Illustrated Handbook

BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Vol.1 Basic Knowledge and Health Effects of Radiation

Radiation Health Management Division, Ministry of the Environment,
Government of Japan

National Institutes for Quantum and Radiological Science and Technology

QR Code

The booklet is also available on the website.

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

Introduction

Seven years have passed since the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station. In order to enable residents returning to areas where evacuation orders have been removed to rebuild their lives and revitalize respective communities as early as possible, support both for realizing early return and for assisting returners' new lives is indispensable. By April 2017, the government of Japan had sequentially removed evacuation orders, and the reconstruction and recovery of Fukushima Prefecture has been steadily progressing.

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 released by the accident. For that purpose, it is important to properly respond to their health problems such as through the Fukushima Health Management Survey, Comprehensive Health Check and easily accessible health counseling services by health nurses, and to provide 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, together with the National Institute of Radiological Sciences, National Institutes for Quantum and Radiological 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 Institute of Radiological Sciences 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.

January 2019
Radiation Health Management Division,
Environmental Health Department,
Minister's Secretariat,
Ministry of the Environment,
Government of Japan
&
National Institutes for Quantum and Radiological Science and Technology

Contents

Chapter 1 Basic Knowledge on Radiation

Chapter 3 Health Effects of Radiation

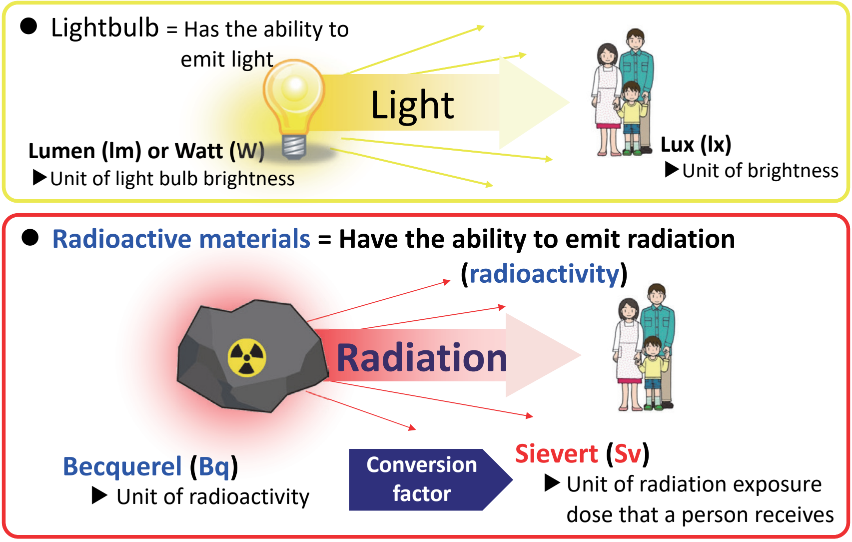
Chapter 4 Concept of Radiological Protection

Chapter 5 Assessments by International Organizations

Chapter 1

Basic Knowledge on Radiation

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").

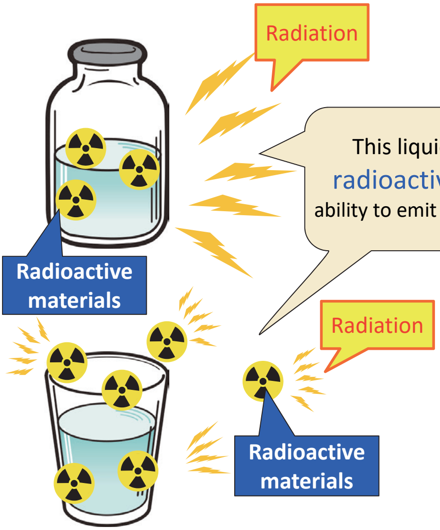
Radioactive materials emit radiation, and this ability is called "radioactivity." In this case, it is expressed as "This rock has radioactivity" or "This rock emits radiation." This ability of emitting radiation is expressed in the unit of "Becquerel (Bq)."

"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.

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

Radiation and Radioactivity

Difference between Radiation and Radioactive Materials



Radioactive materials themselves emit radiation.

This liquid has radioactivity, the ability to emit radiations.

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.

