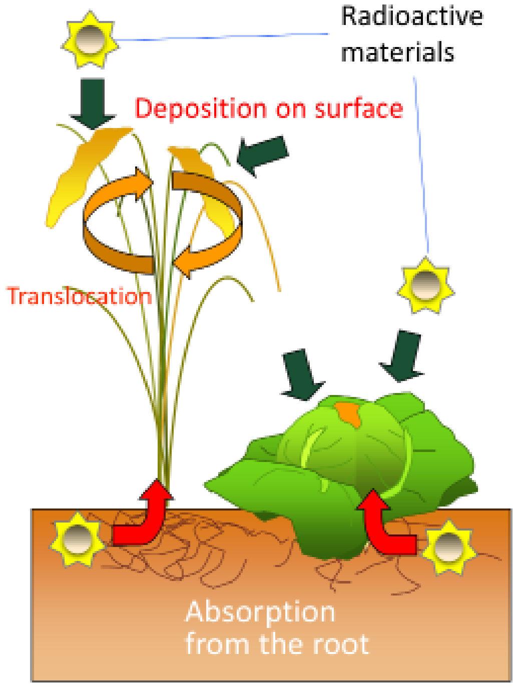
When cooking meat or fish, the amount of radioactive materials can be halved by discarding the cooking liquid. It is known that the removal rate is higher when boiling or cooking than grilling them.

Refer to the webpage (https://www.rwmc.or.jp/library/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

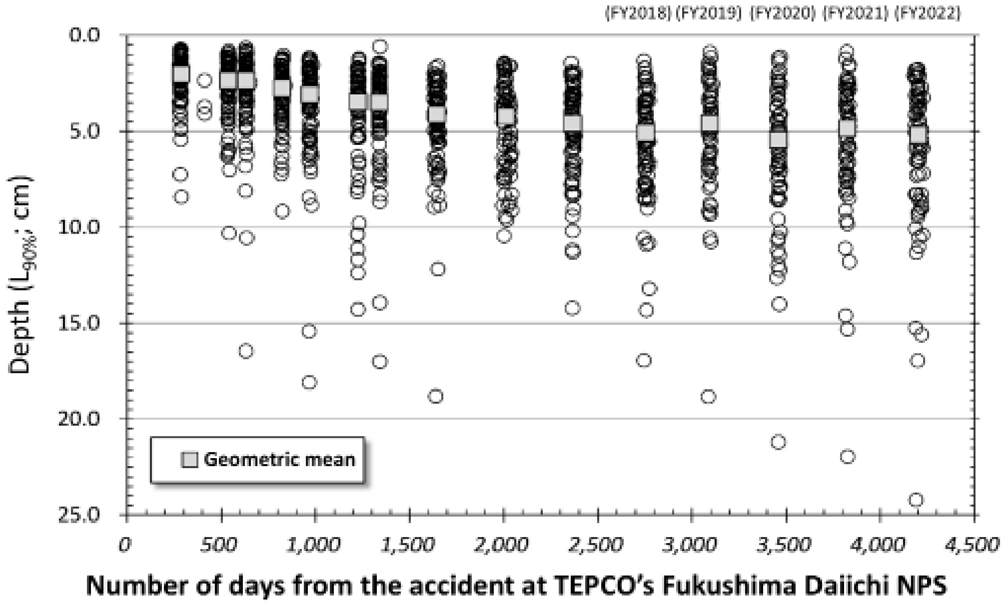


Figure: Data on changes over time in depth ($L_{90\%}$)* since December 2011 (85 locations at uncultivated land in Fukushima Prefecture, the southern part of Miyagi Prefecture and the northern part of Ibaraki Prefecture)

(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 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.

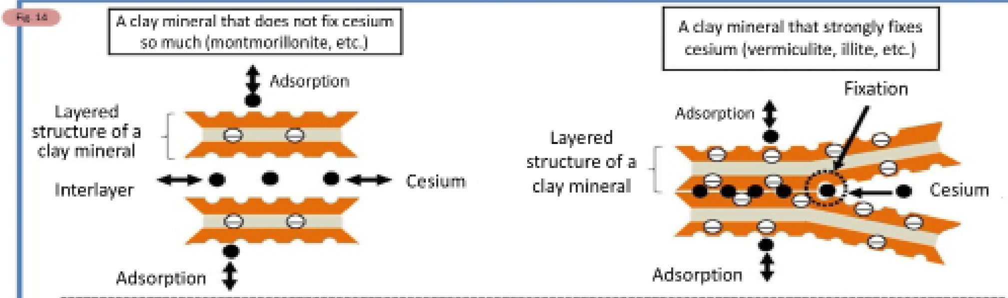
The survey on effects of the Chornobyl NPS Accident that occurred in 1986 revealed that approx. 80% of Cs-137 deposited on soil due to the accident had been staying within 10 cm from the ground surface even after 14 years from the accident (Report of the Chornobyl Forum Expert Group (2006), International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

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

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]

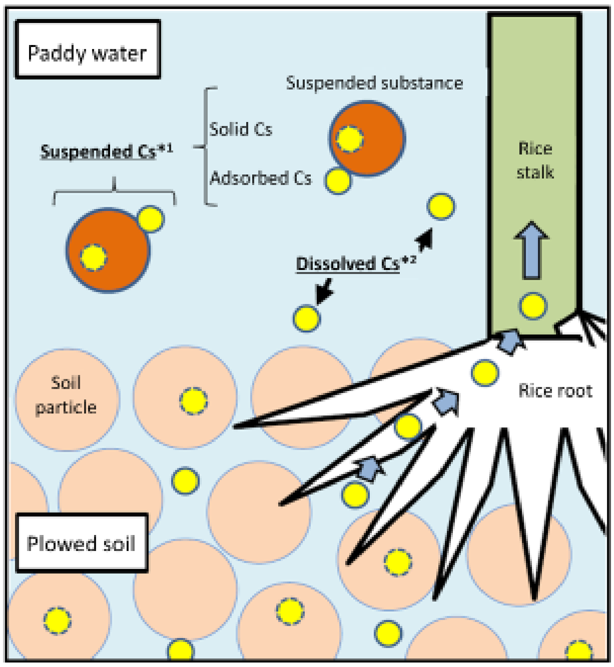
1. Outcome report of the FY2014 project, "Compilation of Data on Distribution of Radioactive Materials Released due to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS and Development of Transfer Model" commissioned by the Secretariat of the Nuclear Regulation Authority

Included in this reference material on March 31, 2017

Long-term Effects

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

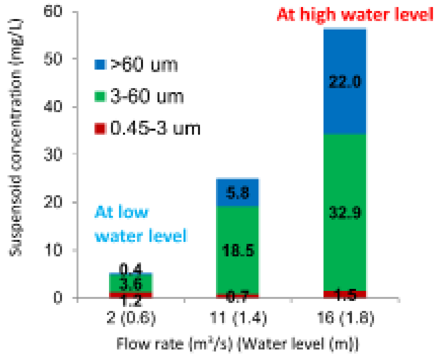
Forms of cesium in water



*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 m^3/s	16 m^3/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

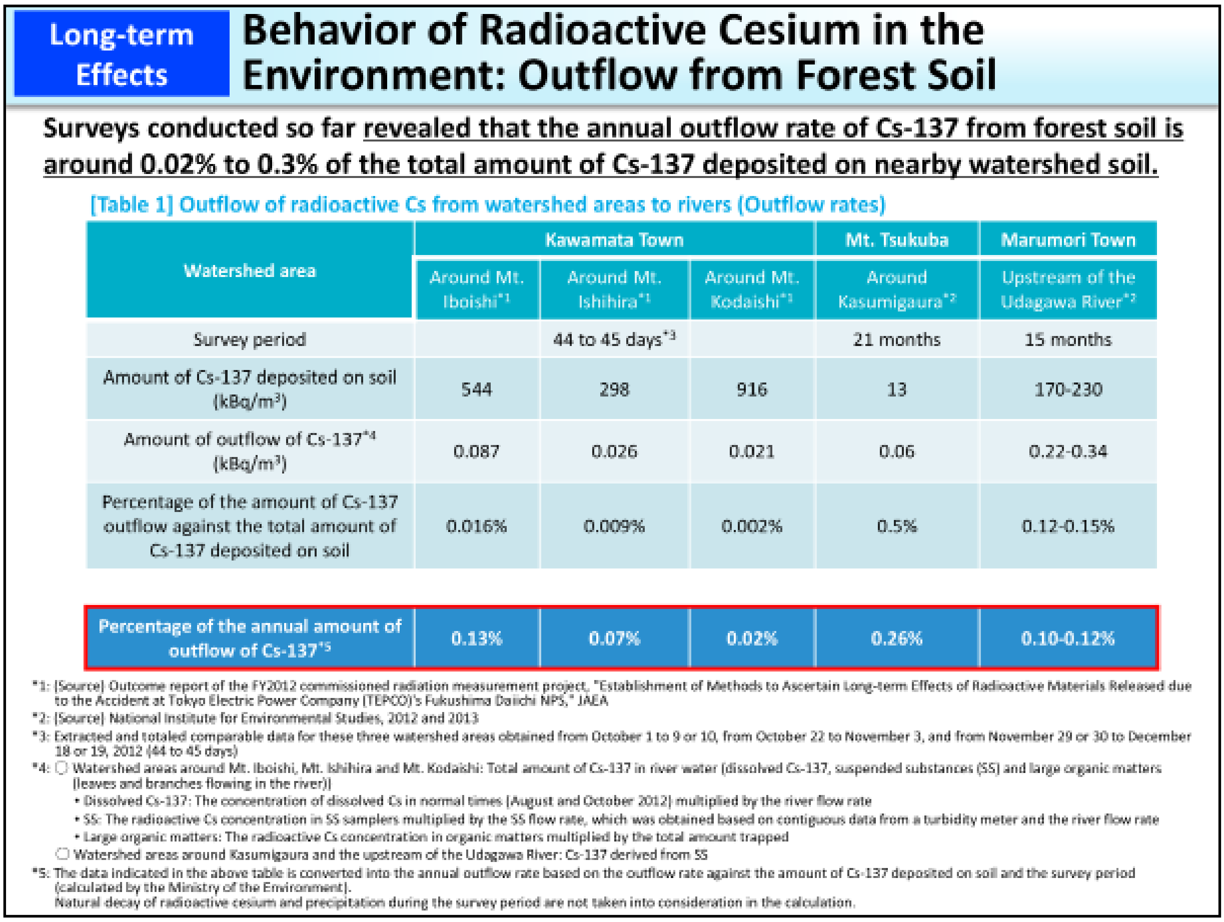
Source: From the following websites (in Japanese):
http://www.maff.go.jp/j/kanbo/joho/saigai/pdf/youin_kome2.pdf
https://fukushima.jaea.go.jp/report/document/pdf/pdf1702/hokokukai11.pdf

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

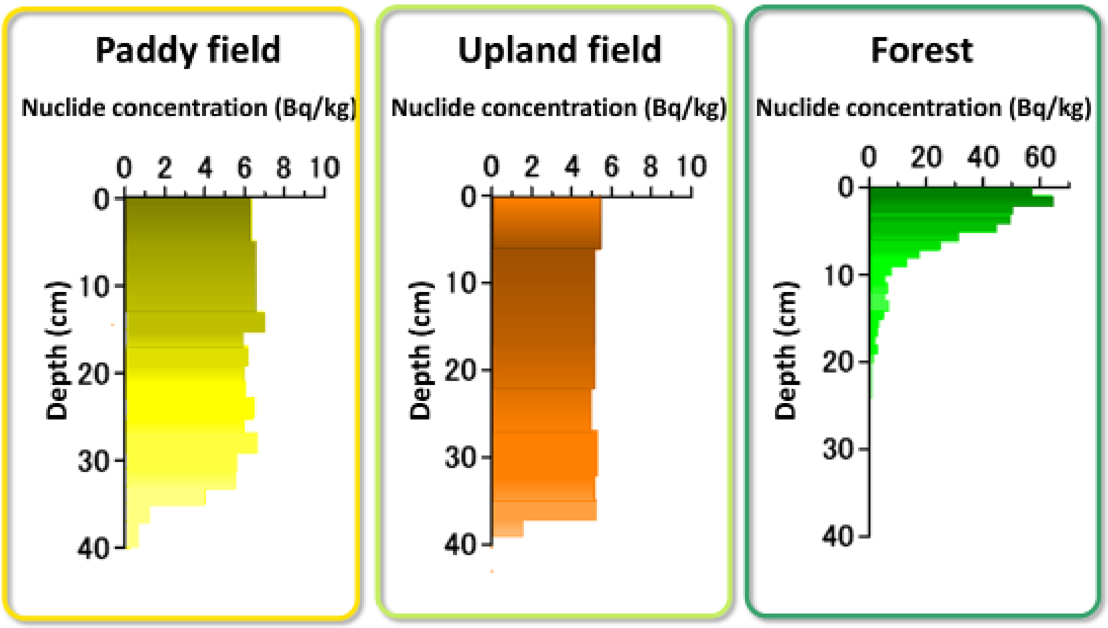
- The material for the 16th meeting of the Environment Recovery Committee

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

Long-term Effects

Distribution of Radioactive Materials in Forests

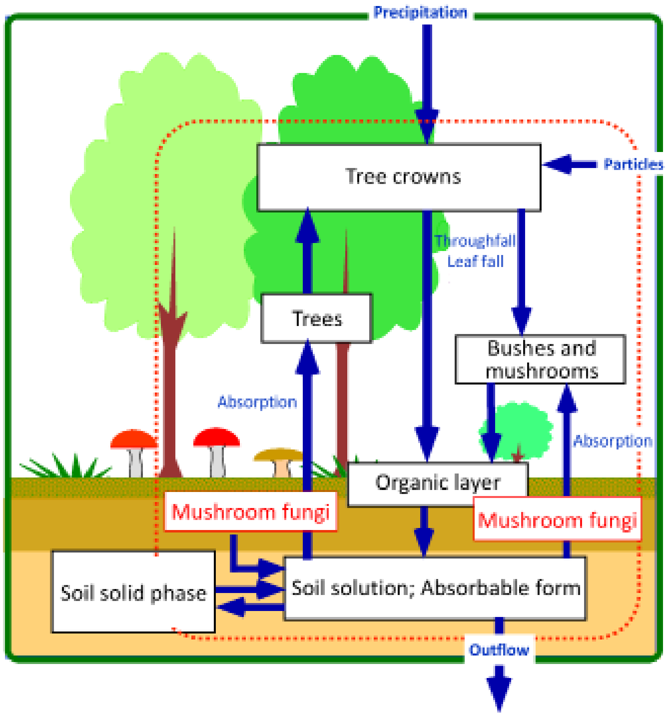
Distribution changes over time (years).

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.

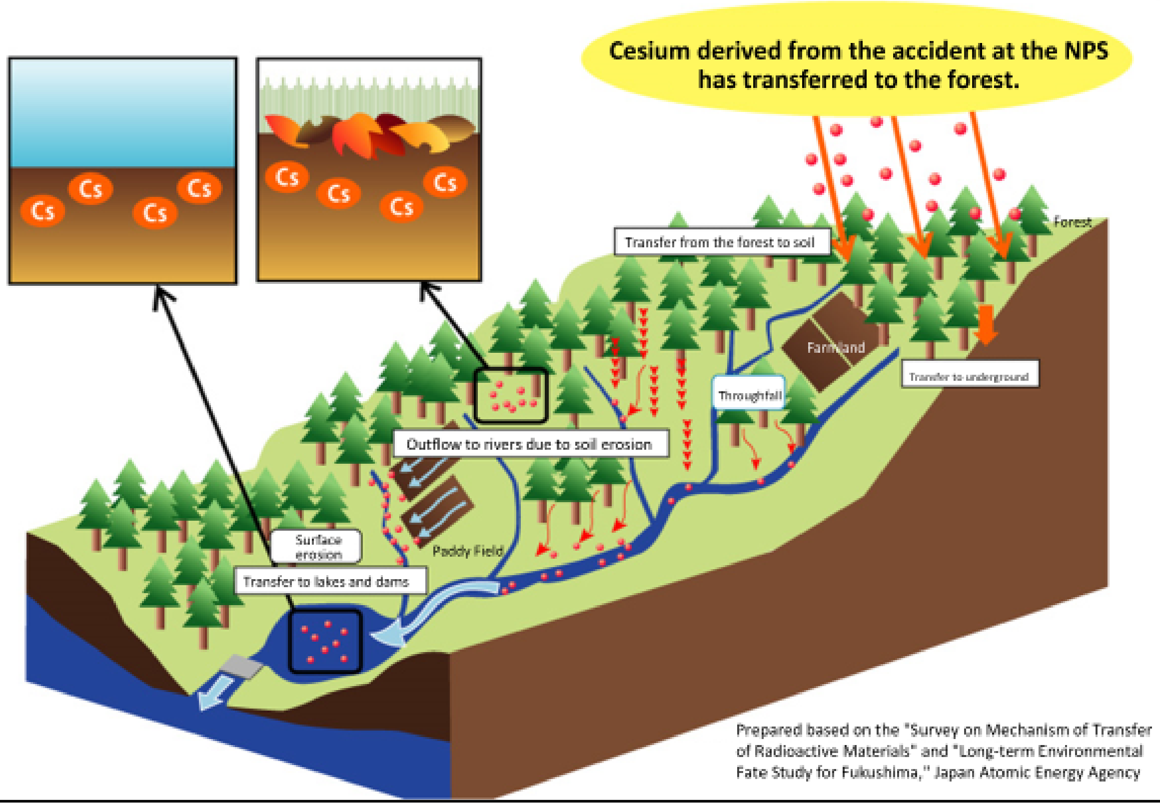
In this manner, radioactive cesium is fixed in the clayey soil in the process of circulating between plants and soil and is finally deposited in the surface layer of soil, as in the case of stable cesium.

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

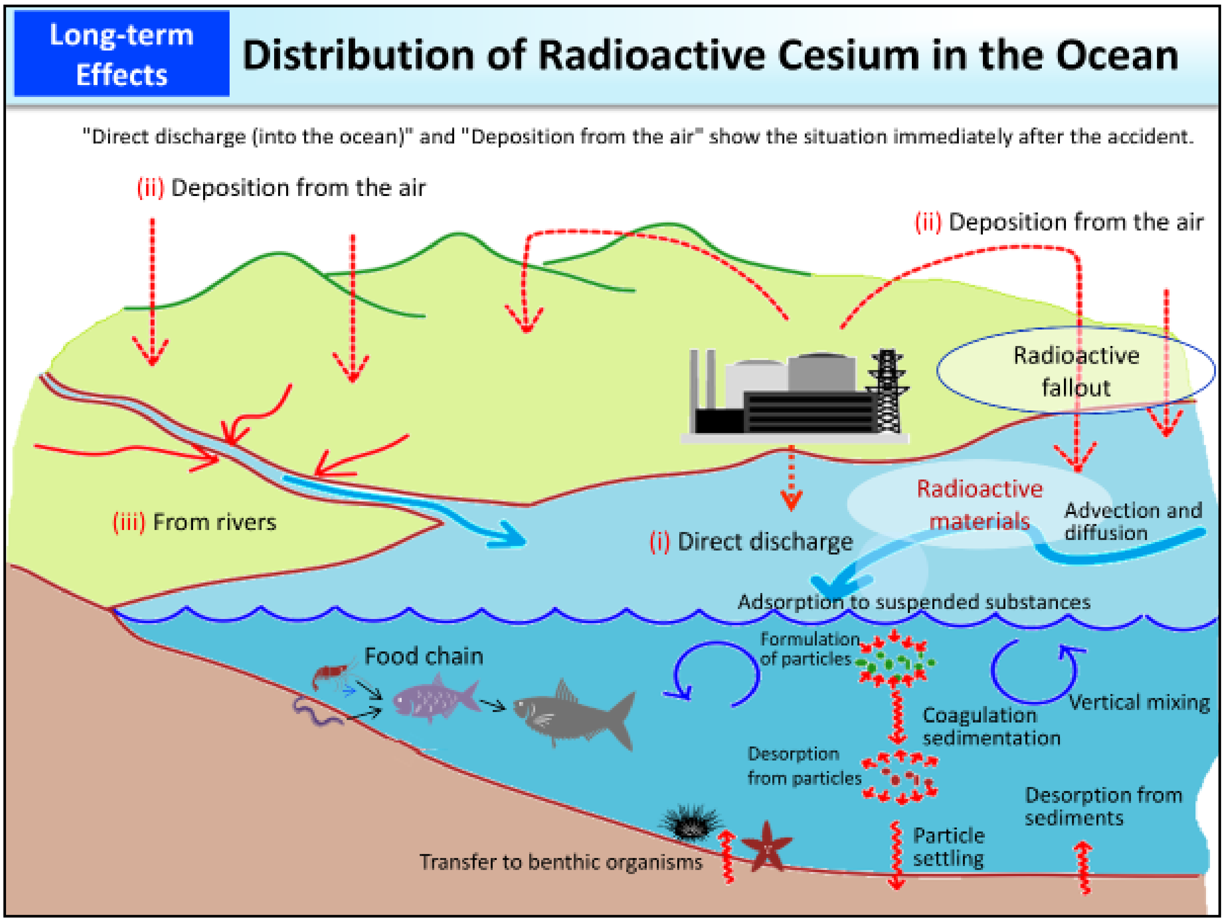
Distribution of radioactive cesium released into the environment due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS has changed significantly over time. Cesium that adhered to tree bark, branches and leaves immediately after the accident transferred onto the forest soil 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.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