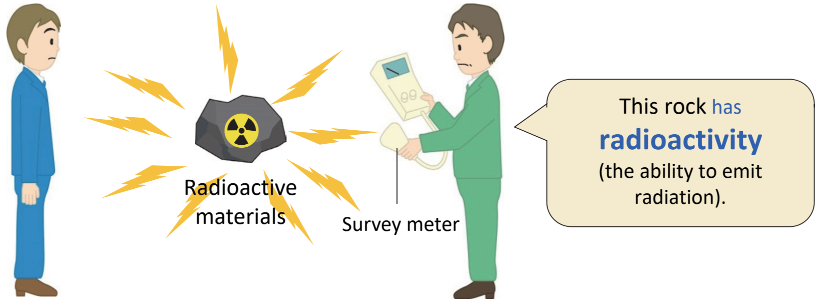
If a sealed container contains water with radioactive materials, radiation may leak from the container, but radioactive materials do not come out. If a container without a lid contains water with radioactive materials, there is a possibility that radioactive materials may spread due to spilling, etc.

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.

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

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 p.33-p.42 of Vol. 1, "2.3 Units of Radiation.")

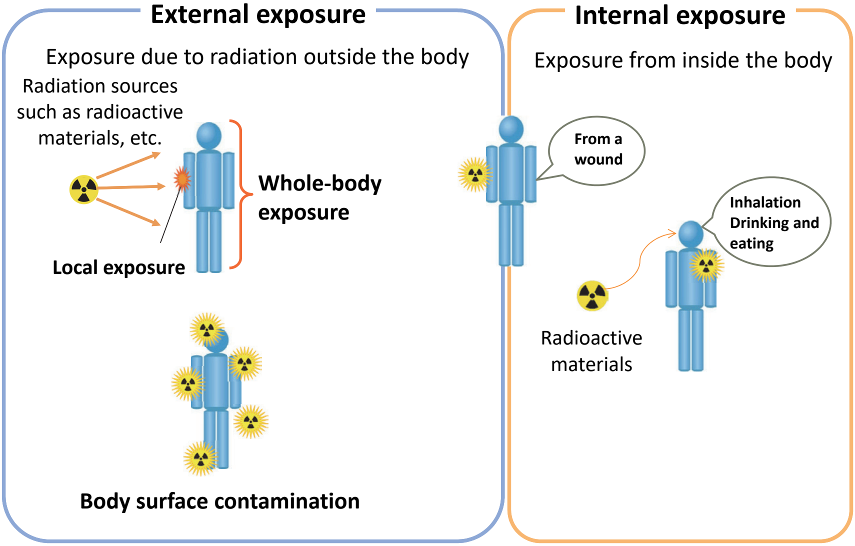
Places where a large amount of radioactive materials exist can be identified with a handheld survey meter. Additionally, the intensity and types of radiation emitted from radioactive materials, as well as personal exposure doses, can be checked with various types of survey meters.

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.

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

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.

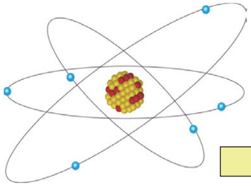
If a person breathes in radioactive materials in the air or takes contaminated food or drink into their body, he/she will be exposed to radiation from inside their body. In addition, radioactive materials can also enter the body from wounds. Receiving radiation in this way is called internal exposure.

For internal and external exposures, the relevant radiation types (α (alpha)-particles, β (beta)-particles and γ (gamma)-rays) (p.13-p.22 of 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.

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

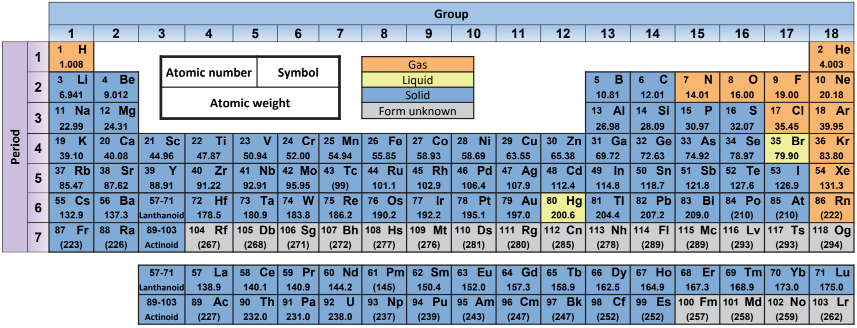
Atomic Structure and Periodic Law



			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

Period	Group																	
	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).

"One Periodic Table per One Household (10th 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.