Long-term Effects

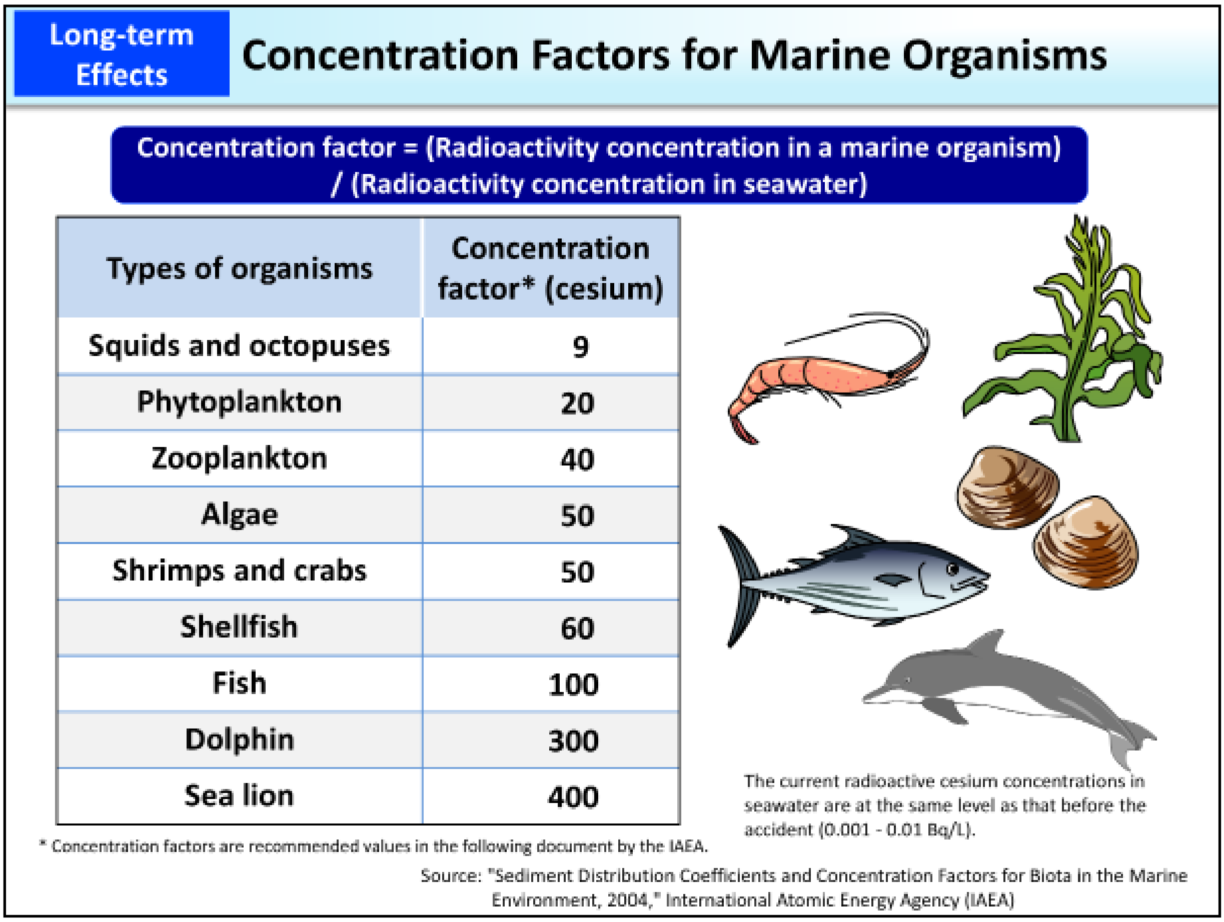
Distribution of Radioactive Cesium in the Ocean

"Direct discharge (into the ocean)" and "Deposition from the air" show the situation immediately after the accident.

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

Chapter 5

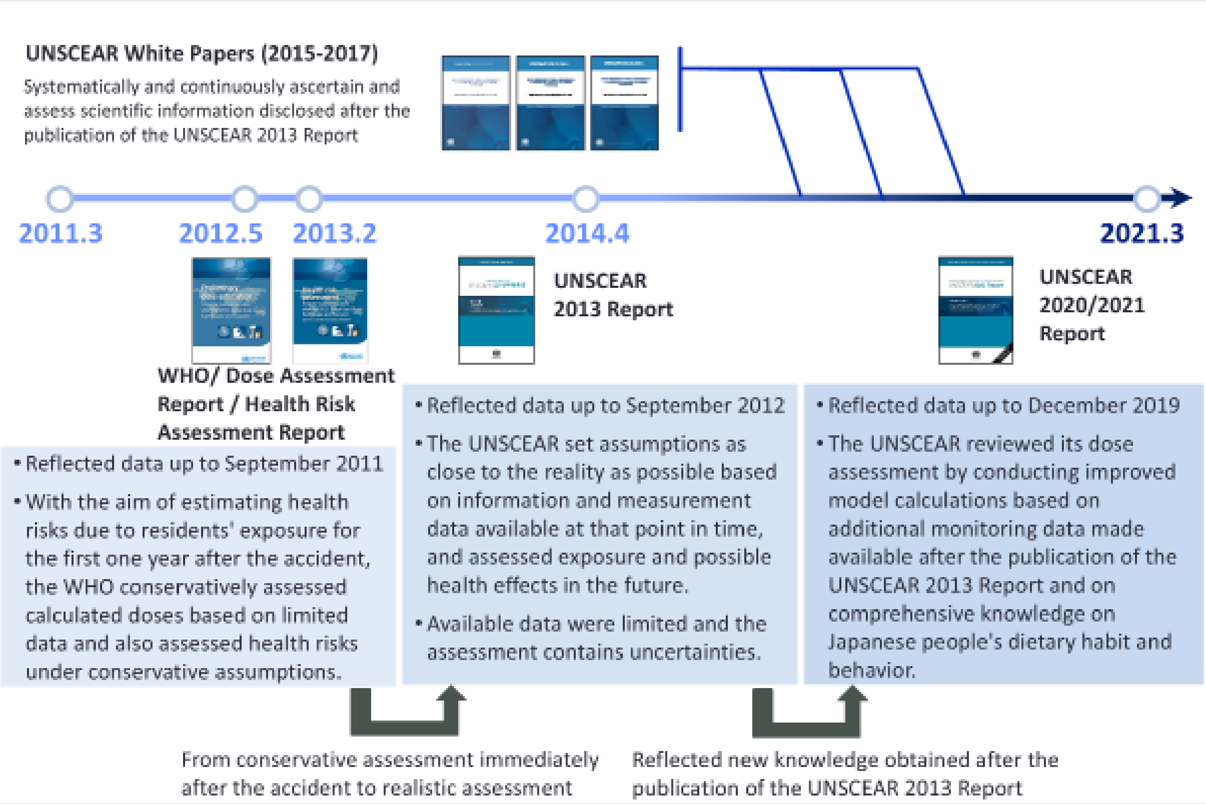
Assessments by International Organizations

Chapter 5 outlines the assessments on radiation exposure made by the World Health Organization (WHO) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS.

You can grasp an outline of how the status and effects of radiation exposure due to the accident are assessed internationally, including the latest reports by international organizations.

Assessments by International Organizations

Changes in International Organizations' Assessments



UNSCEAR White Papers (2015-2017)

Systematically and continuously ascertain and assess scientific information disclosed after the publication of the UNSCEAR 2013 Report

WHO/ Dose Assessment Report / Health Risk Assessment Report

- Reflected data up to September 2011
- With the aim of estimating health risks due to residents' exposure for the first one year after the accident, the WHO conservatively assessed calculated doses based on limited data and also assessed health risks under conservative assumptions.

UNSCEAR 2013 Report

- Reflected data up to September 2012
- The UNSCEAR set assumptions as close to the reality as possible based on information and measurement data available at that point in time, and assessed exposure and possible health effects in the future.
- Available data were limited and the assessment contains uncertainties.

UNSCEAR 2020/2021 Report

- Reflected data up to December 2019
- The UNSCEAR reviewed its dose assessment by conducting improved model calculations based on additional monitoring data made available after the publication of the UNSCEAR 2013 Report and on comprehensive knowledge on Japanese people's dietary habit and behavior.

From conservative assessment immediately after the accident to realistic assessment

Reflected new knowledge obtained after the publication of the UNSCEAR 2013 Report

After the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, the World Health Organization (WHO) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published reports on assessment of exposure doses due to the accident and on health effects of radiation exposure.

The WHO published a report on provisional exposure dose assessment in May 2012, and a report on provisional health risk assessment in February 2013. The assessment by the WHO aimed to estimate people's exposure doses for the first one year after the accident and identify areas requiring emergency measures. Accordingly, based on limited information and by setting conservative assumptions in order to avoid underestimation, the WHO assessed the maximum exposure doses that could be possible.

The UNSCEAR 2013 Report aimed to achieve the most realistic assessment of exposure levels and radiation risks due to the accident to the extent possible. However, the Report also states that all the results of such assessment contain certain uncertainties due to the incompleteness of knowledge or information and depending on setting of assumptions.

Therefore, the UNSCEAR conducted ongoing follow-ups to systematically collect and assess new information published after the publication of the UNSCEAR 2013 Report. The results of the follow-ups were compiled into three White Papers from 2015 to 2017, and the UNSCEAR 2020/2021 Report, which reflects new knowledge obtained after the publication of the UNSCEAR 2013 Report, was published in March 2021.

In the UNSCEAR 2020/2021 Report, doses are estimated using new knowledge on exposure dose assessment in order to reduce the uncertainties in the dose estimation in the UNSCEAR 2013 Report.

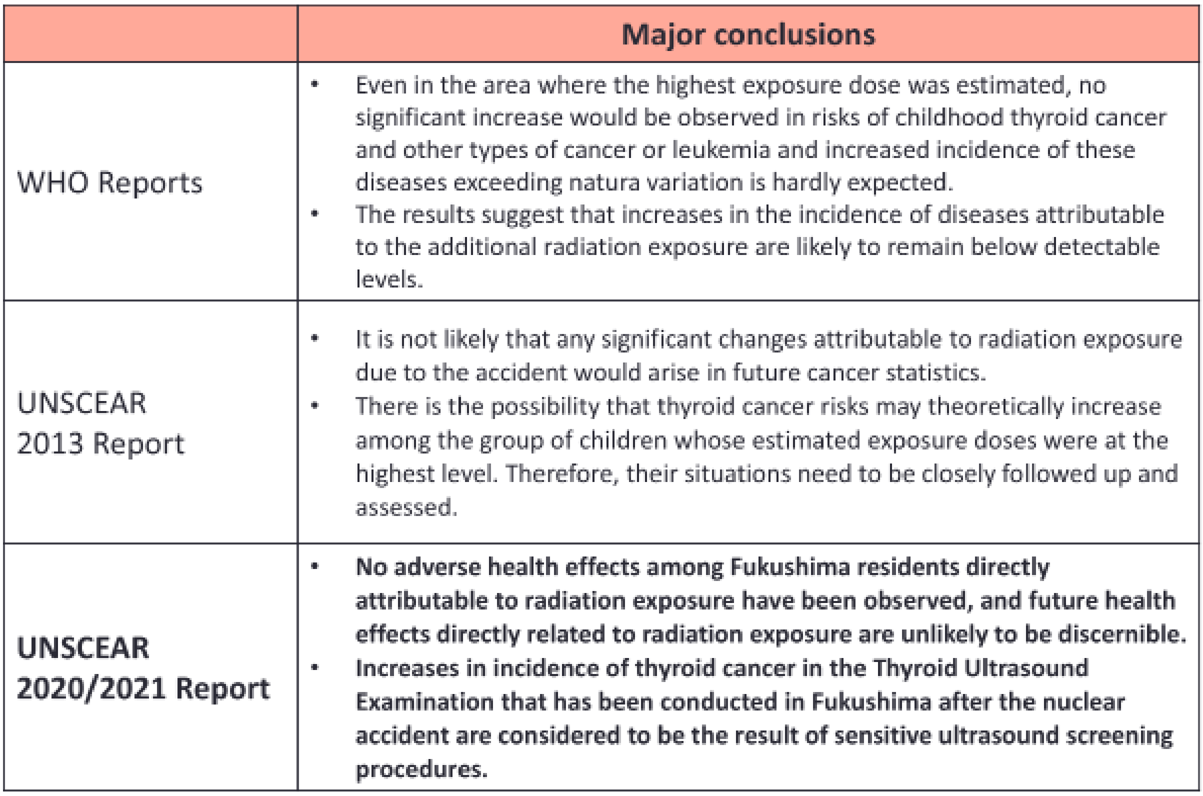
1. WHO Reports on preliminary dose estimation and health risk assessment:
- Preliminary dose estimation from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami (2012)
- Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation (2013)

2. 2013 Annual Report by the UNSCEAR:
- SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION UNSCEAR 2013, Report, Volume I, REPORT TO THE GENERAL ASSEMBLY SCIENTIFIC ANNEX A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami (2013)

3. 2020 Annual Report by the UNSCEAR:
- SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION UNSCEAR 2020/2021, Report, SCIENTIFIC ANNEX B: Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi Nuclear Power Station: Implications of information published since the UNSCEAR2013Report (2020)

Included in this reference material on March 31, 2023
Updated on March 31, 2024

Major Conclusions of the Reports of International Organizations



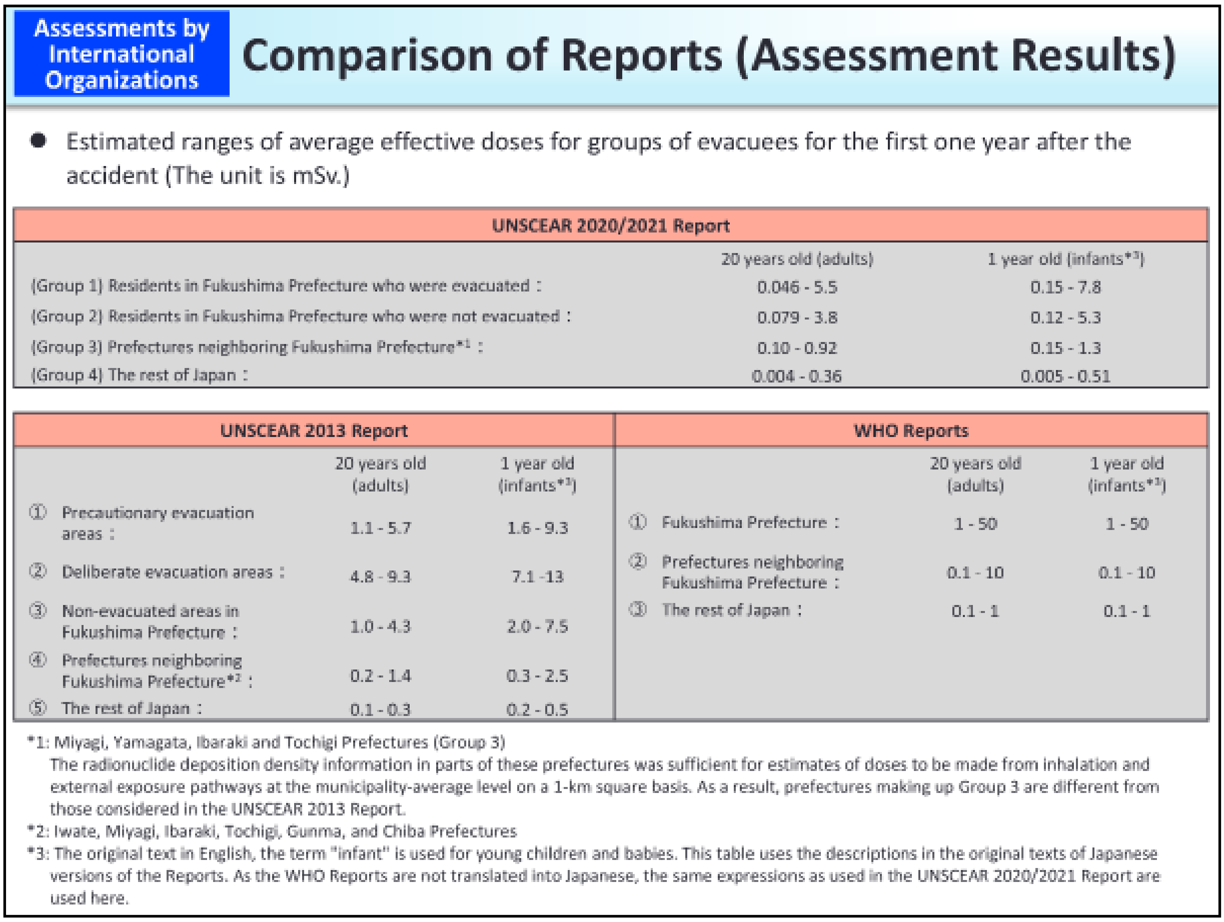
	Major conclusions
WHO Reports	• Even in the area where the highest exposure dose was estimated, no significant increase would be observed in risks of childhood thyroid cancer and other types of cancer or leukemia and increased incidence of these diseases exceeding natura variation is hardly expected. • The results suggest that increases in the incidence of diseases attributable to the additional radiation exposure are likely to remain below detectable levels.
UNSCEAR 2013 Report	• It is not likely that any significant changes attributable to radiation exposure due to the accident would arise in future cancer statistics. • There is the possibility that thyroid cancer risks may theoretically increase among the group of children whose estimated exposure doses were at the highest level. Therefore, their situations need to be closely followed up and assessed.
UNSCEAR 2020/2021 Report	• **No adverse health effects among Fukushima residents directly attributable to radiation exposure have been observed, and future health effects directly related to radiation exposure are unlikely to be discernible.** • **Increases in incidence of thyroid cancer in the Thyroid Ultrasound Examination that has been conducted in Fukushima after the nuclear accident are considered to be the result of sensitive ultrasound screening procedures.**

The WHO Reports published in 2012 and 2013, along with the UNSCEAR 2013 Report, state that their assessments of exposure doses contain certain uncertainties due to uncertainties inherent to basic data. However, the UNSCEAR 2020/2021 Report shows conclusions with less uncertainties on many issues as a broader range of knowledge became available.

The UNSCEAR 2020/2021 Report compiles all pieces of scientific information concerning levels and effects of radiation exposure due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS that were published by the end of 2019 and assesses the influence on the knowledge and conclusions of the UNSCEAR 2013 Report.

Based on new knowledge, etc. on exposure dose assessment that became clear after the publication of the UNSCEAR 2013 Report, it became possible for the UNSCEAR to conduct improved and more realistic assessment of levels and effects of radiation exposure after the accident in its 2020/2021 Report. Based on the fact that public exposure doses that were reviewed based on new knowledge were lower or at the same level compared with those in the 2013 Report, the UNSCEAR concluded that “future health effects directly related to radiation exposure are unlikely to be discernible.” With regard to many cases of thyroid cancer detected in Thyroid Ultrasound Examination, which was conducted as part of the Fukushima Health Management Survey, the UNSCEAR assessed that “these cases are not stem from the result of radiation exposure but rather arise from the result of sensitive ultrasound screening procedures.” Furthermore, the UNSCEAR concluded that “there has been no evidence of excess congenital anomalies, stillbirths, preterm deliveries related to radiation exposure among general public.”

Included in this reference material on March 31, 2023
Updated on March 31, 2024



Assessments by International Organizations

Comparison of Reports (Assessment Results)

- Estimated ranges of average effective doses for groups of evacuees for the first one year after the accident (The unit is mSv.)

UNSCEAR 2020/2021 Report

	20 years old (adults)	1 year old (infants*3)
(Group 1) Residents in Fukushima Prefecture who were evacuated :	0.046 - 5.5	0.15 - 7.8
(Group 2) Residents in Fukushima Prefecture who were not evacuated :	0.079 - 3.8	0.12 - 5.3
(Group 3) Prefectures neighboring Fukushima Prefecture*1 :	0.10 - 0.92	0.15 - 1.3
(Group 4) The rest of Japan :	0.004 - 0.36	0.005 - 0.51

UNSCEAR 2013 Report

	20 years old (adults)	1 year old (infants*3)
① Precautionary evacuation areas :	1.1 - 5.7	1.6 - 9.3
② Deliberate evacuation areas :	4.8 - 9.3	7.1 -13
③ Non-evacuated areas in Fukushima Prefecture :	1.0 - 4.3	2.0 - 7.5
④ Prefectures neighboring Fukushima Prefecture*2 :	0.2 - 1.4	0.3 - 2.5
⑤ The rest of Japan :	0.1 - 0.3	0.2 - 0.5

WHO Reports

	20 years old (adults)	1 year old (infants*3)
① Fukushima Prefecture :	1 - 50	1 - 50
② Prefectures neighboring Fukushima Prefecture :	0.1 - 10	0.1 - 10
③ The rest of Japan :	0.1 - 1	0.1 - 1

*1: Miyagi, Yamagata, Ibaraki and Tochigi Prefectures (Group 3)
The radionuclide deposition density information in parts of these prefectures was sufficient for estimates of doses to be made from inhalation and external exposure pathways at the municipality-average level on a 1-km square basis. As a result, prefectures making up Group 3 are different from those considered in the UNSCEAR 2013 Report.

*2: Iwate, Miyagi, Ibaraki, Tochigi, Gunma, and Chiba Prefectures

*3: The original text in English, the term "infant" is used for young children and babies. This table uses the descriptions in the original texts of Japanese versions of the Reports. As the WHO Reports are not translated into Japanese, the same expressions as used in the UNSCEAR 2020/2021 Report are used here.

The estimated effective doses to the public for the first year after the accident in Reports of the UNSCEAR and the WHO are as shown in the table above. The ranges of doses here show those of average values for prefectures, municipalities in the targeted areas, or evacuation scenarios for targeted groups.

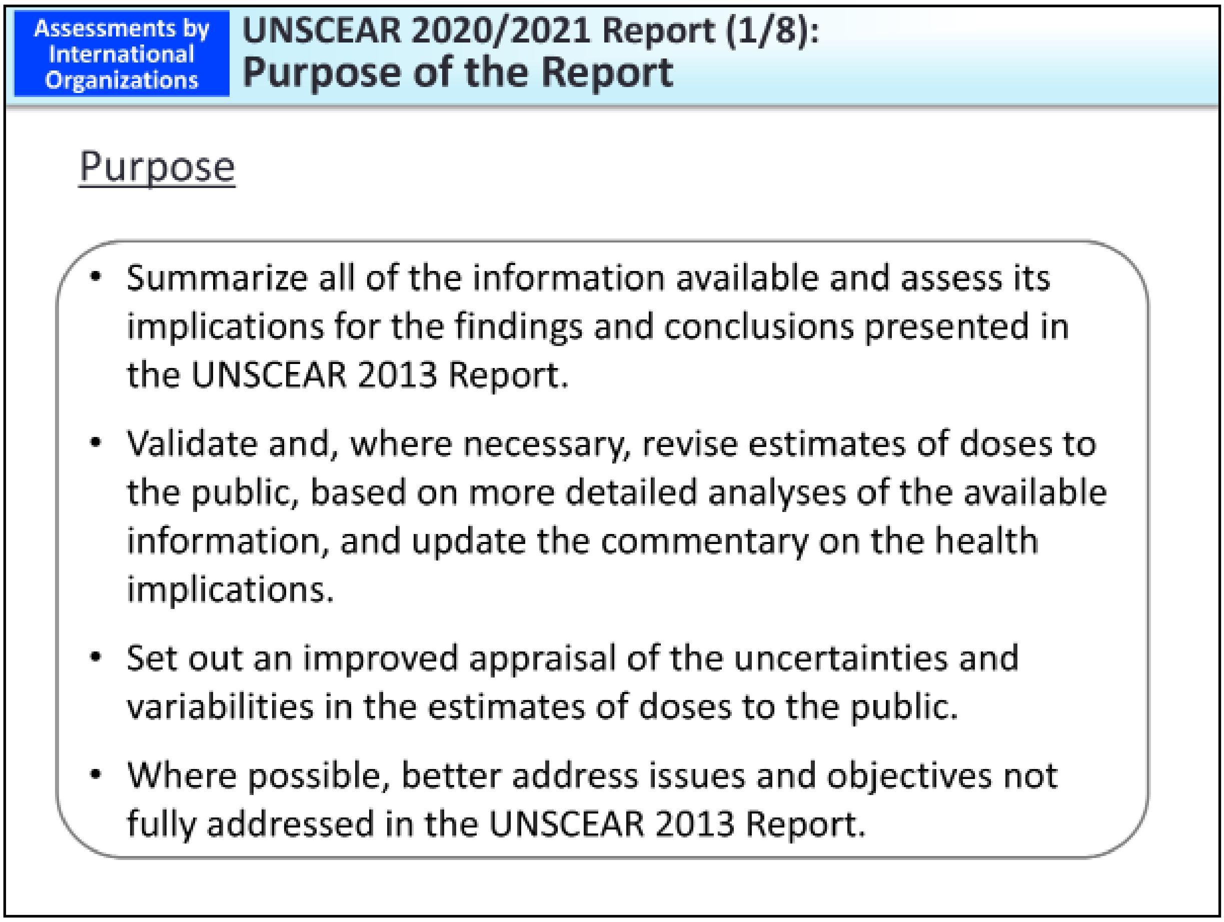
The results of dose assessment in the UNSCEAR 2020/2021 Report are lower or at the same level compared with those presented in the UNSCEAR 2013 Report (p.196 of Vol. 1, “UNSCEAR 2020/2021 Report (3/8): Update from the UNSCEAR 2013 Report upon Assessing Public Exposure Doses”). The UNSCEAR 2020/2021 Report also assesses the uncertainties in dose assessment.

The WHO Reports and the UNSCEAR 2013 Report state that their assessments of exposure doses contain certain uncertainties due to uncertainties inherent to basic data. However, in the UNSCEAR 2020/2021 Report, dose estimation with less uncertainties became possible as a broader range of knowledge was made available.

[Relevant parts in the Reports]

- WHO’s Preliminary dose assessment (prepared based on pages 40 to 45 (3. Results))
- UNSCEAR 2013 Report (prepared based on paragraphs 209 to 214 on pages 86 to 87, Annex A)
- UNSCEAR 2020/2021 Report (prepared based on paragraphs 166 to 169 on pages 64 to 66, ANNEX B)

Included in this reference material on March 31, 2023
Updated on March 31, 2024



Assessments by International Organizations

UNSCEAR 2020/2021 Report (1/8): Purpose of the Report

Purpose

- Summarize all of the information available and assess its implications for the findings and conclusions presented in the UNSCEAR 2013 Report.
- Validate and, where necessary, revise estimates of doses to the public, based on more detailed analyses of the available information, and update the commentary on the health implications.
- Set out an improved appraisal of the uncertainties and variabilities in the estimates of doses to the public.
- Where possible, better address issues and objectives not fully addressed in the UNSCEAR 2013 Report.

The UNSCEAR 2020/2021 Report Scientific Annex B titled "Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi Nuclear Power Station: implications of information published since the UNSCEAR 2013 Report" was prepared for the purpose of compiling all scientific knowledge concerning levels and effects of radiation exposure due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS that was available by the end of 2019, and for the purpose of assessing the influence on the content of the UNSCEAR 2013 Report. More specifically, the purpose is described as shown in the above figure.

On the other hand, the following three points are indicated as being out of the Report's intended purpose.

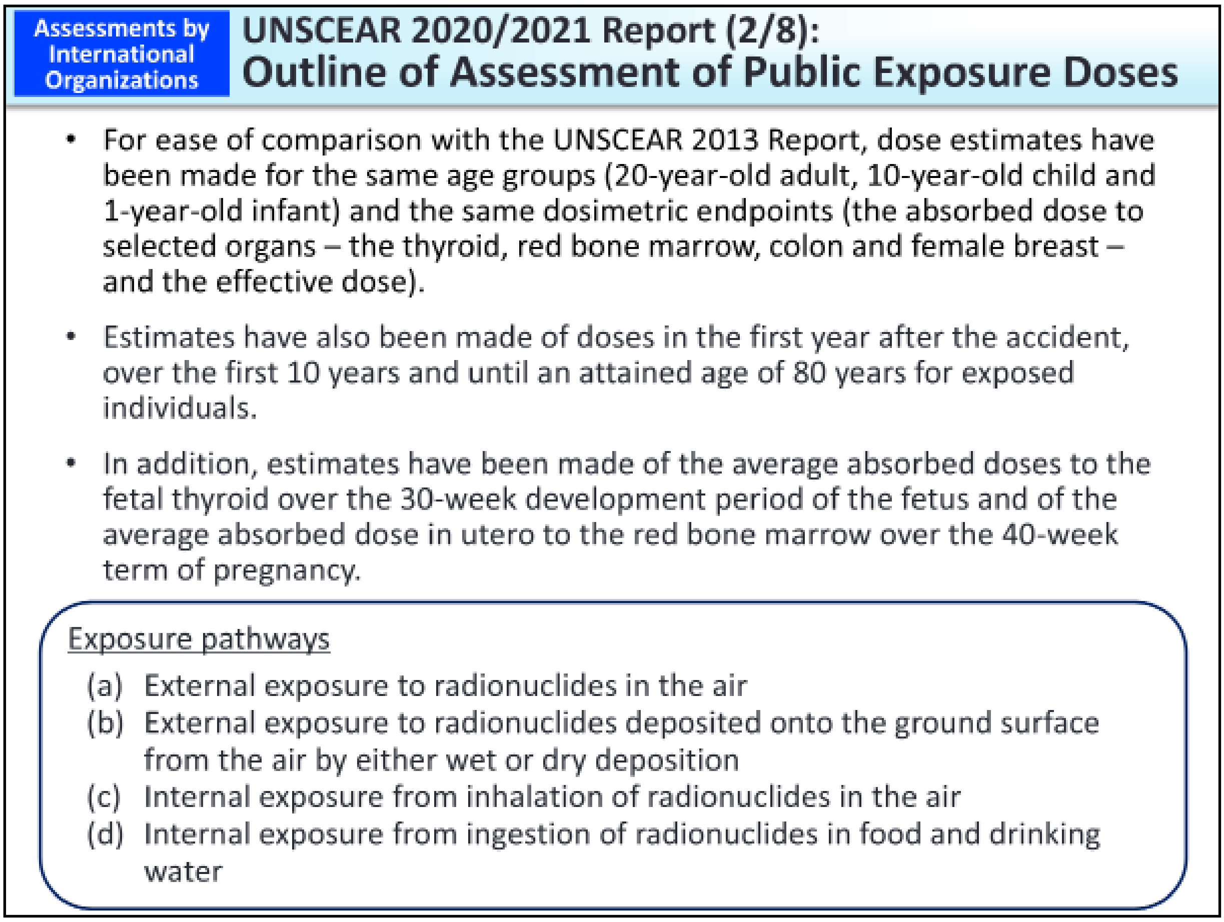
- The annex does not address policy issues with respect to human rights, public health protection, environmental protection, radiation protection, emergency preparedness and response, accident management, nuclear safety, radioactive waste management, prospective releases, and related issues.
- It does not intend to provide advice to local governments, the Government of Japan or to national and international bodies.
- The annex also does not address other effects (not associated with exposure to radiation) that can arise as a result of accidents, such as that at TEPCO's Fukushima Daiichi NPS, including distress and anxiety from, among other things, disruption of life, loss of homes and livelihoods, and social stigma, which can have major impacts on mental and social well-being.

The UNSCEAR 2020/2021 Report is an independent report, but is intended to be read together with the UNSCEAR 2013 Report and White Papers published thereafter. Accordingly, the Report does not contain information in full that can be obtained from these other documents.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraphs 7 to 8 on pages 6 to 7, ANNEX B)

Included in this reference material on March 31, 2023
Updated on March 31, 2024



Assessments by International Organizations

UNSCEAR 2020/2021 Report (2/8): Outline of Assessment of Public Exposure Doses

- For ease of comparison with the UNSCEAR 2013 Report, dose estimates have been made for the same age groups (20-year-old adult, 10-year-old child and 1-year-old infant) and the same dosimetric endpoints (the absorbed dose to selected organs – the thyroid, red bone marrow, colon and female breast – and the effective dose).
- Estimates have also been made of doses in the first year after the accident, over the first 10 years and until an attained age of 80 years for exposed individuals.
- In addition, estimates have been made of the average absorbed doses to the fetal thyroid over the 30-week development period of the fetus and of the average absorbed dose in utero to the red bone marrow over the 40-week term of pregnancy.

Exposure pathways

(a) External exposure to radionuclides in the air
(b) External exposure to radionuclides deposited onto the ground surface from the air by either wet or dry deposition
(c) Internal exposure from inhalation of radionuclides in the air
(d) Internal exposure from ingestion of radionuclides in food and drinking water

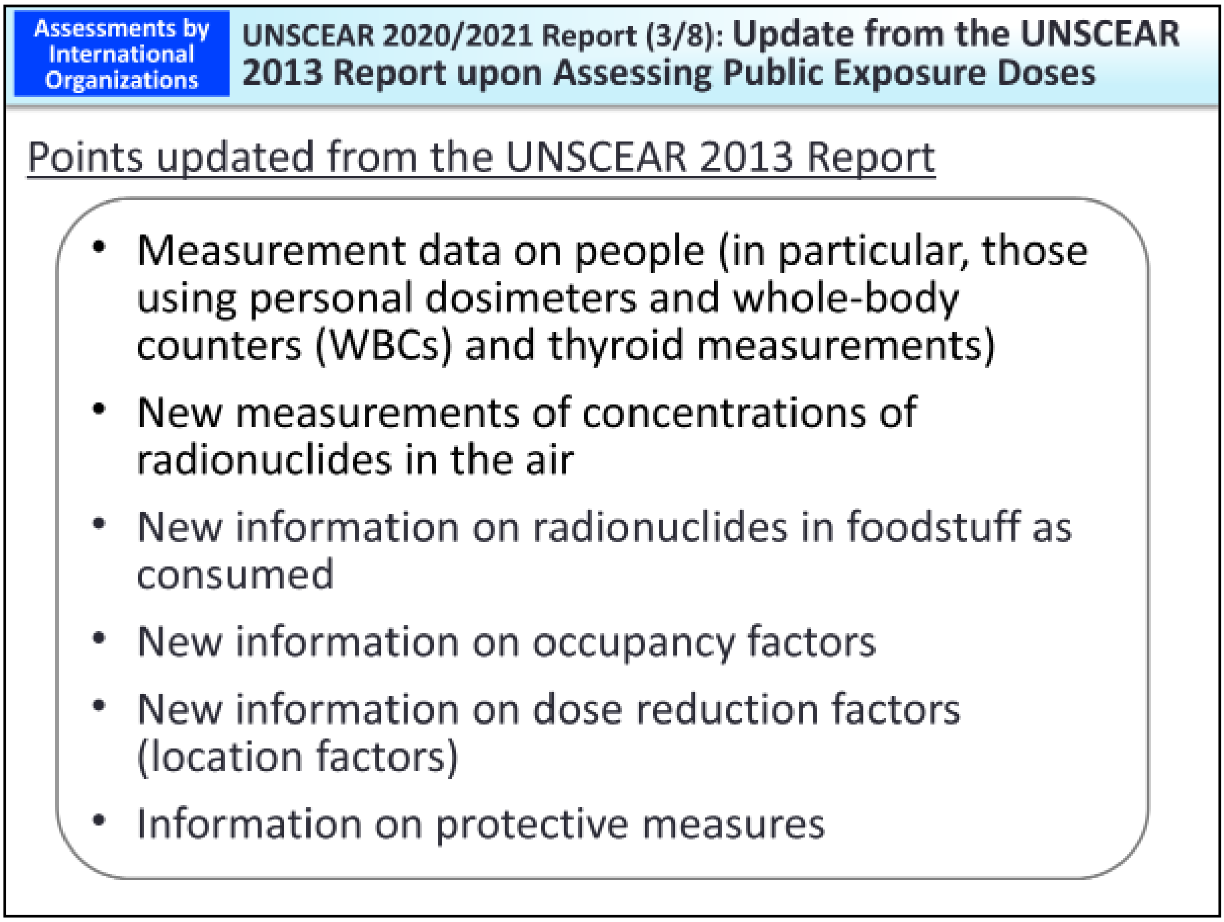
For ease of comparison with the UNSCEAR 2013 Report, dose estimates in the UNSCEAR 2020/2021 Report have been made for the same age groups and the same dosimetric endpoints. Concrete conditions are as shown above.

Dose assessment was conducted based on actual measurement data, while reflecting the latest scientific knowledge and progress that were published after the publication of the UNSCEAR 2013 Report up to the end of 2019 (p.196 of Vol. 1, “UNSCEAR 2020/2021 Report (3/8): Update from the UNSCEAR 2013 Report upon Assessing Public Exposure Doses”).

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraphs A4 to A5 on page 110, ANNEX B)

Included in this reference material on March 31, 2023
Updated on March 31, 2024



Assessments by International Organizations

UNSCEAR 2020/2021 Report (3/8): Update from the UNSCEAR 2013 Report upon Assessing Public Exposure Doses

Points updated from the UNSCEAR 2013 Report

- Measurement data on people (in particular, those using personal dosimeters and whole-body counters (WBCs) and thyroid measurements)
- New measurements of concentrations of radionuclides in the air
- New information on radionuclides in foodstuff as consumed
- New information on occupancy factors
- New information on dose reduction factors (location factors)
- Information on protective measures

It became possible to estimate doses based on enhanced measurement-based information by the use of the latest knowledge up to the end of 2019 that became available, following the publication of the UNSCEAR 2013 Report.

Numerous measurement campaigns have been carried out to assess individual doses from external exposure through surveys of daily activity patterns of residents, measurements of ambient dose rates and individual measurements using personal dosimeters. The UNSCEAR has made use of some of these data and other scientific results published in peer-reviewed journals to validate its estimates of doses from external exposure and in the development of a revised model to apply to the wider population. Furthermore, the UNSCEAR has validated its estimates of thyroid doses from internal exposure based on the results of the thyroid measurements covering more than 1,500 persons in total that were conducted in 2011.[1] Whole-body monitoring campaigns have also been carried out by national institutes, such as the Japan Atomic Energy Agency (JAEA) and the National Institute of Radiological Sciences (NIRS), and by universities, hospitals and municipalities, and the measured levels of radioactive cesium in the body were used to estimate doses from its intake by inhalation and ingestion.

Regarding environment monitoring data, part of the results of the monitoring conducted in Japan from March 2011 to March 2018 (data on dose rate in air, radionuclide ground deposition density, and radionuclide concentrations in air and in food and drinking water) was used to estimate doses. For example, measurement data regarding radionuclide concentrations in air while radionuclides were being discharged from Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS were limited for the initial stage of the accident and for the areas damaged by the tsunami, in particular, but data on radionuclide concentrations in suspended particles in air at seven locations in Japan from March to May 2011, which had not been available, were newly made available.

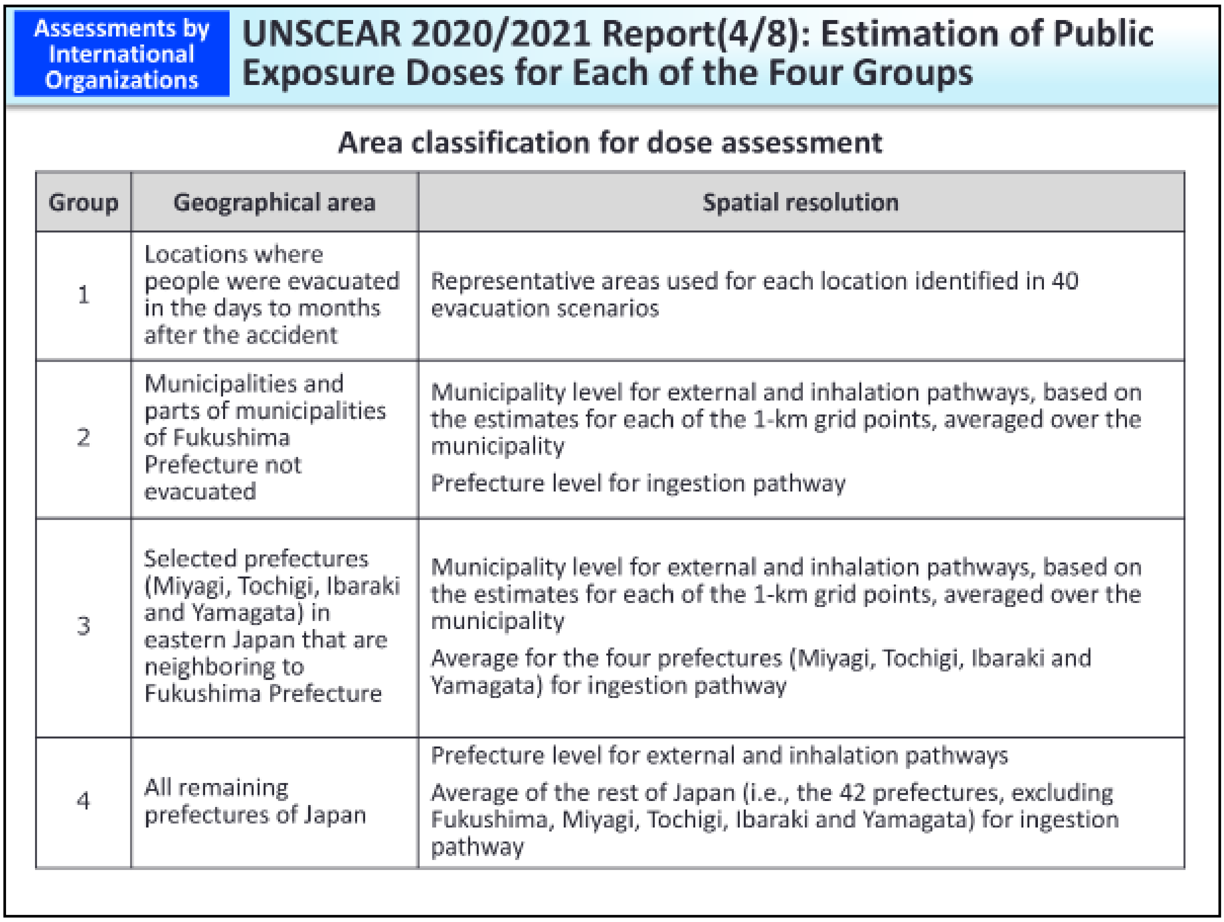
Regarding food and drinking water, in addition to their monitoring data, information on measurements of the radioactive cesium content in the whole daily diet sampled by the duplicate-diet or market-basket methods was updated.

1. The data for around 1,300 persons that are reported in papers etc., while omitting such data as those under conditions with high background levels, were analyzed.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraphs A11 and A13, A16, A17, A19, A20, A23, A29, and A31 on pages 112 to 122, ANNEX B)

Included in this reference material on March 31, 2023
Updated on March 31, 2024



Assessments by International Organizations

UNSCEAR 2020/2021 Report(4/8): Estimation of Public Exposure Doses for Each of the Four Groups

Area classification for dose assessment

Group	Geographical area	Spatial resolution
1	Locations where people were evacuated in the days to months after the accident	Representative areas used for each location identified in 40 evacuation scenarios
2	Municipalities and parts of municipalities of Fukushima Prefecture not evacuated	Municipality level for external and inhalation pathways, based on the estimates for each of the 1-km grid points, averaged over the municipality Prefecture level for ingestion pathway
3	Selected prefectures (Miyagi, Tochigi, Ibaraki and Yamagata) in eastern Japan that are neighboring to Fukushima Prefecture	Municipality level for external and inhalation pathways, based on the estimates for each of the 1-km grid points, averaged over the municipality Average for the four prefectures (Miyagi, Tochigi, Ibaraki and Yamagata) for ingestion pathway
4	All remaining prefectures of Japan	Prefecture level for external and inhalation pathways Average of the rest of Japan (i.e., the 42 prefectures, excluding Fukushima, Miyagi, Tochigi, Ibaraki and Yamagata) for ingestion pathway

Public exposure radiation due to the accident differs by location, and evacuees changed their locations over time. Therefore, in the UNSCEAR 2020/2021 Report, areas were classified into four groups for assessing public exposure doses, and the targets were further narrowed down depending on the exposure pathways.

For ease of comparison with the UNSCEAR 2013 Report, the classification is basically the same. However, the neighboring prefectures in Group 3 were changed from six (Iwate, Miyagi, Ibaraki, Tochigi, Gunma, and Chiba Prefectures) for the UNSCEAR 2013 Report to four (Miyagi, Yamagata, Ibaraki, and Tochigi Prefectures). This is due to differences in the spatial coverage of the most recent radionuclide deposition density information used in the dose assessment.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on Table 7 in paragraph 129 on pages 49 to 50, ANNEX B)

Included in this reference material on March 31, 2023
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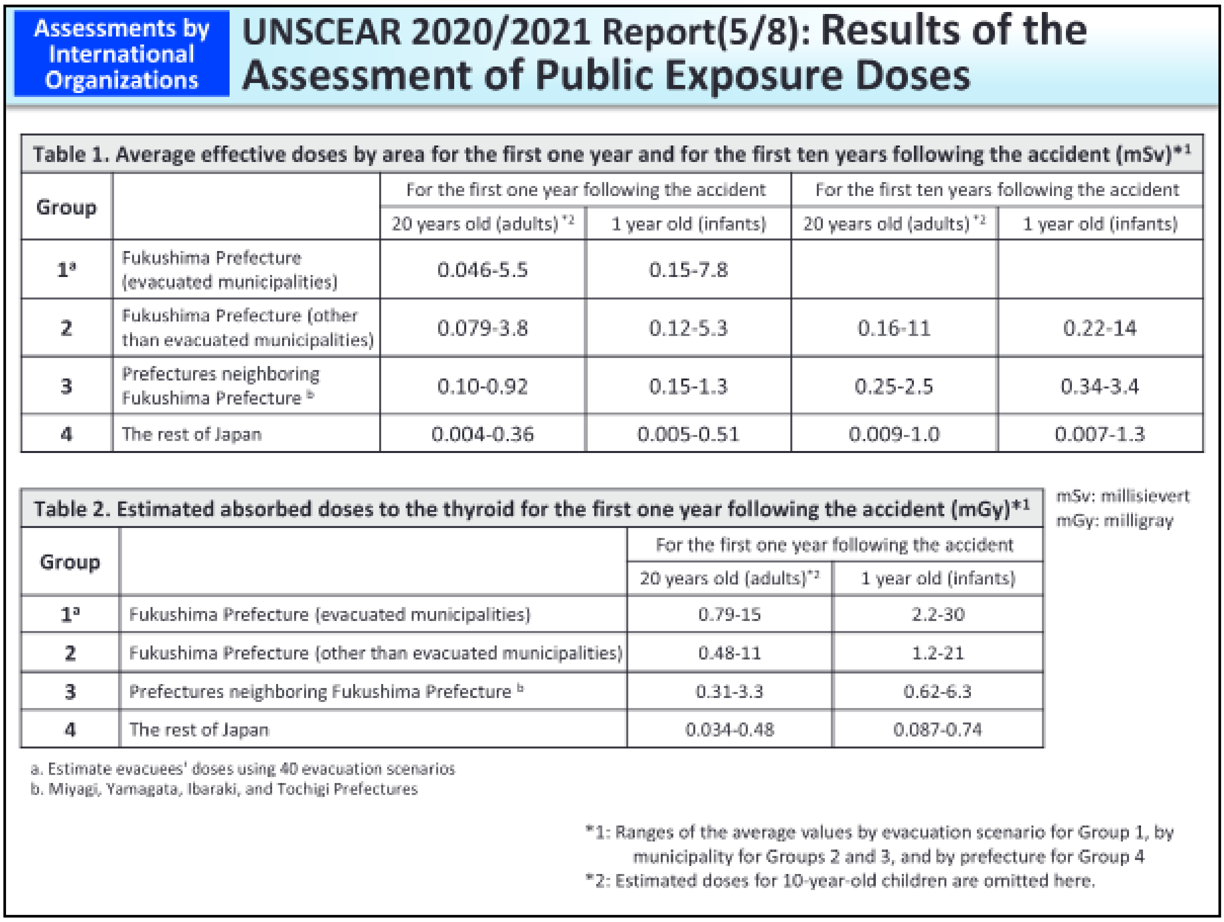

Assessments by International Organizations

UNSCEAR 2020/2021 Report(5/8): Results of the Assessment of Public Exposure Doses

Table 1. Average effective doses by area for the first one year and for the first ten years following the accident (mSv)*1

Group		For the first one year following the accident		For the first ten years following the accident	
		20 years old (adults) *2	1 year old (infants)	20 years old (adults) *2	1 year old (infants)
1ᵃ	Fukushima Prefecture (evacuated municipalities)	0.046-5.5	0.15-7.8		
2	Fukushima Prefecture (other than evacuated municipalities)	0.079-3.8	0.12-5.3	0.16-11	0.22-14
3	Prefectures neighboring Fukushima Prefecture ᵇ	0.10-0.92	0.15-1.3	0.25-2.5	0.34-3.4
4	The rest of Japan	0.004-0.36	0.005-0.51	0.009-1.0	0.007-1.3

Table 2. Estimated absorbed doses to the thyroid for the first one year following the accident (mGy)*1

Group		For the first one year following the accident	
		20 years old (adults)*2	1 year old (infants)
1ᵃ	Fukushima Prefecture (evacuated municipalities)	0.79-15	2.2-30
2	Fukushima Prefecture (other than evacuated municipalities)	0.48-11	1.2-21
3	Prefectures neighboring Fukushima Prefecture ᵇ	0.31-3.3	0.62-6.3
4	The rest of Japan	0.034-0.48	0.087-0.74

mSv: millisievert
mGy: milligray

a. Estimate evacuees' doses using 40 evacuation scenarios
b. Miyagi, Yamagata, Ibaraki, and Tochigi Prefectures

*1: Ranges of the average values by evacuation scenario for Group 1, by municipality for Groups 2 and 3, and by prefecture for Group 4
*2: Estimated doses for 10-year-old children are omitted here.

Table 1 shows the effective doses of residents in evacuated municipalities and residents in Fukushima Prefecture other than evacuated municipalities or in other prefectures, for both the first one year and the first ten years following the accident. Table 2 shows estimated absorbed doses to the thyroid of the same targeted residents for the first one year following the accident. For all these four groups, the average regional effective doses were lower than the estimated doses in the foregoing UNSCEAR 2013 Report (p.193 of Vol. 1, "Comparison of Reports (Assessment Results)").

Doses in the tables show those added to background doses due to natural sources of radiation, that is, estimated exposure doses from the radionuclides released into the environment due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS.

Ranges of doses show those of the average values among targeted groups by prefecture or by municipality in the targeted areas, or by evacuation scenario.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraph 158 on page 58 and paragraphs 166 to 169 on pages 64 to 66, ANNEX B)

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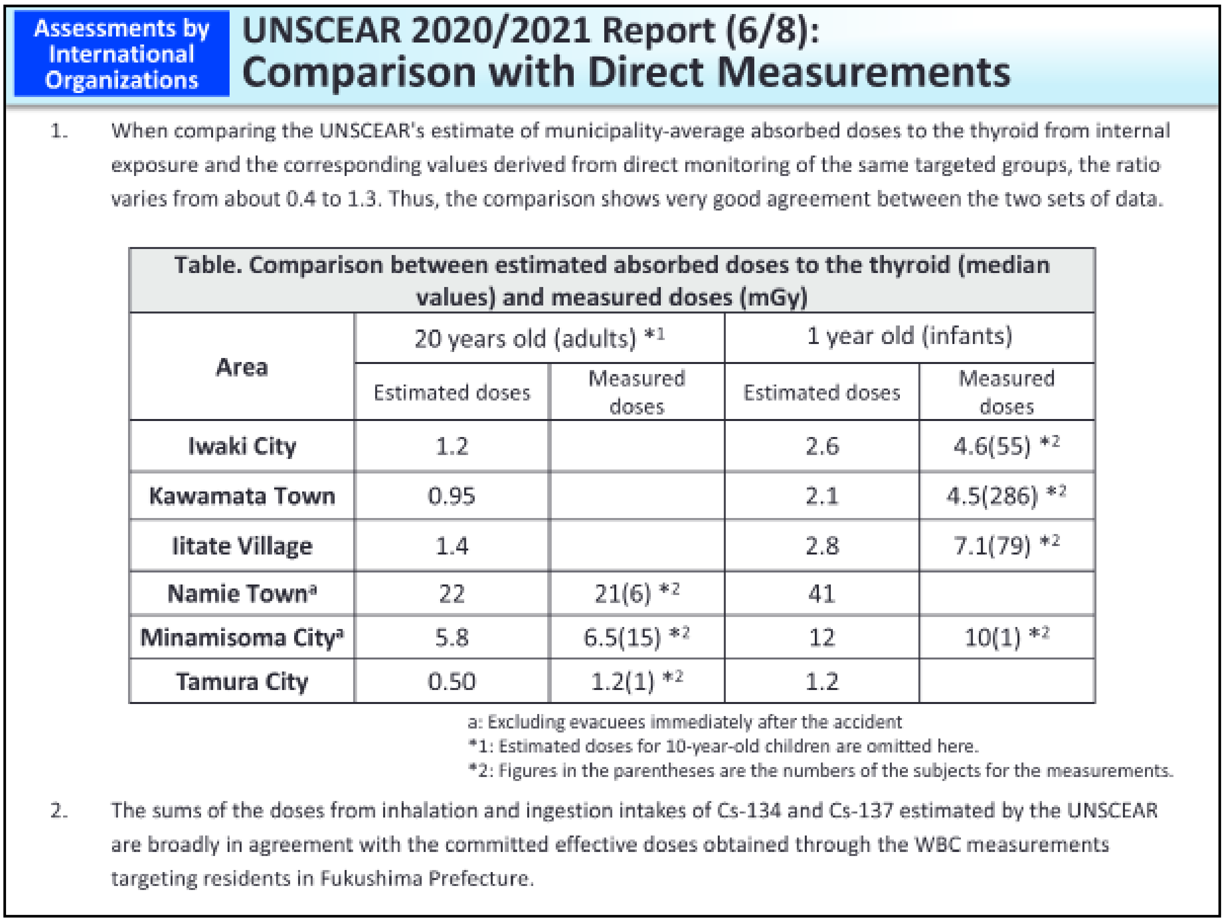

Assessments by International Organizations

UNSCEAR 2020/2021 Report (6/8): Comparison with Direct Measurements

1. When comparing the UNSCEAR's estimate of municipality-average absorbed doses to the thyroid from internal exposure and the corresponding values derived from direct monitoring of the same targeted groups, the ratio varies from about 0.4 to 1.3. Thus, the comparison shows very good agreement between the two sets of data.

Table. Comparison between estimated absorbed doses to the thyroid (median values) and measured doses (mGy)

Area	20 years old (adults) *1		1 year old (infants)	
	Estimated doses	Measured doses	Estimated doses	Measured doses
Iwaki City	1.2		2.6	4.6(55) *2
Kawamata Town	0.95		2.1	4.5(286) *2
Iitate Village	1.4		2.8	7.1(79) *2
Namie Town[a]	22	21(6) *2	41	
Minamisoma City[a]	5.8	6.5(15) *2	12	10(1) *2
Tamura City	0.50	1.2(1) *2	1.2	

a: Excluding evacuees immediately after the accident

*1: Estimated doses for 10-year-old children are omitted here.

*2: Figures in the parentheses are the numbers of the subjects for the measurements.

2. The sums of the doses from inhalation and ingestion intakes of Cs-134 and Cs-137 estimated by the UNSCEAR are broadly in agreement with the committed effective doses obtained through the WBC measurements targeting residents in Fukushima Prefecture.

A comparison has been made between estimated doses in the UNSCEAR 2020/2021 Report and measured doses through thyroid measurements conducted in Fukushima Prefecture immediately after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. Additionally, a comparison with the results of the WBC measurements of Cs-134 and Cs-137 has also been made.

As shown in the Table above, these measured data and estimates by the UNSCEAR are almost the same.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraph A136 on pages 180 to 181 and paragraph A140 on page 183, ANNEX B)

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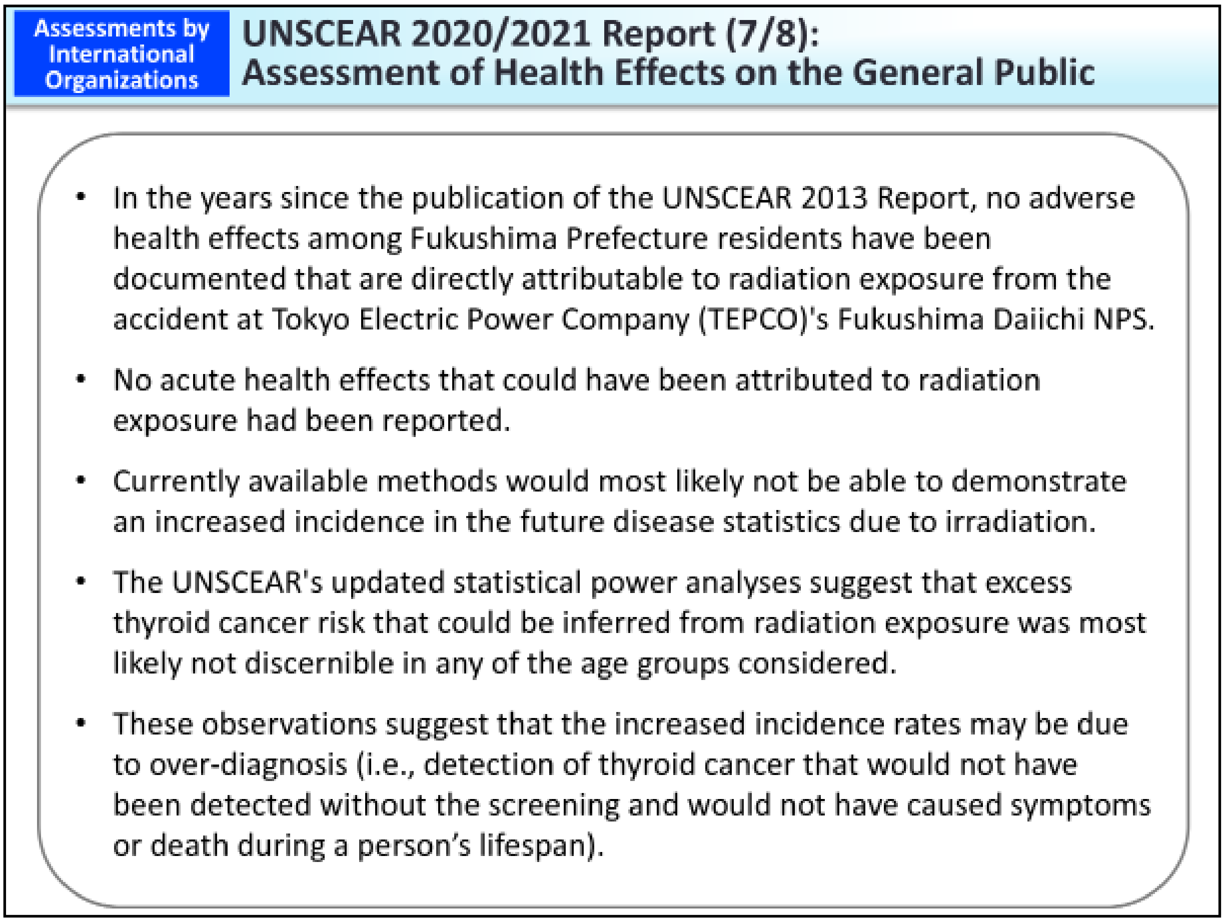
Updated on March 31, 2024



Assessments by International Organizations

UNSCEAR 2020/2021 Report (7/8): Assessment of Health Effects on the General Public

- In the years since the publication of the UNSCEAR 2013 Report, no adverse health effects among Fukushima Prefecture residents have been documented that are directly attributable to radiation exposure from the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS.
- No acute health effects that could have been attributed to radiation exposure had been reported.
- Currently available methods would most likely not be able to demonstrate an increased incidence in the future disease statistics due to irradiation.
- The UNSCEAR's updated statistical power analyses suggest that excess thyroid cancer risk that could be inferred from radiation exposure was most likely not discernible in any of the age groups considered.
- These observations suggest that the increased incidence rates may be due to over-diagnosis (i.e., detection of thyroid cancer that would not have been detected without the screening and would not have caused symptoms or death during a person's lifespan).

The UNSCEAR assessed public health effects as indicated above based on its exposure dose assessment.

A substantial number of thyroid cancers have been detected among exposed children. However, the excess does not appear to be associated with radiation exposure, but rather a result of the application of highly sensitive ultrasound screening procedures. The reasons are as follows:

(a) no excess of thyroid cancer has been observed in those exposed before age 5 in Fukushima Prefecture, in contrast to the large excess observed in the same age group exposed as a result of the Chornobyl accident; and

(b) thyroid cancers were observed within 1 to 3 years after exposure following the accident in Fukushima Prefecture rather than beginning 4 to 5 years after exposure as in Chornobyl and other radiation studies.

There has been no credible evidence of excess congenital anomalies, stillbirths, preterm deliveries or low birthweights related to radiation exposure. Increases in the incidence of cardiovascular and metabolic conditions have been observed among those evacuated following the accident but are probably associated with concomitant social and lifestyle changes and are not attributable to radiation exposure.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraphs 213, 215, and 225 on pages 84 to 88 and paragraphs 244 to 248 on pages 96 to 97, ANNEX B)

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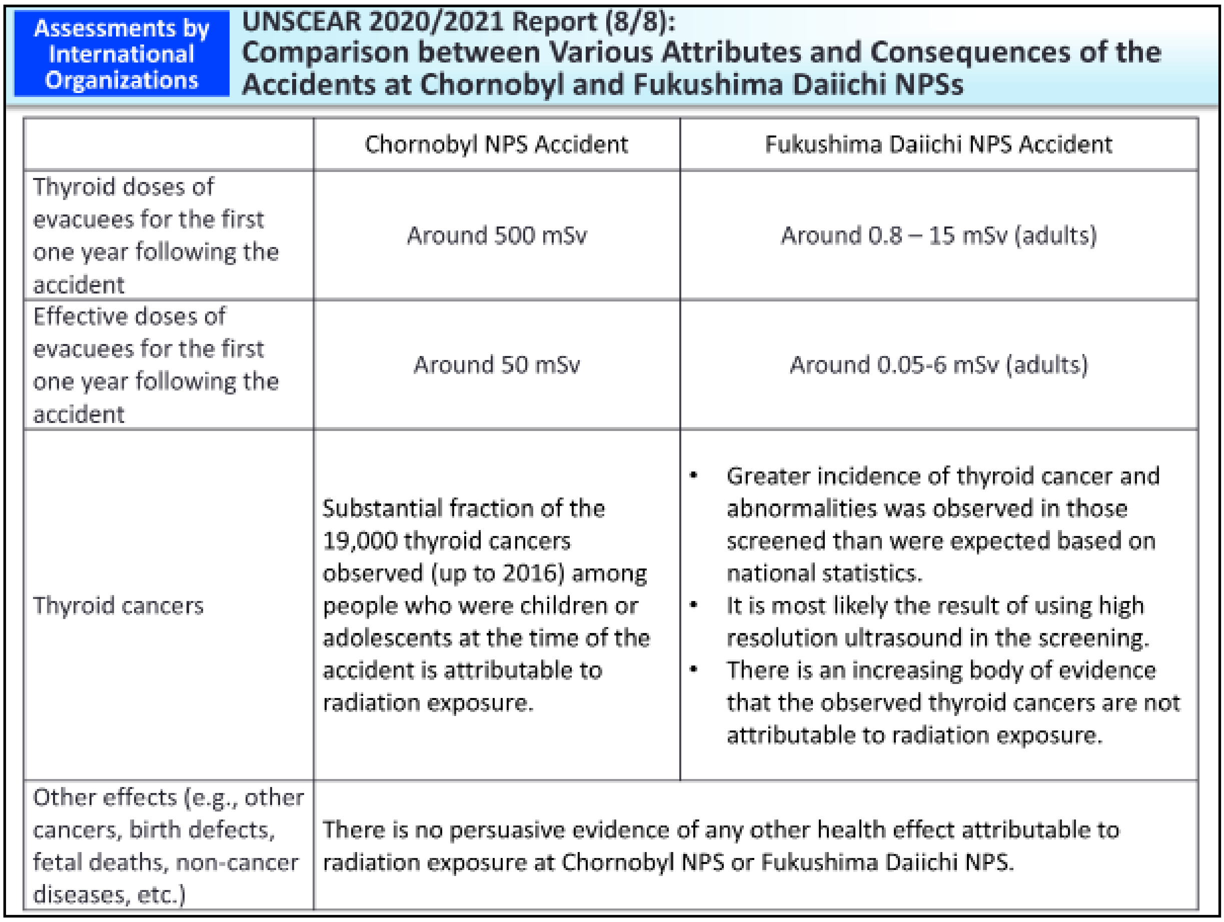

Assessments by International Organizations

UNSCEAR 2020/2021 Report (8/8): Comparison between Various Attributes and Consequences of the Accidents at Chornobyl and Fukushima Daiichi NPSs

	Chornobyl NPS Accident	Fukushima Daiichi NPS Accident
Thyroid doses of evacuees for the first one year following the accident	Around 500 mSv	Around 0.8 – 15 mSv (adults)
Effective doses of evacuees for the first one year following the accident	Around 50 mSv	Around 0.05-6 mSv (adults)
Thyroid cancers	Substantial fraction of the 19,000 thyroid cancers observed (up to 2016) among people who were children or adolescents at the time of the accident is attributable to radiation exposure.	• Greater incidence of thyroid cancer and abnormalities was observed in those screened than were expected based on national statistics. • It is most likely the result of using high resolution ultrasound in the screening. • There is an increasing body of evidence that the observed thyroid cancers are not attributable to radiation exposure.
Other effects (e.g., other cancers, birth defects, fetal deaths, non-cancer diseases, etc.)	There is no persuasive evidence of any other health effect attributable to radiation exposure at Chornobyl NPS or Fukushima Daiichi NPS.	

The UNSCEAR 2020/2021 Report compiles major characteristics and features of the accidents at Fukushima Daiichi NPS and Chornobyl NPS, as well as estimated exposure doses and health effects due to these accidents regarding radiation workers and the general public. Results of the comparison concerning some items are shown in the table above.

The Report states that the consequences of the accident at Fukushima Daiichi NPS were much milder than those at Chornobyl NPS. As one of the reasons, it points out that the reactors at Fukushima Daiichi NPS had specifically designed containments within which most of the radionuclides released from the molten fuel were retained; by contrast, the reactor at Chornobyl NPS did not have a containment and the core was directly exposed to the atmosphere as a result of the explosion that occurred at the beginning of the accident. Additionally, cited major reasons include the rates of dispersed radionuclides deposited over the ocean and those deposited over the land mass, the transfer of radionuclides to agricultural products, the binding or fixation of radioactive cesium in soil, protective measures in respect of people and foodstuffs after the accidents, and differences in the regulations.

[Relevant parts in the Report]

- UNSCEAR 2020/2021 Report (prepared based on paragraph B1 on pages 189 to 198, ANNEX B)

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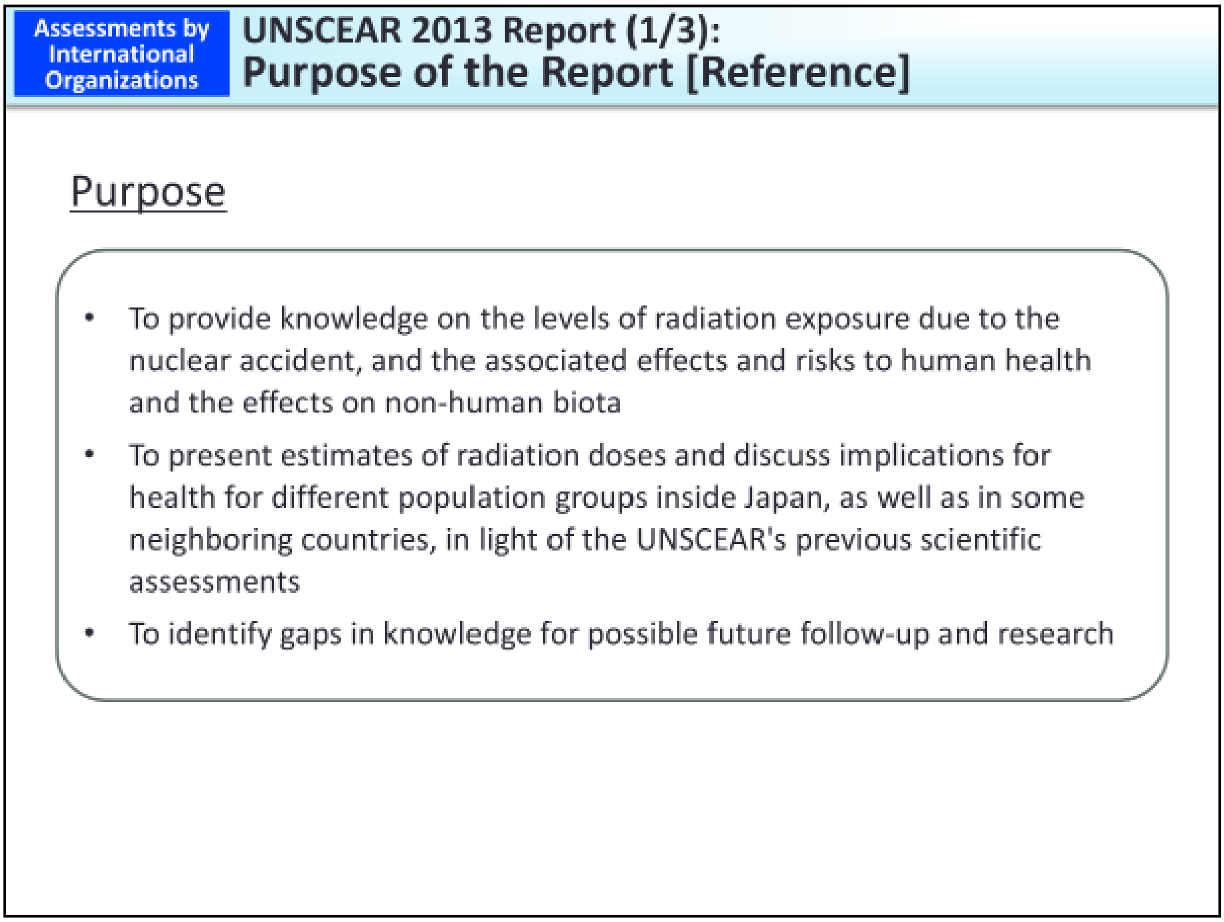

Assessments by International Organizations

UNSCEAR 2013 Report (1/3): Purpose of the Report [Reference]

Purpose

- To provide knowledge on the levels of radiation exposure due to the nuclear accident, and the associated effects and risks to human health and the effects on non-human biota
- To present estimates of radiation doses and discuss implications for health for different population groups inside Japan, as well as in some neighboring countries, in light of the UNSCEAR's previous scientific assessments
- To identify gaps in knowledge for possible future follow-up and research

The UNSCEAR 2013 Report “Volume I, Scientific Annex A: Levels and Effects of Radiation Exposure due to the Nuclear Accident after the 2011 Great East-Japan Earthquake and Tsunami” was prepared for the following three purposes as shown above.

As stated in the Introduction of the Report, at its fifty-eighth meeting (in May 2011), the UNSCEAR decided to carry out, once sufficient information was available, an assessment of the levels of exposure and radiation risks attributable to the nuclear power plant accident following the great east-Japan earthquake and tsunami, and published the Report in April 2014.

The Report is based on prefectural data and government organizations’ data released in Japan up to September 2012, and other data and documents provided by UN member countries other than Japan and by international organizations such as the International Atomic Energy Agency (IAEA) and the WHO. Additionally, new important information obtained by the end of 2013 was also taken into consideration to the extent possible.

The outline of the assessment of exposure doses in the UNSCEAR 2013 Report is as follows.

- The assessment was based on measurement data as far as possible.
- Doses that the public received for the first one year after the accident were assessed.
- The assessment targeted 20-year-old adults, 10-year-old children and 1-year-old infants
- Projections were also made of doses to be received over the first 10 years and up to age 80 years.
- Models were used, with realistic assumptions, to provide an objective evaluation of the situation.
- Protective actions taken during the first year were considered and the doses averted by them were estimated.

[Relevant parts in the Report]

- UNSCEAR 2013 Report (prepared based on paragraph 8 on page 27, paragraphs 3 to 4 on pages 25 to 26, and paragraph 12 on page 27, Scientific Annex A)

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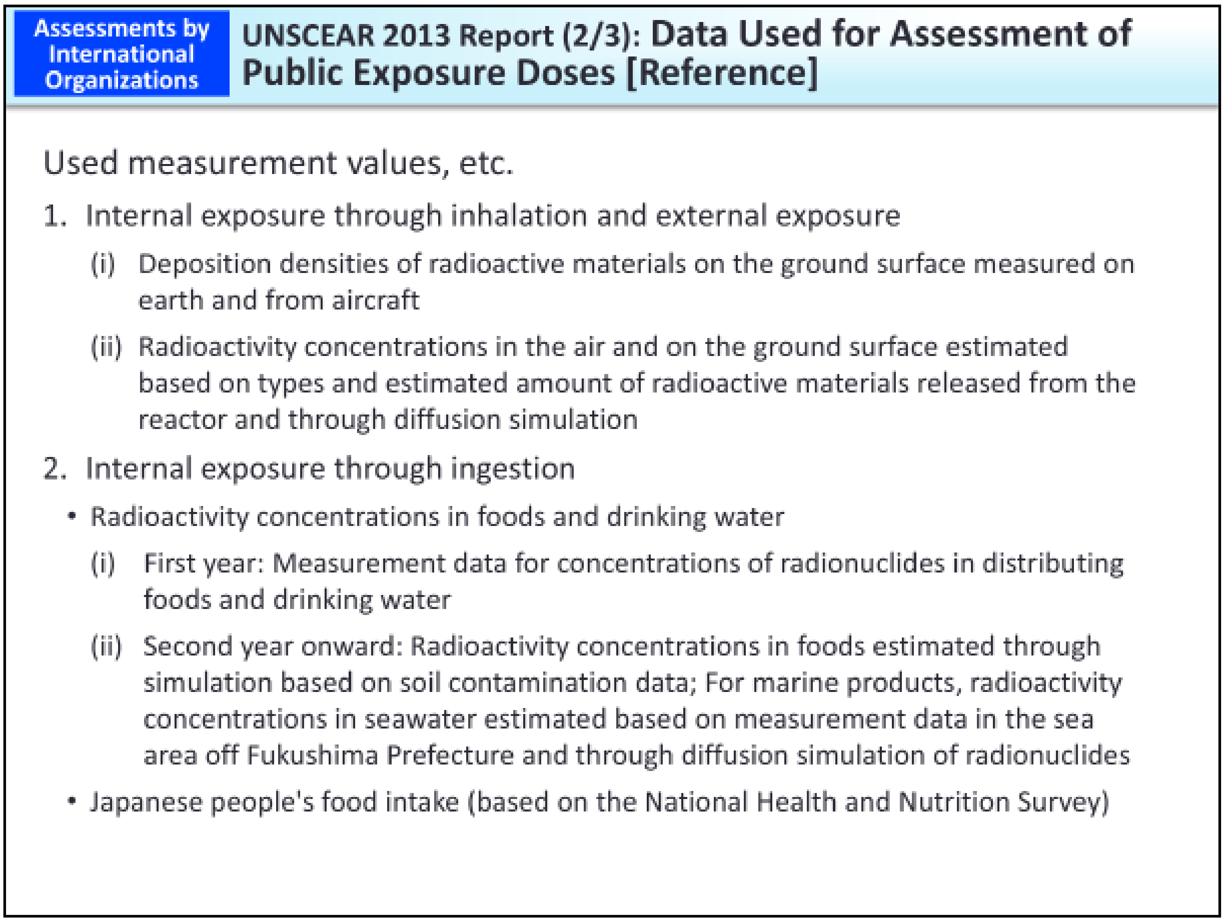

Assessments by International Organizations

UNSCEAR 2013 Report (2/3): Data Used for Assessment of Public Exposure Doses [Reference]

Used measurement values, etc.

1. Internal exposure through inhalation and external exposure
   - (i) Deposition densities of radioactive materials on the ground surface measured on earth and from aircraft
   - (ii) Radioactivity concentrations in the air and on the ground surface estimated based on types and estimated amount of radioactive materials released from the reactor and through diffusion simulation
2. Internal exposure through ingestion
   - Radioactivity concentrations in foods and drinking water
     - (i) First year: Measurement data for concentrations of radionuclides in distributing foods and drinking water
     - (ii) Second year onward: Radioactivity concentrations in foods estimated through simulation based on soil contamination data; For marine products, radioactivity concentrations in seawater estimated based on measurement data in the sea area off Fukushima Prefecture and through diffusion simulation of radionuclides
   - Japanese people's food intake (based on the National Health and Nutrition Survey)

Out of the radioactive materials released due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, Iodine-131, Cesium-134, and Cesium-137 are considered to have mainly contributed to people's exposure.

Doses can be assessed most reliably through the measurement using personal dosimeters in the case of external exposure and the measurement using whole-body counters in the case of internal exposure. Such data was partially available regarding the accident at the NPS but was not sufficient for calculating internal exposure doses for all people in Fukushima Prefecture as a whole and in other prefectures.

Therefore, the UNSCEAR conducted dose estimation based on the data indicated above and used other measurement data for verifying the calculation results.

[Relevant parts in the reports]

- UNSCEAR 2013 Report (prepared based on paragraphs 67 to 78 on pages 48 to 50, Scientific Annex A, Appendix A, and "IV. TRANSPORT AND DISPERSION IN THE OCEAN" of Appendix B)

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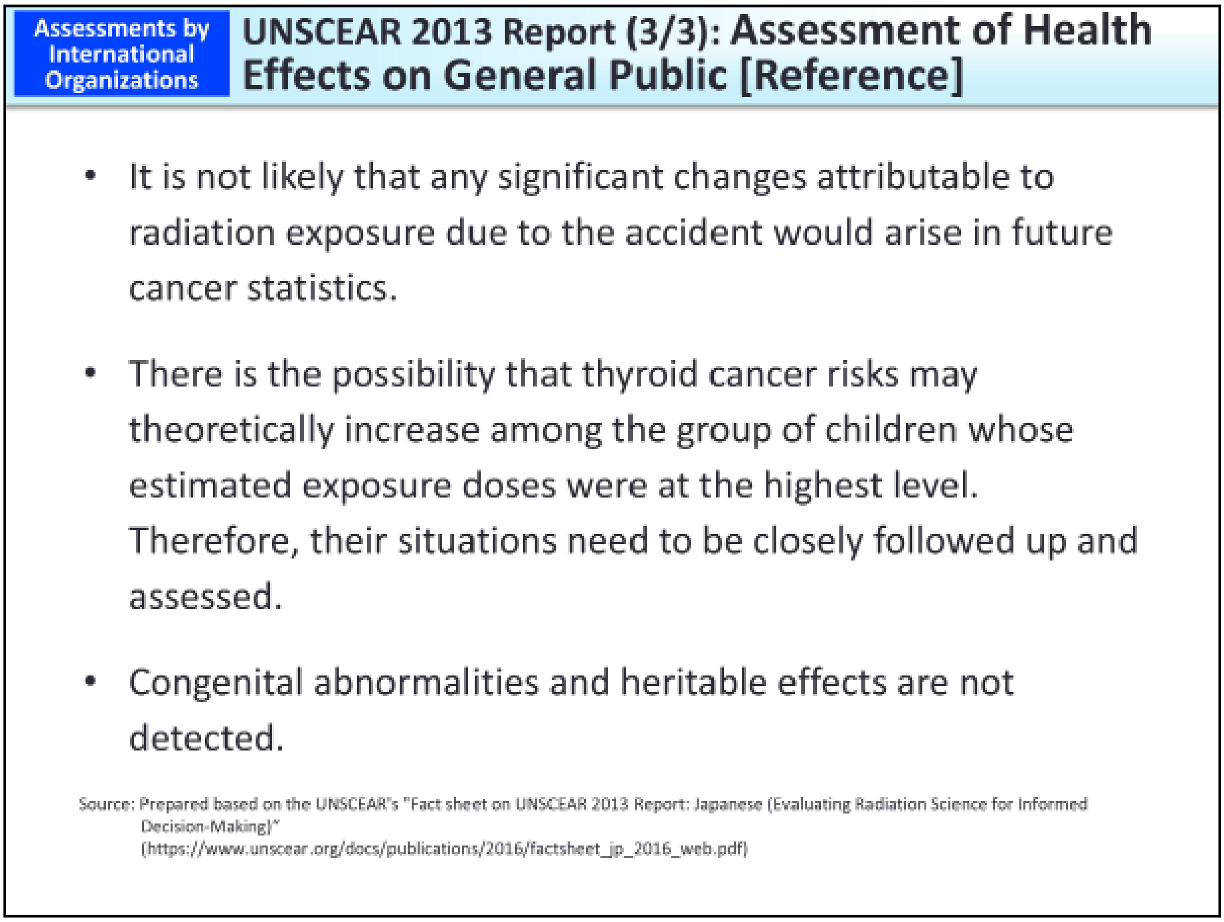

Assessments by International Organizations

UNSCEAR 2013 Report (3/3): Assessment of Health Effects on General Public [Reference]

- It is not likely that any significant changes attributable to radiation exposure due to the accident would arise in future cancer statistics.
- There is the possibility that thyroid cancer risks may theoretically increase among the group of children whose estimated exposure doses were at the highest level. Therefore, their situations need to be closely followed up and assessed.
- Congenital abnormalities and heritable effects are not detected.

Source: Prepared based on the UNSCEAR's "Fact sheet on UNSCEAR 2013 Report: Japanese (Evaluating Radiation Science for Informed Decision-Making)"
(https://www.unscear.org/docs/publications/2016/factsheet_jp_2016_web.pdf)

The UNSCEAR assessed public health effects as indicated above based on its exposure dose assessment.

Assessment concerning risks of specific types of cancer and other diseases is as follows.

- Thyroid cancer: Most of the doses were in a range for which an excess incidence of thyroid cancer due to radiation exposure has not been confirmed. However, absorbed doses to the thyroid towards the upper bounds could lead to a discernible increase in the incidence of thyroid cancer among sufficiently large population groups. Nevertheless, the occurrence of a large number of radiation induced thyroid cancers in Fukushima Prefecture—such as occurred after the Chornobyl NPS Accident—can be discounted, because absorbed doses to the thyroid after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS were substantially lower than those after the Chornobyl NPS Accident.
- Leukemia: The UNSCEAR considered the risk to those exposed as fetus embryo during pregnancy, and during infancy and childhood, and concluded that no discernible increases in the incidence of leukemia among those groups are expected.
- Breast cancer: The UNSCEAR considered the risk to those exposed at the stage of youth, and concluded that no discernible increases in the incidence of breast cancer among those groups are expected.
- Exposure during pregnancy: The UNSCEAR does not expect any increases in spontaneous abortion, miscarriages, perinatal mortality, congenital effects or cognitive impairment resulting from exposure during pregnancy, nor does it expect any discernible increases in heritable diseases among the descendants of those exposed from the accident at TEPCO's Fukushima Daiichi NPS.

The UNSCEAR states that their assessment of public exposure doses due to radioactive materials from the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS contains uncertainties because the assessment was premised on certain assumptions based on insufficient knowledge and information.

[Relevant parts in the Report]

- UNSCEAR 2013 Report (prepared based on paragraphs 220 and 222 to 224 on page 89, Scientific Annex A)

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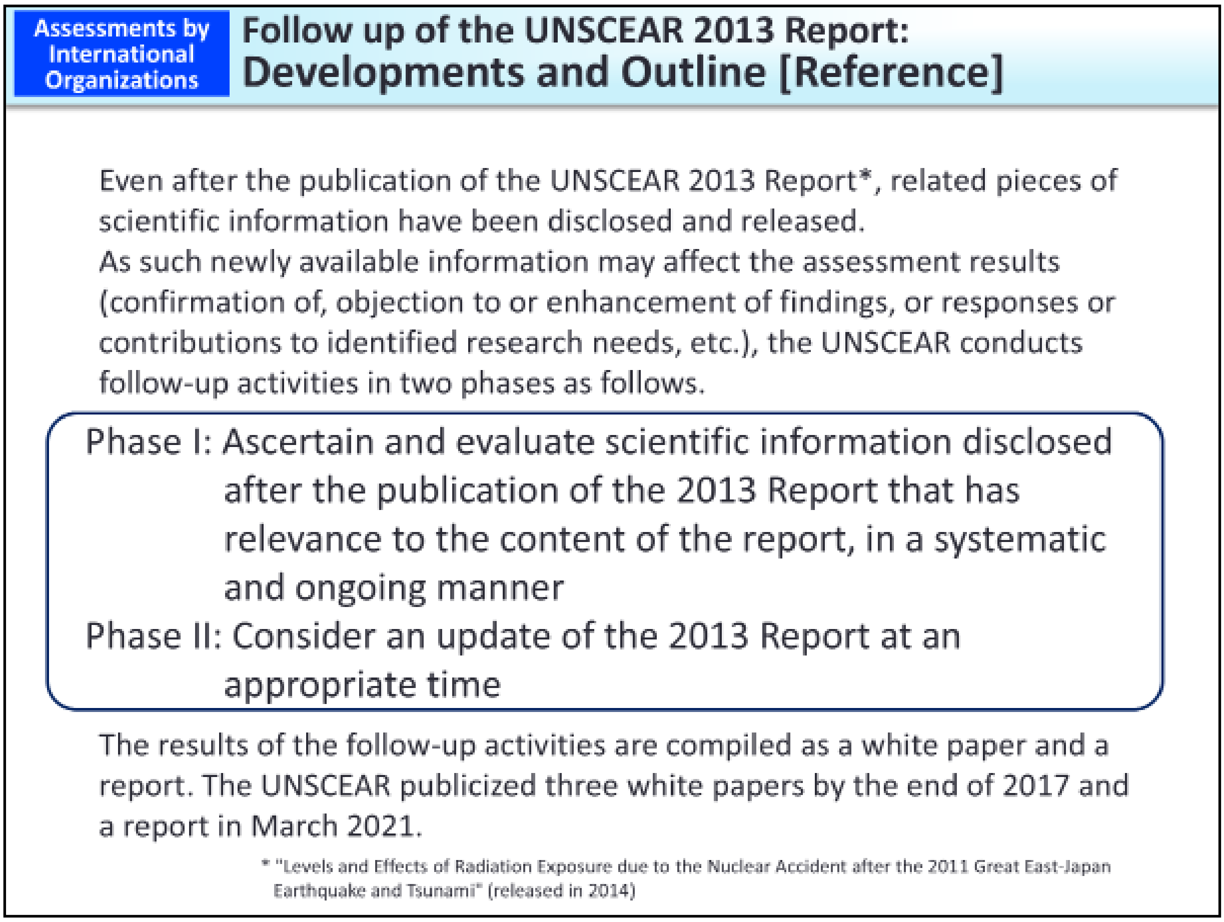

Assessments by International Organizations

Follow up of the UNSCEAR 2013 Report: Developments and Outline [Reference]

Even after the publication of the UNSCEAR 2013 Report*, related pieces of scientific information have been disclosed and released.
As such newly available information may affect the assessment results (confirmation of, objection to or enhancement of findings, or responses or contributions to identified research needs, etc.), the UNSCEAR conducts follow-up activities in two phases as follows.

Phase I: Ascertain and evaluate scientific information disclosed after the publication of the 2013 Report that has relevance to the content of the report, in a systematic and ongoing manner
Phase II: Consider an update of the 2013 Report at an appropriate time

The results of the follow-up activities are compiled as a white paper and a report. The UNSCEAR publicized three white papers by the end of 2017 and a report in March 2021.

* "Levels and Effects of Radiation Exposure due to the Nuclear Accident after the 2011 Great East-Japan Earthquake and Tsunami" (released in 2014)

New pieces of information released since the publication of the UNSCEAR 2013 Report may affect the assessment results of the UNSCEAR (confirmation of, objection to or enhancement of findings, or responses or contributions to identified research needs, etc.). Therefore, the UNSCEAR conducted ongoing follow-up activities to collect and evaluate such pieces of information systematically. The results of the follow-up activities have been compiled as three white papers published by the end of 2017 and as the 2020/2021 Report published in March 2021 (p.191 of Vol. 1, "Changes in International Organizations' Assessments").

These White Papers fairly analyze new pieces of scientific information from the perspective of whether they materially affect the conclusions of the 2013 Report or whether they respond to research needs identified in the 2013 Report. A total of over 300 publications released since October 2012 was reviewed in these three White Papers.

Major subjects include the following.

- Release and diffusion of radioactive materials in the air and in water areas
- Transfer of radionuclides in land areas and freshwater environment (newly added in the 2016 White Paper)
- Evaluation of public exposure and occupational exposure
- Health effects on radiation workers and general public
- Doses and effects for non-human biota

Source

- "Fukushima 2015 White Paper," UNSCEAR
  https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2015_WP.pdf
- "Fukushima 2016 White Paper," UNSCEAR
  https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2016_WP.pdf
- "Fukushima 2017 White Paper," UNSCEAR
  https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2017_WP.pdf
- "UNSCEAR 2020/2021 FUKUSHIMA REPORT," UNSCEAR
  https://www.unscear.org/unscear/uploads/documents/publications/UNSCEAR_2020_21_Annex-B-CORR.pdf

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

Assessments by International Organizations

Follow up of the UNSCEAR 2013 Report: Major Conclusions [Reference]

The 2015 White Paper, 2016 White Paper and 2017 White Paper publicized so far concluded that there were no newly released publications that would materially affect the main findings in, or challenge the major assumptions of, the 2013 Report. These White Papers also selected and compiled publications that would contribute to research needs identified in the 2013 Report. The conclusions of the latest 2017 White Paper (publicized in October 2017) are summarized as follows.

Conclusions (from the Executive Summary of the 2017 White Paper)

- A large proportion of new publications that the UNSCEAR reviewed have again confirmed the main assumptions and findings of the 2013 Report.
- None of the publications have materially affected the main findings in, or challenged the major assumptions of, the 2013 Report.
- A few have been identified for which further analysis or more conclusive evidence from additional research is needed.
- On the basis of the material reviewed, the Committee sees no need, at the current time, to make any change to its assessment or its conclusions. However, several of the research needs identified by the Committee have yet to be addressed fully by the scientific community.

Source: "DEVELOPMENTS SINCE THE 2013 UNSCEAR REPORT ON THE LEVELS AND EFFECTS OF RADIATION EXPOSURE DUE TO THE NUCLEAR ACCIDENT FOLLOWING THE GREAT EAST-JAPAN EARTHQUAKE AND TSUNAMI; A 2017 white paper to guide the Scientific Committee's future programme of work," UNSCEAR

The 2015 White Paper and 2016 White Paper concluded that there were no newly released publications that would materially affect the main findings in, or challenge the major assumptions of, the 2013 Report.

The 2017 White Paper publicized in October 2017 also concluded that a large proportion of new publications that the UNSCEAR reviewed have again confirmed the main assumptions and findings of the 2013 Report and that none of the publications have materially affected the main findings in, or challenged the major assumptions of, the 2013 Report.

On the other hand, the 2017 White Paper suggests that some publications may potentially challenge the findings of the 2013 Report but states that there are questions over some of the data presented therein that need to be resolved before definitive conclusions can be drawn.

Additionally, it is pointed out that several of the research needs identified in the 2013 Report have yet to be addressed fully as peer-reviewed documents by the scientific community.

On the basis of the material reviewed, the Committee found no need to make any change to its most important conclusions of its 2013 Report, as of the time of the publication of the 2017 White Paper.

[Relevant parts in the reports]

- UNSCEAR 2017 White Paper (extracted from paragraphs 137 to 143 on pages 34 to 38)

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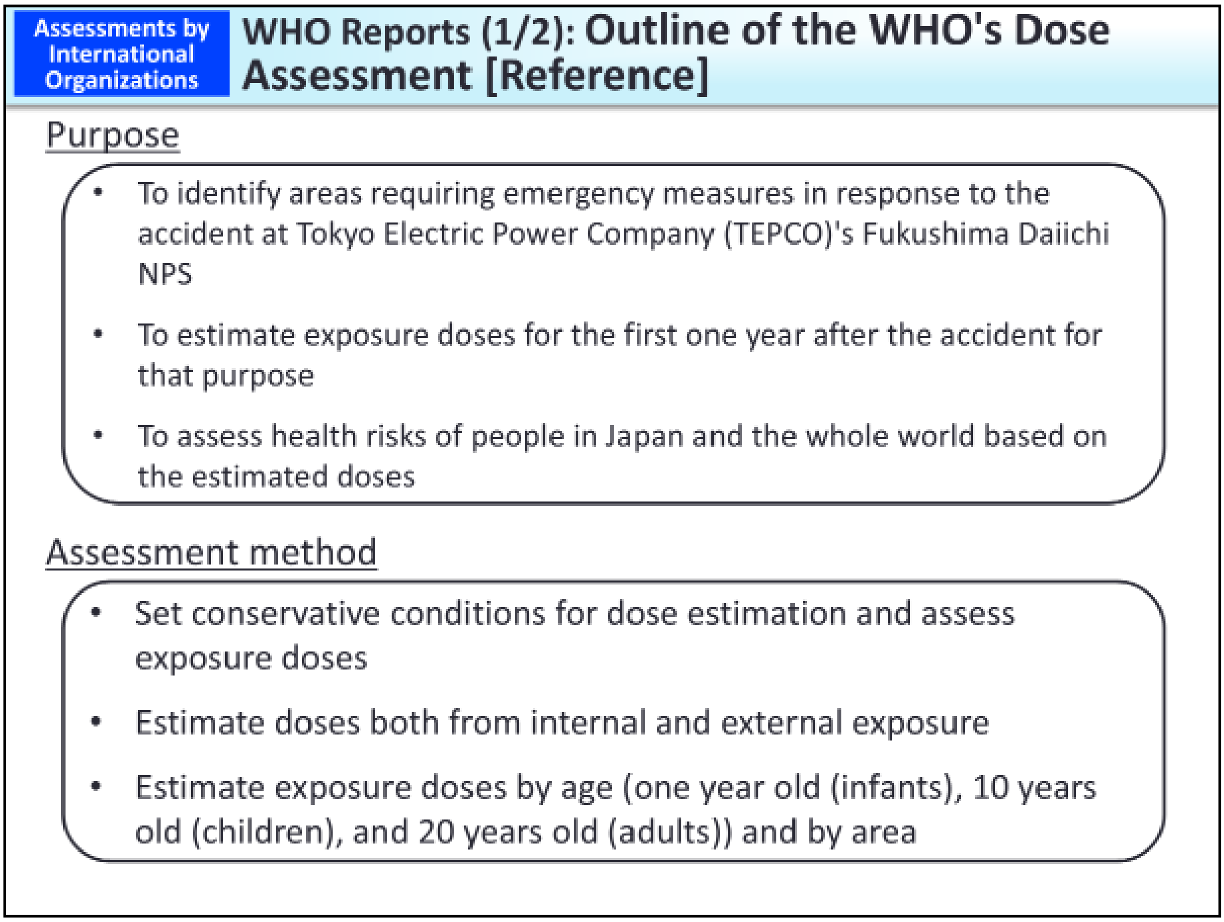

Assessments by International Organizations

WHO Reports (1/2): Outline of the WHO's Dose Assessment [Reference]

Purpose

- To identify areas requiring emergency measures in response to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS
- To estimate exposure doses for the first one year after the accident for that purpose
- To assess health risks of people in Japan and the whole world based on the estimated doses

Assessment method

- Set conservative conditions for dose estimation and assess exposure doses
- Estimate doses both from internal and external exposure
- Estimate exposure doses by age (one year old (infants), 10 years old (children), and 20 years old (adults)) and by area

The WHO is an organization responsible for assessing health risks posed by radiation in an emergency. Therefore, after the accident at TEPCO’s Fukushima Daiichi NPS, it conducted assessment of exposure doses for the first one year regarding people in Japan and the whole world for the purpose of identifying areas and groups of people for which emergency measures should be taken.

The WHO assessed doses due to exposure to radiation via four pathways: (i) external exposure from the ground surface, (ii) external exposure from radioactive plumes (p.29 of Vol. 1, “Effects of Reactor Accidents”), (iii) internal exposure through inhalation, and (iv) internal exposure through ingestion. Doses due to external exposure via (i) and (ii) and internal exposure via (iii) were estimated through simulation based on information on contamination density on the soil surface as of September 2011, while doses due to internal exposure via (iv) were estimated based on the measurement values for foods and drinking water.

People’s exposure doses are to be calculated by summing up estimated values for (i) to (iv), but in order to avoid underestimation, the WHO set conservative assumptions and calculated the largest exposure doses imaginable. Concretely, the WHO adopted the preconditions that protective measures such as deliberate evacuation, sheltering indoors, or shipping restrictions on foods were not at all taken.

As exposure doses vary by area and age, the WHO estimated doses by dividing areas into Fukushima Prefecture, neighboring prefectures (Chiba, Gunma, Ibaraki, Miyagi and Tochigi Prefectures), the rest of Japan, neighboring countries and the rest of the world, and by dividing people by age into those aged one year old (infants), 10 years old (children), and 20 years old (adults) at the time of the accident.

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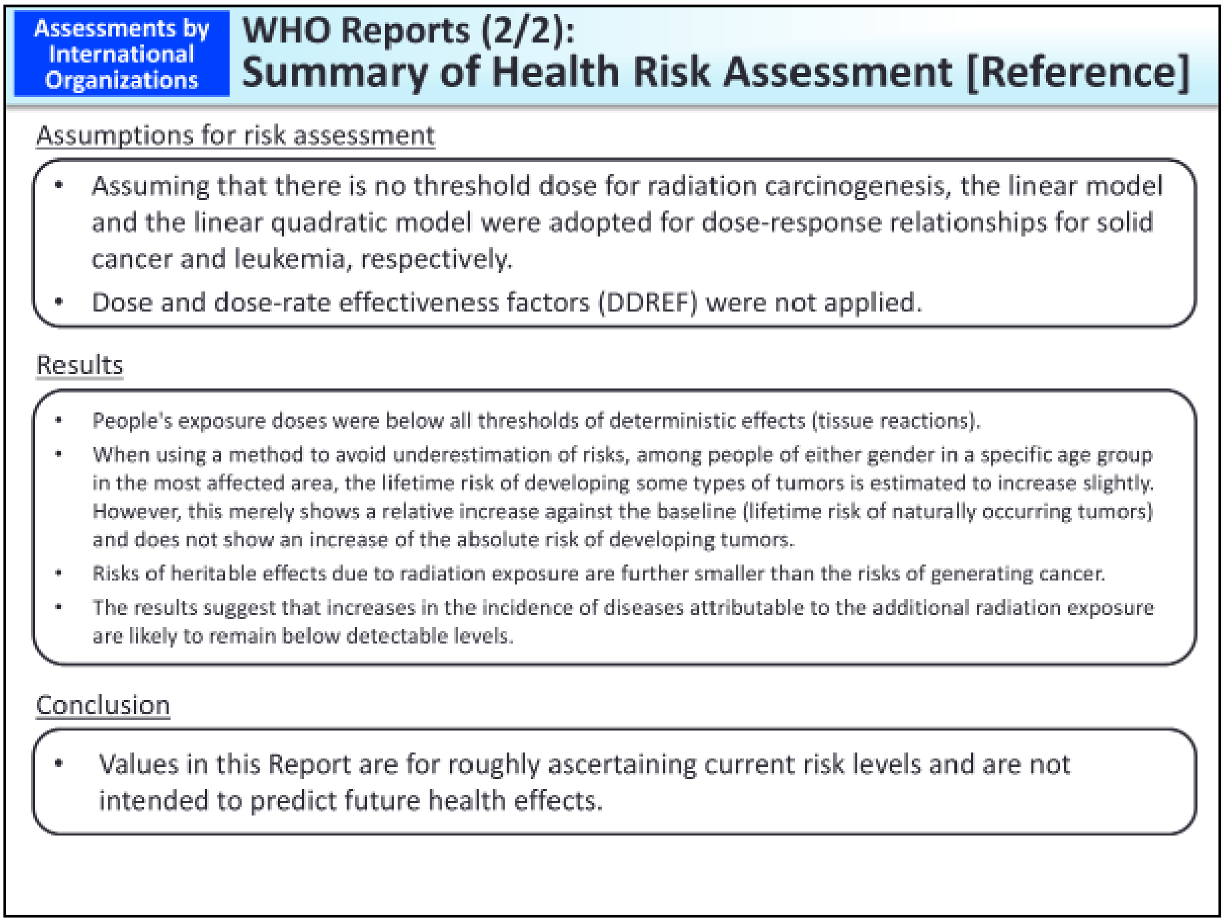

Assessments by International Organizations

WHO Reports (2/2): Summary of Health Risk Assessment [Reference]

Assumptions for risk assessment

- Assuming that there is no threshold dose for radiation carcinogenesis, the linear model and the linear quadratic model were adopted for dose-response relationships for solid cancer and leukemia, respectively.
- Dose and dose-rate effectiveness factors (DDREF) were not applied.

Results

- People's exposure doses were below all thresholds of deterministic effects (tissue reactions).
- When using a method to avoid underestimation of risks, among people of either gender in a specific age group in the most affected area, the lifetime risk of developing some types of tumors is estimated to increase slightly. However, this merely shows a relative increase against the baseline (lifetime risk of naturally occurring tumors) and does not show an increase of the absolute risk of developing tumors.
- Risks of heritable effects due to radiation exposure are further smaller than the risks of generating cancer.
- The results suggest that increases in the incidence of diseases attributable to the additional radiation exposure are likely to remain below detectable levels.

Conclusion

- Values in this Report are for roughly ascertaining current risk levels and are not intended to predict future health effects.

The WHO's health risk assessment was conducted for the purpose of examining the scopes of people to be subject to health management and diseases whose incidence should be monitored. This assessment was based on exposure doses estimated under considerably conservative assumptions in order to avoid underestimation. Accordingly, resulting values in this Report are for roughly ascertaining current risk levels and are not intended to predict future health effects.

[Relevant parts in the reports]
- WHO Report on preliminary dose estimation (Tables 3 and 4 on pages 44 to 47)
- WHO Report on health risk assessment (pages 8 and 92 to 93, and Table 43 on page 156)

Included in this reference material on March 31, 2015
Updated on March 31, 2024

Abbreviations

Act on Special Measures Concerning Nuclear Emergency	Act on Special Measures Concerning Nuclear Emergency Preparedness
Act on Special Measures (Concerning the Handling of Environment Pollution by Radioactive Materials)	Act on Special Measures Concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District - Off the Pacific Ocean Earthquake that Occurred on March 11, 2011
ADI	Acceptable Daily Intake
ALARA	As Low As Reasonably Achievable
ALPS	Advanced Liquid Processing System
BMI	Body Mass Index
BSS	Basic Safety Standards
CT	Computed Tomography
DDREF	Dose and Dose Rate Effectiveness Factor
DNA	Deoxyribonucleic Acid
EEG	Electroencephalogram
EUROCAT	European Surveillance of Congenital Anomalies
GM counter	Geiger-Müller counter
HPCI	High Pressure Coolant Injection System
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILO	International Labour Organization
INES	International Nuclear and Radiological Event Scale
IQ	Intelligence Quotient
IXRPC	International X-ray and Radium Protection Committee
JAEA	Japan Atomic Energy Agency
JESCO	Japan Environmental Storage & Safety Corporation
J-RIME	Japan Network for Research and Information on Medical Exposure
LNT model	Linear Non-Threshold model
MRI	Magnetic Resonance Imaging

MRL	Maximum Residue Levels
NAS	National Academy of Sciences
ND	Not Detected
OECD/NEA	Organisation for Economic Co-operation and Development/Nuclear Energy Agency
PET	Positron Emission Tomography
PFA	Psychological First Aid
PTSD	Posttraumatic Stress Disorder
RCIC	Reactor Core Isolation Cooling System
SDQ	Strengths and Difficulties Questionnaire
SPEEDI	System for Prediction of Environmental Emergency Dose Information
TDI	Tolerable Daily Intake
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WBC	Whole Body Counter
WHO	World Health Organization

■ Units

Sv	Sievert
Bq	Becquerel
Gy	Gray
eV	electron volt
J	Joule

SI prefixes

Symbol	Reading	Exponential (decimal notation)
T	tera	10^{12} (1 000 000 000 000)
G	giga	10^{9} (1 000 000 000)
M	mega	10^{6} (1000 000)
k	kilo	10^{3} (1 000)
d	deci	10^{-1} (0.1)
c	centi	10^{-2} (0.01)
m	milli	10^{-3} (0.001)
µ	micro	10^{-6} (0.000 001)
n	nano	10^{-9} (0.000 000 001)

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Symbols

Glossary

A

Act on Special Measures Concerning the Handling of Environment Pollution by Radioactive Materials

The radioactive materials released due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station (NPS) after the Great East Japan Earthquake caused environmental pollution. This Act aims to promptly reduce the influence of this environmental pollution on human health and living environments, and provides for the monitoring and measurement of the environmental pollution, disposal of waste contaminated with radioactive materials, decontamination of soil and other countermeasures. (Based on the website of the Ministry of the Environment)

Actinoid

The actinoid (actinide) series encompasses the 15 elements with atomic numbers from 89 to 103, namely Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, and Lr. All actinoids are radioactive and release energy upon radioactive decay. Naturally occurring uranium and thorium and artificially produced plutonium are the most abundant actinides on Earth.

Additional doses

The term "additional dose" refers to a dose received from radioactive sources that were unintentionally generated. After the TEPCO's Fukushima Daiichi NPS Accident, the additional dose often refers to the dose from the artificial radionuclides (e.g., Cesium-137) distinct from the dose from naturally existing radionuclides (e.g., Potassium-40).

Advanced Liquid Processing System

Multi-nuclide removal equipment (known as the Advanced Liquid Processing System, or ALPS) that removes 62 kinds of radioactive materials other than tritium. "ALPS treated water" refers to water that has been treated by the Advanced Liquid Processing System (ALPS) and other equipment and has been purified to a level where contained radioactive materials, except for tritium, satisfy the regulatory standards for environmental discharge. Prior to the treatment using ALPS, contaminated water is purified to remove cesium, strontium, etc.

ALPS treated water

See "Advanced Liquid Processing System".

Ambient dose

An ambient dose refers to the amount of radiation in the air. Gamma rays from radioactive materials on or near the ground surface and gamma rays from radioactive materials in the air affect ambient dose levels.

Areas under Evacuation Orders

Areas for which evacuation orders were issued based on Article 15, paragraph (3) of the Act on Special Measures Concerning Nuclear Emergency Preparedness; Areas under Evacuation Orders consisted of Deliberate Evacuation Areas and the 20-

km zone of the Nuclear Power Station. The areas were reviewed and were newly organized as Preparation Areas for Lift of Evacuation Order, Habitation Restricted Areas, and Restricted Areas.

Areas where Returning is Difficult

See "Restricted Areas".

Artificial radionuclides

Man-made radionuclides produced by a nuclear reactor and an accelerator in contrast to naturally-occurring radionuclides. (Based on the website of the Nuclear Fuel Cycle Engineering Laboratories, JAEA)

Atmospheric nuclear testing

Nuclear testing conducted on the ground, at sea or in the air; There are also underwater nuclear testing, underground nuclear testing and exoatmospheric nuclear testing. Nuclear testing other than that to be conducted underground was all banned under the Partial Test Ban Treaty (PTBT), which was signed in 1963. (Based on the website of Japan Atomic Energy Agency)

B

Basic Survey

The Basic Survey is a questionnaire survey targeting roughly 2,050,000 residents of and visitors to Fukushima Prefecture as of March 11, 2011. Estimated external radiation doses were calculated based on recorded movements of respondents in the four months following the nuclear accident. (Based on the website of the Radiation Medical Science Center, Fukushima Medical University)

C

Calibration constant

Calibration means to clarify the relationship between a correct value and instrument readings, and such relationship expressed in a ratio is referred to as a calibration constant. When measuring radiation, correct values are to be obtained by multiplying instrument readings by a calibration constant. A calibration constant is generally indicated on a calibration label attached to a radiation meter.

Cell degeneration

Passing from a state of goodness to a lower state by losing qualities desirable for normal cell function that results in, for example, deformity or malfunctioning.

Cesium

Cesium (Caesium) is a chemical element with atomic number 55. Cesium-137 (Cs-137) and Cesium-134 (Cs-134) are radioisotopes of cesium and their physical half-lives are about 30 and two years, respectively. Cs-137 decomposes to Ba-137 through beta decay associated with gamma radiation (0.662 MeV), and then to nonradioactive barium. Cs-137 is generated as one of the fission products, whereas Cs-134 is generated through neutron capture of stable cesium. The biological half-life of cesium is about 70 to 100 days for adults and is shorter for children. Cs-137 and Cs-134 were released into the environment due to the TEPCO's Fukushima Daiichi NPS Accident as well as other radioisotopes such as radioiodine. On the other hand, Cs-

137 is commonly used as a gamma emitter in industrial application.

Chornobyl Nuclear Power Station Accident

A nuclear reactor accident that occurred at Unit 4 of the Chornobyl Nuclear Power Station in the Ukrainian Republic on April 26, 1986.

Chronic exposure

Chronic exposure means continuous or intermittent exposure to radiation over a long period of time. In contrast to acute exposure, tissue reactions caused by exposure are less severe if the total radiation dose is the same.

Codex Alimentarius Commission

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.

Cold shut-down

A situation where a fission reaction has been suppressed through the insertion of control rods and the temperature in the reactor is stably maintained at 100°C or lower by continued cooling.

Committed effective dose

The sum of the products of the committed organ or tissue equivalent doses and the appropriate tissue weighting factors (w_T). The commitment period is taken to be 50 years for adults, and to age 70 years for children. (Cited from ICRP, 2007) (See p.56 in Vol. 1 (Chapter 2) for details)

Committed effective dose coefficient

The coefficient is indicated as a committed effective dose for a person who has ingested or inhaled 1Bq of radioactive materials considering type of radionuclide, intake route (ingestion, inhalation, etc.), and age group (adults, young children, infants). The coefficient differs by age group because time integrated dose is taken into account for a period of 50 years for adults and for a period of becoming up to age 70 for children, and also because biological half-lives and sensitivity differ between adults and children.

Intake (Bq) × (Committed) effective dose coefficient (mSv/Bq) = (Committed) effective dose (mSv)

(Based on the website of the Food Safety Commission of Japan)

Committed effective doses per unit intake (Bq)

See "Committed effective dose coefficient".

Comprehensive Health Checkup

The program aims at early detection and treatment of diseases as well as prevention of lifestyle-related diseases. Its main target includes 210,000 former residents of evacuation zones whose lifestyle changed drastically after the accident. Additional tests such as differential leukocyte count are performed apart from the routine tests included in the general medical check-up at the workplace or by the local government. (Based on the website of the Radiation Medical Science Center, Fukushima Medical University)

Confidence interval

In “frequentist inference”, a confidence interval is an interval defined in terms of the sampling distribution of a statistic of interest (i.e. the distribution of estimates of the statistic that would arise from repeated—generally hypothetical—realizations of data generated from the same underlying distribution as the observed data) such that, for example, the probability that a 95% confidence interval for a given parameter contains the true value of that parameter is 0.95. (Cited from UNSCEAR, 2017)

Confinement function

A function as a protective wall to prevent diffusion of radioactive materials into the environment; At a reactor, even if radioactive materials leak from the primarily cooling system by pipe rupture, etc., it should be ensured that the confinement function of the reactor containment vessel works properly to prevent diffusion of radioactive materials into the environment.

Containment vessel

Steel vessel enclosing a nuclear reactor containing radioactive material. It is designed, in any emergency, to keep radioactive materials inside of the vessel and to prevent the release thereof when the radioactive material is leaked from nuclear reactor.

Contaminated water

Contaminated water is water containing radioactive materials of fuel debris. It is generated due to continued water injection for cooling fuel that had been melted and solidified (fuel debris) and due to the inflow of rainwater and groundwater into the reactor building. Contaminated water has been generated every day since the accident at TEPCO’s Fukushima Daiichi NPS. Contaminated water is treated using cesium adsorption equipment and a desalinator. Separated clean water is repeatedly used for cooling fuel debris. (See p.13 in Vol. 2 (Chapter 6) for details)

Controlled disposal sites

One type of disposal site where countermeasures have been taken to prevent contamination of groundwater and public waters caused by seeping water from radioactive waste. One of the countermeasures is water shielding work that covers the sides and bottom of the disposal site with plastic sheets, etc. Disposal sites are categorized into three types depending on methods of reducing influence of the waste to be landfilled on the surrounding environment, i.e., controlled type, isolated type, and stabilized type. (Based on the website of the EIC Network)

Cooling system

A system to remove the heat generated in a reactor; There are the primary core cooling system and the emergency core cooling system.

Core fuel

There is an area to load fuel assemblies in the inside of the reactor pressure vessel. This area is referred to as a reactor core. Nuclear fuel in the area is referred to as core fuel.

Core melt

A situation where fuel assemblies overheat due to abnormal deterioration of the cooling capacity of a reactor, and the fuel assemblies in the reactor core or core internals melt down. (Based on the website of Fukushima Prefecture [d])

Cosmic rays

High energy ionizing particles such as protons, neutrons, etc. from outer space. These particles produce complex compositions at the surface of the earth through nuclear reaction with nitrogen or oxygen in the air.

Count per minute (cpm)

Number of counts per unit time when measuring radiation using a counting device (a device to count the amount of incident radiation); Number of counts per minute is indicated as cpm and number of counts per second is indicated as cps. (kcpm=1000cpm) (Based on the website of Fukushima Prefecture [d])

D

Decay (disintegration)

The process of spontaneous transformation of a radionuclide. The decrease in the activity of a radioactive substance. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Declaration of a nuclear emergency situation

A declaration of an emergency situation that the Prime Minister issues based on the Act on Special Measures Concerning Nuclear Emergency (see the Act on Special Measures Concerning Nuclear Emergency Preparedness) for the purpose of protecting citizens' lives, bodies and property from a nuclear disaster; Based on the declaration, the national government establishes the Nuclear Emergency Response Headquarters (headed by the Prime Minister) and provides instructions necessary for protecting citizens to nuclear operators, government organizations and relevant local governments, etc.

Decommissioning

Dismantling a nuclear reactor and the other related facilities for which it has been decided to discontinue operation or make adjustments to ensure that they pose no risks into the future.

Deliberate Evacuation Areas

Areas in municipalities located within 20km to 30km in radius from TEPCO's Fukushima Daiichi NPS where exposure doses are highly likely to reach 20 mSv in one year after the accident; The designation of Deliberate Evacuation Areas is one of the physical protection measures taken after the accident at the NPS. (Based on the website of Fukushima Prefecture [d])

Designated waste

Contaminated waste that is confirmed to be over 8,000 Bq/kg of radioactive concentration and is designated by the Minister of the Environment. The Minister of the Environment designates the waste when it is contaminated with more than 8,000 Bq/kg, based on the investigation results of the contamination status of incinerated ash and such or an application submitted by the owner of the waste.

Detection limit

The minimum amount or concentration of a targeted radioactive material in a test sample that can be detected by a certain analysis method under appropriate management and operation. (Based on the website of the Food Safety Commission of

Japan)

Deterministic effect

Health effects that only appear if a threshold level of dose is exceeded, e.g. radiation-induced erythema (burns). Deterministic effects will appear within the hours, days or weeks following a high radiation exposure.
(Cited from the website of UK Health Security Agency, Radiation Protection Services)

Directional dose equivalent

The dose equivalent at a point in a radiation field that would be produced by the corresponding expanded field in the ICRU sphere at a depth, d, on a radius in a specified direction, X. The unit of directional dose equivalent is joule per kilogram (J kg^{-1}) and its special name is sievert (Sv). (Cited from ICRP, 2007)

Director General of the Nuclear Emergency Response Headquarters

In the event of a nuclear emergency situation as prescribed in Article 15 of the Act on Special Measures Concerning Nuclear Emergency, the Prime Minister issues a declaration of a nuclear emergency situation. The national government establishes the Nuclear Emergency Response Headquarters (headed by the Prime Minister), provides necessary instructions to nuclear operators, government organizations and relevant local governments, etc., and also establishes the Local Nuclear Emergency Response Headquarters (headed by the Vice-Minister) at an off-site center and formulates the Joint Council for Nuclear Emergency Response. (Based on the website of Fukushima Prefecture [d])

Dissolved Cs

See “Cesium”.

Distribution Restrictions

Based on the Act on Special Measures Concerning Nuclear Emergency Preparedness, when any agricultural products containing radioactive materials at levels exceeding the standard values are found, the national government issues distribution restrictions to prevent the distribution of products from the relevant production areas for each of such areas (for each of the present or former municipalities; regarding fishery products, additionally for each sea area, lake or river).

Dose constraint

A prospective and source-related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimisation of protection for that source. For occupational exposures, the dose constraint is a value of individual dose used to limit the range of options considered in the process of optimisation. For public exposure, the dose constraint is an upper bound on the annual doses that members of the public should receive from the planned operation of any controlled source. (Cited from ICRP, 2007)

Dose-response relationship

Relationship between the magnitude of a dose and the biological response in an organism, system or (sub)population. (Cited from WHO, Health Risk Assessment, 2013)

Dosimeter

A device for measuring an individual's exposure to ionizing radiation. (Cited from UNSCEAR, 2013)

E

Electron

An elementary particle with low mass, 1/1836 that of a proton, and unit negative electric charge. Positively charged electrons, called positrons, also exist. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Emergency core cooling system

A safety system to cool a reactor core in the event of pipe rupture in the reactor cooling system, etc. by immediately injecting coolant into the reactor core; Even if a nuclear fission chain reaction is stopped by insertion of control rods immediately in an emergency, fission products continue to generate decay heat and the fuel assemblies need to be cooled. An emergency core cooling system is used for this purpose.

Energetically unstable (Unstable energy state)

See "Nucleus Stability/Instability".

Enriched uranium

See "Uranium".

Environmental monitoring

The measurement of external dose rates due to sources in the environment or of radio-nuclide concentrations in environmental media. (Cited from WHO, Health Risk Assessment, 2013)

Environmental radiation

Naturally occurring radiation or artificial radiation in the living environment; Naturally occurring radiation includes cosmic rays from the outer atmosphere and radiation deriving from naturally occurring radioactive elements that constitute the earth's crust. Part of artificial radiation that is referred to as environmental radiation is radiation released from fallout from past nuclear testing and radiation that was generated at nuclear facilities and exists in the environment. (Based on the website of Japan Atomic Energy Agency)

Epidemiological Studies

Studies of the distribution in a population of disease and other health issues as related to age, sex, race, ethnicity, occupation, economic status, or other factors. (Cited from the website of the United States Environmental Protection Agency)

Exposure dose

A situation where a human body is exposed to radiation is referred to as exposure and the amount of radiation that a person has received is referred to as an exposure dose, which is expressed in Grays (Gy) or Sieverts (Sv). (Based on the website of Japan Atomic Energy Agency)

F

Fine-needle aspiration cytology

This diagnostic procedure entails puncturing a fine needle into suspicious lesions, aspirating cells from the lesions through a needle and inspecting the nature of the cells, i.e., malignant or not, under the microscope. (Based on the website of the National Cancer Center Japan)

Food Sanitation Act

An Act for securing food safety and preventing the occurrence of sanitary hazards caused by eating and drinking. (Based on the website of the Ministry of Health, Labour and Welfare [b])

Frozen soil wall

A frozen soil wall is made by freezing the surrounding ground like a wall. Thereby the flow of the underground water is blocked. The frozen soil wall reduces the inflow of underground water into reactor buildings and inhibits the generation of contaminated water. This mechanism was adopted as one of the countermeasures to inhibit the generation of contaminated water at TEPCO's Fukushima Daiichi NPS. (Based on the website of Fukushima Prefecture [d])

Fuel cladding

A thin circular tube covering fuel; A fuel clad prevents radioactive fission products from leaking from the fuel into the coolant. Zircalloy is used for fuel clads of a light-water reactor's fuel rods. (Based on the website of Japan Atomic Energy Agency)

Fuel debris

"Fuel debris" is a complex of fuel, metallic cladding, channel boxes, etc. that were melted out from fuel assemblies and were re-solidified afterwards. Fuel debris needs to be cooled continuously as its thermal energy increases due to the radiation emitted therefrom. When handling fuel debris, which emits radiation, radiation shielding is required.

Fukushima Health Management File

An A4-sized Fukushima Health Management File is composed of three parts: the first part contains individual records such as dose measurements, health status, health checkup data, and hospital records, the second part contains leaflets about radiation etc., and the third part is "clear holders" as a storage space for record sheets. The file has been provided to each Fukushima resident so as to utilize the file for individual health management. In addition, it is an individual database about long-term health status, laboratory measurements, etc. that can be informative for future study. (Based on the website of Fukushima Prefecture [c])

G

Gaseous cesium

See "Cesium" and "Plume".

Germanium semiconductor detector

A radiation detector using a germanium semiconductor; A germanium semiconductor detector has excellent energy resolution and is widely used for gamma-ray spectrometry to identify radionuclides.

Groundwater drain

A well pumping up groundwater.

H

Habitation Restricted Areas

Areas designated by municipal mayors as areas where entry should be restricted and evacuation is ordered for the purpose of preventing risks on residents' lives and bodies; After the accident, areas within a 20-km radius from TEPCO's Fukushima Daiichi NPS were designated as former Restricted Areas. (Based on the website of Fukushima Prefecture [d])

Hand-held dose-rate instrument

An easy-to-carry-around instrument to measure ambient dose rates (e.g., a NaI (Tl) survey meter).

High Pressure Coolant Injection System (HPCI)

A safety system to cool a reactor core in the event of a loss of coolant in the reactor core by immediately injecting coolant into the reactor core at high pressure; One of the multiple safety systems contained in the emergency core cooling system.

High-dose radiation

According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), a total dose exceeding 2,000 mGy (2 Gy) is referred to as high-dose radiation. (Based on UNSCEAR, 1993)

Hydrogen explosion

A phenomenon where hydrogen precipitously reacts with oxygen to explode.

I

ICRP Recommendations

The basic idea (concept) and numerical standards for radiological protection recommended by the International Commission on Radiological Protection (ICRP); These are collectively referred to as ICRP Recommendations. (Based on the website of Japan Atomic Energy Agency)

Inert element

An inert element does not readily enter into chemical combination with other elements. Examples are helium, argon, krypton, xenon and radon. (Cited from WHO, Health Risk Assessment, 2013)

Infrared

A kind of electromagnetic wave in region of the spectrum comprising wavelengths in the range 700 nm to 1 mm. This wave does not ionize material but makes material warm.

Inspection of All Rice Bags

Fukushima Prefecture measures the radioactive cesium level of rice produced in the prefecture in 2012 or later. The rice is tested on a bag-by-bag basis with radiation detectors prepared by the prefectural government. Each bag, containing 30 kilograms of rice, is inspected for safety before shipment so as to prevent the distribution of rice whose radioactive cesium level exceeds the safety standard limit. (Based on the website of Fukushima Prefecture [b])

Intake

The activity of a radionuclide taken into the body (by inhalation or ingestion or through the skin) in a given time period or as a result of a given event. (Cited from WHO, Health Risk Assessment, 2013)

Intensive Contamination Survey Areas

Areas where municipalities take the initiative in decontamination work; Of municipalities including areas where measured ambient dose rates were 0.23 μSv/h or higher, 65 municipalities in eight prefectures are designated as Intensive Contamination Survey Areas (as of the end of March 2025).

Interim storage facility

A facility to manage and store the soil and waste containing radioactive materials safely and intensively until their final disposal.

International Atomic Energy Agency (IAEA)

An autonomous international organization within the United Nations system for scientific and technical co-operation in the nuclear field concerning nuclear safety, nuclear energy, nuclear security, etc. The headquarters is located in Vienna, Austria.

International Basic Safety Standards (BSS)

The BSS is an IAEA document of General Safety Requirements published in collaboration with other international bodies such as WHO, ILO, OECD/NEA, etc., that is issued for IAEA member states in order to materialize the ICRP's recommendations on radiation protection into actual laws and guidelines. The latest version published in 2014 that incorporates the ICRP 2007 Recommendation.

Intervention level

An intervention level is the level of avertable dose at which a specific protective action or remedial action is taken in an emergency exposure situation or chronic exposure situation. (Cited from IAEA, 1999)

Inversion tillage

Replacement of topsoil with subsoil, thereby radioactivity concentrations are reduced in the soil layer where plants take root.

Iodine

Iodine is a chemical element with symbol I and atomic number 53. It is the fourth halogen below fluorine, chlorine, and bromine. Stable and non-radioactive iodine is an essential nutrient that humans need and get through intake of food. Iodine is essential for the thyroid gland to function properly and produce thyroid hormones. Radioiodine, such as I-131, I-125, is used as a radioactive tracer in research and clinical diagnosis in nuclear medicine for diagnostic tests as well as in radiotherapy for hyperactive thyroid gland (hyperthyroidism). I-131 also plays a major role as a radioactive isotope present in nuclear fission products, and was a significant contributor to the health hazards from the Chornobyl NPS accident. Radioactive iodine can disperse in gaseous or particulate form. In soil, however, it combines easily with organic materials and moves more slowly through the environment.

Ionizing radiation

Ionizing radiation is a more precise name of all types of radiation with energy large enough to ionize a molecule. Included under this designation are radiation from radioactive sources, X-rays, short wavelength UV, particles from accelerators, particles from outer space and neutrons. Ionizing radiation is categorized into direct (primary) ionizing radiation and indirect (secondary) ionizing radiation. The former includes charged particles such as α-particles, β-particles (electrons), positrons and the latter includes γ-rays, X-rays, neutrons. (Cited from Henriksen & Maillie, 2002, p.20)

Isotope

Nuclides with the same number of protons but different numbers of neutrons. Not a synonym for nuclide. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

J

Japan’s national doses

The average exposure doses received by one Japanese person; Radiation sources include naturally occurring radiation and artificial radiation (medical radiation and radiation derived from nuclear power plant accidents, etc.). Japan’s national dose is evaluated to be 2.1 mSv on average from naturally occurring radiation and 3.87 mSv on average from medical radiation (for diagnosis) per year. (Based on NSRA, 2011)

K

Kerma

Unit of exposure that represents the kinetic energy transferred to charged particles per unit mass of irradiated medium when indirectly ionizing (uncharged) particles, such as photons or neutrons, traverse the medium. If all of the kinetic energy is absorbed “locally”, the kerma is equal to the absorbed dose. The quantity (K) is expressed in µGy/h at 1 m. (Cited from WHO, Preliminary Dose Estimation, 2012)

L

Lanthanoid

The lanthanoid (lanthanide) series of chemical elements comprises the 15 metallic chemical elements with atomic numbers 57 through 71. They are called lanthanoids because the elements in the series are chemically similar to lanthanum.

Linear non-threshold (LNT) model

The assumption that the risk of cancer increases linearly as radiation dose increases. This means, for example, that doubling the dose doubles the risk and that even a small dose could result in a correspondingly small risk. Using current science, it is impossible to know what the actual risks are at very small doses. (Cited from the website of the United States Environmental Protection Agency)

Local exposure

A situation where part of the body, not the whole body, is mainly exposed to radiation.

M

Medical exposure

Exposure incurred by patients as part of their own medical or dental diagnosis or treatment; by persons, other than those occupationally exposed, knowingly, while voluntarily helping in the support and comfort of patients; and by volunteers in a programme of biomedical research involving their exposure. (Cited from ICRP, 2007)

Melt of nuclear fuel

Melting of core fuel from overheating that occurs in a severe nuclear reactor accident.

Mental Health and Lifestyle Survey

The survey aims to provide adequate care mainly for evacuees who are at a higher risk of developing mental health problems (e.g., post-traumatic stress disorder, depression, anxiety disorder) and lifestyle-related issues (e.g., obesity, problem drinking, sleep difficulties).

N

NaI scintillation spectrometer

A gamma-ray measurement system that detects scintillation consisting of NaI crystals is generally referred to as an NaI scintillator. (Based on the website of Japan Atomic Energy Agency)

Naturally occurring radioactive materials

Materials found in nature that emit ionizing radiation that have not been moved or concentrated artificially. K-40 is one natural radioactive material and exists in plants and human bodies.
(Cited from the website of the United States Environmental Protection Agency)

Neutron

An elementary particle with unit atomic mass approximately and no electric charge. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Noble gas

An inert radioactive gas that does not readily enter into chemical combination with other elements. Examples are helium, argon, krypton, xenon and radon. (Cited from WHO, Health Risk Assessment, 2013)

Nuclear and Industrial Safety Agency

An organization that the national government established in the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, for the purpose of ensuring safety of nuclear power and other types of energy and securing industrial safety; The Agency was abolished as part of the full-fledged revision of the safety regulation system in response to the accident at TEPCO’s Fukushima Daiichi NPS in

March 2011. (Based on the website of Japan Atomic Energy Agency)

Nuclear fuel rods

A nuclear fuel rod consists of nuclear material covered with a metal clad. Multiple rods constitute a fuel assembly and multiple fuel assemblies constitute a reactor core. For light-water reactors, uranium dioxide is used for nuclear material and zircalloy is used for metal clads.

Nuclear reactor

A device in which nuclear fission can be sustained in a self-supporting chain reaction involving neutrons. In thermal reactors, fission is brought about by thermal neutrons. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Nuclear Safety Commission

The Nuclear Safety Commission was established in the Cabinet Office in 1978 as an organization that plans, deliberates and decides how to ensure safety concerning research, development and utilization of nuclear power. The accident at TEPCO's Fukushima Daiichi NPS in March 2011 triggered fundamental reform of the safety regulation system, and the Nuclear Regulation Authority was newly established as an administrative organ that integrally regulates nuclear safety on September 19, 2012, and the Nuclear Safety Commission was abolished. (Based on the website of Japan Atomic Energy Agency)

Nucleus stability/instability

Whether a nucleus is stable or unstable depends on the numbers of its constituent protons and neutrons. An unstable nucleus emits radiation to change into a nucleus that is energetically more stable.

Nuclide

A species of atom characterised by the number of protons and neutrons and, in some cases, by the energy state of the nucleus. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Nuclide concentration

The concentration of radioisotopes in certain materials, such as soil, water, air, foodstuff, and so on.

O

Ordinance on Prevention of Ionizing Radiation Hazards

The Ordinance on Prevention of Ionizing Radiation Hazards aims to minimize the health hazards out of radiation for workers and was established based on the Industrial Safety and Health Law. (Based on the website of the Ministry of Health, Labour and Welfare [a])

Organization for Economic Cooperation and Development / Nuclear Energy Agency (OECD/NEA)

An international organization that aims to contribute to the development of nuclear energy as an economic energy source; A subordinate agency of the Organization for Economic Cooperation and Development (OECD).

P

Particulate cesium

See “Cesium” and “Plume”.

Personal dose equivalent

An operational quantity: the dose equivalent in soft tissue (commonly interpreted as the ‘ICRU sphere’) at an appropriate depth, d, below a specified point on the human body. The unit of personal dose equivalent is joule per kilogram ($J\ kg^{-1}$) and its special name is sievert (Sv). The specified point is usually given by the position where the individual’s dosimeter is worn. (Cited from ICRP, 2007)

Physical attenuation

A phenomenon that the number of radioactive isotopes decrease due to radioactive decay.

Plume (Radiation plume)

Mass of air and vapour in the atmosphere carrying radioactive material released from a source.
(Cited from WHO, Preliminary Dose Estimation, 2012)

Plutonium

Plutonium is a radioactive chemical element with symbol Pu and atomic number 94. It is an actinide metal and is produced by a nuclear reaction of uranium. Pu-239 is a fissile isotope and can be used for nuclear fuels and nuclear weapons. Man-made plutonium existing in the environment originates from radioactive fallout associated with nuclear weapon tests in the past. (Based on the website of Fukushima Prefecture [d])

Post-Traumatic Stress Disorders (PTSD)

Post-traumatic stress disorder (PTSD) is a mental disorder triggered by a terrifying event, causing flashbacks, nightmares and severe anxiety for prolonged periods. (Based on the website of National Center of Neurology and Psychiatry)

Potassium

Potassium is a chemical element with symbol K and atomic number 19. It is one of the alkali metals. Potassium in nature occurs only in ionic salts and is chemically similar to sodium. Naturally occurring potassium is composed of three isotopes, of which K-40 is the most common radioisotope in the human body. Natural potassium contains 0.0117% of K-40, which exists in animals and plants. About 4,000 Bq of K-40 is contained in the body of an adult male. Potassium ions are vital for the functioning of all living cells. Potassium is also used for agricultural fertilizer.
Potassium and cesium are alkali metals and cesium absorbed in plants shows behavior similar to potassium. Therefore, after the accident at TEPCO’s Fukushima Daiichi NPS, potassic fertilizer is used for crops as a measure to inhibit radioactive cesium absorption. (Based on the website of Fukushima Prefecture [d])

Precautionary Evacuation Areas

A term used in the 2013 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which refers to areas where evacuation orders were issued from March 12 to March 15, 2011; Specifically, the term refers to

Futaba, Okuma, Tomioka, Naraha, Hirono, Minamisoma, Namie, Tamura, Kawauchi and Katsurao. (Based on UNSCEAR, 2013)

Pregnancy and Birth Survey

The survey aims to provide appropriate medical care and support to mothers who were given a Maternal and Child Health Handbook and to their children. (Based on the website of the Radiation Medical Science Center, Fukushima Medical University)

Preparation Areas for Lift of Evacuation Order

Areas where it has been confirmed that annual accumulated doses will surely be below 20 mSv and efforts are to be made for early return of residents; Passing on major roads and temporary return of residents are flexibly permitted. Physical protection measures, such as screening and dose management, are not necessary in principle upon temporary entry. (Based on the website of Fukushima Prefecture [d])

Provisional regulation values

Provisional regulation values were regulation values that were used provisionally for regulation of the radioactivity in foodstuffs just after the accident at TEPCO's Fukushima Daiichi NPS because there had been no standard values. The provisional regulation values were used until the start of use of the standard values newly determined by the government.

Public exposure

Exposure incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation. (Cited from ICRP, 2007)

Q

Quantitation limit

The minimum amount or concentration of a nuclide whose quantity can be determined by a certain analysis method. (Based on the website of the EIC Network)

R

Radiation Dose Map

See "Spatiotemporal Distribution of Ambient Dose Rates".

Radiation effects

There are two major types of radiation effects: somatic effects and heritable effects. Somatic effects are classified into acute effects, which include hair loss and sterility, and late effects, which include cataracts and cancer. From the perspective of protection against radiation, somatic effects are also classified as deterministic effects (tissue reactions) and stochastic effects (cancer and heritable disorders). Although heritable effects have been demonstrated in animal studies, the effects have not been found among the offspring of atomic bomb survivors or cancer survivors treated with radiation. (Based on the website of the National Institute of Radiological Sciences)

Radiation fluence

Radiation (particle) fluence is defined as the quotient of dN by da, where dN is the number of particles incident upon a sphere of cross-sectional area da. (Cited from ICRP, 2007)

Radiation management
Measures and control to protect workers in charge of operations at nuclear/radiation facilities and residents living near such facilities from radiation exposure. (Based on the website of Japan Atomic Energy Agency)

Radiation monitoring posts
A facility installed for monitoring environmental radiation around the nuclear facilities; In general, a facility for only measuring ambient dose rates is referred to as a monitoring post, and a facility for also measuring radioactive concentrations and meteorological data is referred to as a monitoring station. (Based on the website of Fukushima Prefecture [d])

Radiation protection
Radiation protection is the means for protection of people from harmful effects of exposure to ionizing radiation or contamination with radioactive materials. (Based on the website of Japan Atomic Energy Agency)

Radiation protection culture
Health-promoting lifestyle of people living in the contaminated area by radioactive materials, lifestyle which is backed up with knowledge and skills about radiation and radiation protection.

Radiation weighting factor
A dimensionless factor by which the organ or tissue absorbed dose is multiplied to reflect the higher biological effectiveness of high-LET radiations compared with low-LET radiations. It is used to derive the equivalent dose from the absorbed dose averaged over a tissue or organ. (Cited from ICRP, 2007)

Radioactive Cesium
See “Cesium”.

Radioactive cloud (plume) immersion
See “Plume”.

Radioactive decay
See “Decay (disintegration) ”.

Radioactive disintegration
See “Decay (disintegration) ”.

Radioactive Iodine
See “Iodine”.

Radioactive strontium
See “Strontium”.

Radiosensitivity (radiation sensitivity/sensitivity to radiation/sensitive to radiation)
Proneness of cells to be killed by radiation; As a rule, radiation exposure kills cells

more easily that are dividing or programmed to divide many times in the future or in a developmentary immature stage. (Based on the website of Japan Atomic Energy Agency)

Reactor building

A concrete building that houses major equipment of a reactor.

Reactor core

The area in a reactor where fuel assemblies are loaded and fission reaction occurs actively.

Reactor core isolation cooling System

A safety system for boiling-water reactors that provides cooling water to a reactor core using a pump powered by steam in a reactor when an abnormal incident in the reactor results in preventing the ordinary system from supplying water to the reactor. (Based on the website of Japan Atomic Energy Agency)

Reactor pressure vessel

A steel vessel that houses nuclear fuel, a moderator, coolant and other major components and wherein high-pressure steam is produced by fission energy. (Based on the website of Fukushima Prefecture [d])

Reconstruction Agency

The national government’s administrative agency that was organized for proactively carrying out reconstruction work with due consideration to areas severely damaged by the Great East Japan Earthquake with the aim of achieving reconstruction as early as possible. (Based on the website of the Reconstruction Agency [b])

Recriticality

Criticality is a situation where a fission reaction continues without supply of neutrons from the outside. Recriticality is a phenomenon where changes in the temperature, shape or composition of a reactor core results in criticality again. (Based on the website of Japan Atomic Energy Agency)

Recycling of the removed soil

On the premise of securing radiation safety, “recycling” here means to make the soil and waste removed through off-site decontamination work into materials again after volume reduction. These materials are to be used for construction, such as the basic structure of banks in public projects which are assumed not to change shape artificially for a long time. Also, areas which use the removed soil are supposed to be managed by an appropriate administrator and responsibility-taking system.

Reduction coefficient (Dose reduction coefficient)

A ratio between the ambient dose rate due to artificial radioactive materials measured inside a building and that measured outside, when contamination by artificial radioactive materials inside the building and under the floor can be ignored; It is a value specific to a building and is also referred to as a shielding coefficient.

Reference level

In an emergency exposure situation or an existing exposure situation, the level of dose, risk or activity concentration above which it is not appropriate to plan to allow exposures to occur and below which optimization of protection and safety would continue to be implemented. (Cited from WHO, Preliminary Dose Estimation, 2012)

Repair enzymes (DNA repair enzymes)

Enzymes necessary for repairing DNA damage. Genetic mutation affecting such enzymes induces cancer proneness. There are several DNA repair mechanisms such as mismatch repair, nucleotide excision repair, homologous recombination repair, non-homologous end joining repair and so on, and each mechanism utilizes unique or shared enzymes to repair DNA damage.

Restricted Areas

Areas where annual accumulated doses are currently over 50 mSv and are highly likely to be over 20 mSv even six years after the accident at TEPCO's Fukushima Daiichi NPS; Residents who temporarily enter these areas must undergo thorough screening, manage their own individual doses and wear protective gear. The term "Areas where returning is difficult" was formerly used instead of "Restricted Areas" as a literal translation from Japanese. (Based on the website of Fukushima Prefecture [d] and the website of the Ministry of Economy, Trade and Industry)

* Areas formerly called "Restricted Areas" were areas within a 20km radius of TEPCO's Fukushima Daiichi NPS as designated in April 2011. In March 2012, this area designation was reviewed in consideration of radiation doses and region-specific problems for individual areas and the designation was lifted for all areas formerly designated as Restricted Areas by August 2013.

Risk communication

Risk communication is a component of risk management, which is the selection of risk control options. It is the process that provides the information on which government, industry, or individual decision makers base their choices. Successful risk communication does not guarantee that risk management decisions will maximize general welfare; it only ensures that decision makers will understand what is known about the implications for welfare of the available options. (Cited from Improving Risk Communication, 1989)

S

Scintillation counter

A device containing material that emits light flashes when exposed to ionising radiation. The flashes are converted to electric pulses and counted. The number of pulses is related to dose. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Screening

In the field of health and medical care, "screening" means to provisionally identify persons with a disease or disorder by rapid and high through-put laboratory tests or procedures. In the field of analysis and inspection, "screening" means to provisionally select samples containing target substances or organisms, etc. by rapid and high through-put laboratory tests. Screening results are not conclusive, and further detailed examinations or diagnoses, etc. are needed to reach the final conclusions. (Based on the website of the Food Safety Commission of Japan)

Secretariat of the Nuclear Regulation Authority (NRA)

An organization that functions as the secretariat of the Nuclear Regulation Authority newly inaugurated in September 2012 after the accident at TEPCO's Fukushima Daiichi NPS.

Self-shielding effect

An effect in measurement in a situation where radiation in the air is shielded by a person or sample subject to the measurement; For example, when a person wears a personal dosimeter around his/her chest, radiation from behind is shielded by the person him/herself upon the measurement.

Solid cancers

Cancers originating in solid organs, as opposed to blood cancers such as leukaemia. (Cited from WHO, Health Risk Assessment, 2013)

Source term

The types, quantities, and chemical forms of the radionuclides that encompass the source of potential for exposure to radioactivity; After a nuclear accident, a source term including its release rate is critical for risk assessment. (Based on the US Health Physics Society)

Spatiotemporal distribution of ambient dose rates

Ambient dose rates change with time and place due to the physical decay and environmental migration of radionuclides. (Based on the website of Fukushima Prefecture [d])

Special Decontamination Areas

Areas where the national government directly conducts decontamination work; Basically, 11 municipalities in Fukushima Prefecture which were once designated as a former Restricted Area or a Deliberately-Evacuated Settlement are designated.

Specific Spots Recommended for Evacuation

Areas that do not fall under former Restricted Areas or Deliberately-Evacuated Settlements but where accumulated doses are highly likely to be over 20 mSv in one year after the accident were designated as Specific Spots Recommended for Evacuation and the national government recommended evacuation. The designation of these areas was lifted on December 28, 2014. (Based on the website of Fukushima Prefecture [a])

Specified Reconstruction and Revitalization Base Areas

Zones among Restricted Areas for which evacuation orders are lifted and where people are allowed to reside; As a result of the amendment of the Act on Special Measures for the Reconstruction and Revitalization of Fukushima (in May 2017), it was made possible to designate these zones. (Based on the website of the Reconstruction Agency [a])

Spent fuel pool

A spent fuel pool is a storage where nuclear spent fuels are cooled until their heat production due to the remaining radioactivity (after shutdown of a reactor) decreases sufficiently.

Stable cold shut-down conditions

See "Cold shut-down".

Stable iodine tablets

A drug containing a certain amount of non-radioactive or "cold" sodium iodide or potassium iodine; If one takes an adequate amount of the drug before inhalation or consumption of radioactive iodine after a nuclear accident, "cold" iodine fills the thyroid organ and prevents the accumulation of radioactive or "hot" iodine into the thyroid. (Based on the website of Japan Atomic Energy Agency)

Stochastic (health) effect

Health effect whose probability of occurrence depends on the dose received. Occurrence is usually many years after the exposure, and there is believed to be no threshold level of dose below which no effect will occur. (Cited from the website of UK Health Security Agency, Radiation Protection Services)

Stripping of topsoil (Topsoil removal)

Topsoil of farmland is to be shallowly (4 - 5cm) stripped using a tractor or other equipment to remove radioactive cesium. Radioactive cesium that fell down onto farmland is easily absorbed into soil and remained in the surface layer. Therefore, stripping and removing topsoil is effective.

Strontium

Strontium is the chemical element with symbol Sr and atomic number 38. Strontium has physical and chemical properties similar to those of calcium. Sr-90 is a radioisotope with a physical half of 28.8 years and is produced as a fission product in a nuclear reactor. Sr-90 is one of the concerned radionuclides in a nuclear accident because it is likely to accumulate in bones in a similar manner to calcium. (Based on the website of Fukushima Prefecture [d])

Subdrain

A well installed for adjusting groundwater levels around a reactor building. (Based on the website of Fukushima Prefecture [d])

Sum of ratios of concentrations required by law

For water that contains multiple nuclides, the regulatory standards for discharge state that the sum of the ratios of their concentrations to the limits respectively required by law must be less than one. This concentration limit applies to the discharge of radioactive waste to the environment, which is stipulated in the Regulation for Enforcement the Reactor Regulation Act (Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors).

Suppression chamber

Torus-shaped steel equipment that is located at the lower part of a reactor containment vessel and stores a large amount of water; A rectangular version made of concrete is referred to as a suppression pool. It is important safety equipment that provides water for the emergency core cooling system (ECCS) in the event of a loss of cooling water due to such reasons as a primary pipe rupture accident. A suppression chamber suppresses pressure increases in a nuclear reactor. When the pressure within a reactor containment vessel increases, steam is sent to a suppression chamber to reduce the increased pressure. A suppression chamber also removes particulate radionuclides upon releasing pressure.

Suppression pool

See “Suppression chamber”.

Suspended Cs

See “Cesium”.

T

The Act on Special Measures Concerning Nuclear Emergency Preparedness

The Act was enacted and enforced in 1999 for the purpose of protecting citizens’ lives, bodies and property in consideration of the unique characteristics of nuclear disasters. The Act specifies various matters concerning nuclear disasters and provides that in an emergency due to a nuclear disaster, the Prime Minister is to issue a declaration of a nuclear emergency situation and establish the Nuclear Emergency Response Headquarters.

The Fukushima Health Management Survey

The accident that occurred at the TEPCO’s Fukushima Daiichi NPS after the Great East Japan Earthquake on 11 March 2011 has resulted in long-term, ongoing anxiety among the residents of Fukushima, Japan. Soon after the disaster, Fukushima Prefecture launched the Fukushima Health Management Survey to investigate long-term low-dose radiation exposure caused by the accident. Fukushima Medical University took the lead in planning and implementing this survey. The primary purpose of this survey is to monitor the long-term health of residents, promote their future well-being, and confirm whether long-term low-dose radiation exposure has health effects. (Based on the website of the Radiation Medical Science Center, Fukushima Medical University)

The Nuclear Emergency Response Headquarters

See “Director General of the Nuclear Emergency Response Headquarters”.

The radiation exposure dose

See “Exposure dose”.

Thermal electrons

Electrons which emit from the surface of highly heated metal.

Threshold

Minimal absorbed radiation dose that will produce a detectable degree of any given effect. (Cited from WHO, Health Risk Assessment, 2013)

Thyroid Ultrasound Examination

Thyroid Ultrasound Examination covers roughly 380,000 residents aged 0 to 18 years at the time of the nuclear accident. The Preliminary Baseline Survey has been performed within the first three years after the accident, followed by complete thyroid examinations to detect newly growing tumors from 2014 onward, and the residents will be monitored regularly thereafter. (Based on the website of the Radiation Medical Science Center, Fukushima Medical University)

Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station (NPS) Accident (2011)

An accident at TEPCO's Fukushima Daiichi NPS located on the Pacific coast in Fukushima Prefecture, which was caused by the Great East Japan Earthquake that occurred at 14:46 on March 11, 2011, and the subsequent massive tsunami. (Based on the website of Fukushima Prefecture [d])

Trench

An underground tunnel for storing utility equipment such as power cables and pipes.

Tritium

Tritium is a radioisotope of hydrogen composed of one proton and two neutrons. Tritium, which combines with oxygen and comprises water molecules in the same manner as ordinary hydrogen, often exists around us while being contained in water molecules. It is created in nature as a result of the reaction of cosmic rays with nitrogen and oxygen in the air, in addition to be artificially created through the operation of a nuclear power plant. In nature, tritium is contained in rainwater, sea water, and tap water, and also exists in the human body as tritium water.

Tritium emits β-particles, one type of radiation, but β-particles emitted from tritium only have weak energy (18.6 keV at the largest) and can be shielded with a piece of paper. Therefore, external exposure from tritium is unlikely to exert any influence on the human body. A biological half-life for water containing tritium is ten days, and even if it is ingested, it will be eliminated from the body promptly and will not accumulate in any specific organs. (See p.79 in Vol. 1 (Chapter 2) for details)

Turbine building

At a nuclear power plant, steam pressure is converted into rotational energy by a turbine, which is further converted into electricity by a power generator. A building that houses a turbine and a power generator is referred to as a turbine building.

U

Undifferentiated

The developmental state of cells or organs that are immature or not differentiated. Any kind of tissues in the body contains stem cells capable of dividing and producing intermediately differentiated cells that further differentiate into mature functioning cells. In this case, stem cells are undifferentiated cells while mature functioning cells are differentiated cells.

UNSCEAR

The United Nations Scientific Committee on the Effects of Atomic Radiation

Uranium

Uranium is a chemical element with symbol U and atomic number 92. In nature, uranium is composed of U-238 (99.275%), U-235 (0.72%) and U-234 (0.005%).

The half-lives of U-238 and U-235 are about 4.47 billion years and 704 million years, respectively. U-235 is the only naturally occurring fissile isotope, which makes it widely used in nuclear reactors.

Enriched uranium is a type of uranium in which the percent composition of U-235 has been increased through the process of isotope separation. Enriched uranium is a critical component for both civil nuclear power generation and military nuclear weapons. (Based on the website of Fukushima Prefecture [d])

V

Vent

An operation to reduce pressure in a reactor containment vessel when the pressure increases abnormally, by way of discharging the inner gas.

W

Waste within the Management Areas

Waste within areas designated by the Minister of the Environment that meet certain requirements, such as areas that are highly contaminated and require special treatment.

Water-zirconium reaction

Zircalloy is used for fuel clads for light-water reactors. If fuel is exposed from cooling water, it becomes hot and this triggers a chemical reaction of zirconium in the fuel clad with water vapor to generate hydrogen. The phenomenon where hot zirconium reacts with water vapor and generates hydrogen in this manner is referred to as a water-zirconium reaction. (Based on the website of Japan Atomic Energy Agency)

WHO

World Health Organization

Whole-body counter

A device to measure the amount of radioactive materials taken into and deposited inside the human body from outside for the purpose of examining the internal exposure dose. (Based on the website of Fukushima Prefecture [d])

Whole-body exposure

A situation where the whole body is evenly exposed to (external) radiation; This term is used in contrast to local exposure, which refers to a situation where only part of the body is exposed to radiation. (Based on the website of Japan Atomic Energy Agency)

Z

Zeolite

Zeolite is Aluminosilicate, a kind of clay mineral. It comprises porous crystals. Fine pores are usually around 0.2 to 1.0 nm in diameter. Zeolite has ion-exchange capacity and adsorptive capacity.

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Illustrated Handbook

Vol. 1

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