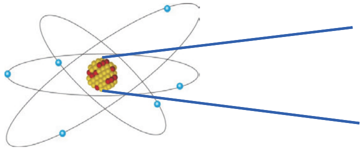
Carbon 14 is a radionuclide which exists in nature and is made through a process where a proton of Nitrogen 14 is hit and removed by a neutron originating from cosmic rays. Carbon 14 has six protons and eight neutrons, and the state is energetically unstable because of the unbalance of both numbers.

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.

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

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		$^{11}\mathrm{C}$	$^{12}\mathrm{C}$	$^{13}\mathrm{C}$	$^{14}\mathrm{C}$	$^{133}\mathrm{Cs}$	$^{134}\mathrm{Cs}$	$^{137}\mathrm{Cs}$
		$^{11}_{6}\mathrm{C}$	$^{12}_{6}\mathrm{C}$	$^{13}_{6}\mathrm{C}$	$^{14}_{6}\mathrm{C}$	$^{133}_{55}\mathrm{Cs}$	$^{134}_{55}\mathrm{Cs}$	$^{137}_{55}\mathrm{Cs}$
		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-134 and Cesium-137 may be released into the environment. They emit β-particles and γ-rays. (Related page: p.30 of Vol. 1, "Products in Nuclear Reactors")

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

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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

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.

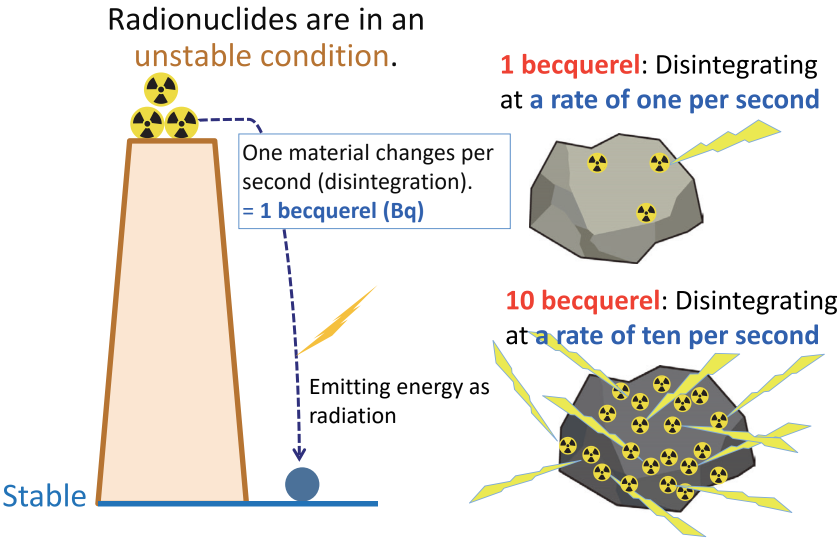
Carbon-14, which is also a naturally occurring radionuclide, is created when nitrogen that accounts for 80% of the atmosphere is bombarded with neutron beams, which are cosmic beams. Carbon-14 returns to nitrogen by emitting β-particles.

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.

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

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

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.

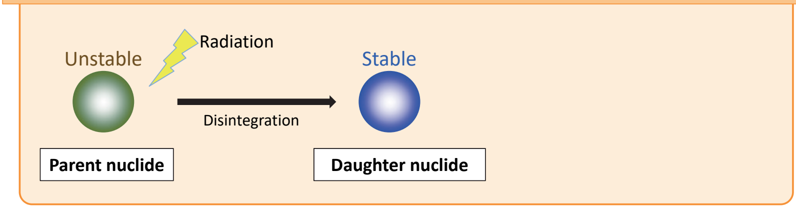
Once nuclei of a radionuclide disintegrate and the radionuclide becomes stable by emitting radiation, it will no longer emit radiation. Some types of radionuclides repeat disintegration multiple times until becoming stable.
(Related page: p.10 of Vol. 1, "Parent and Daughter Nuclides")

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

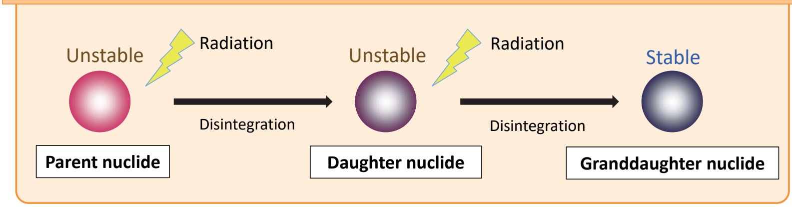
Radioactive Materials

Parent and Daughter Nuclides

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



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



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.

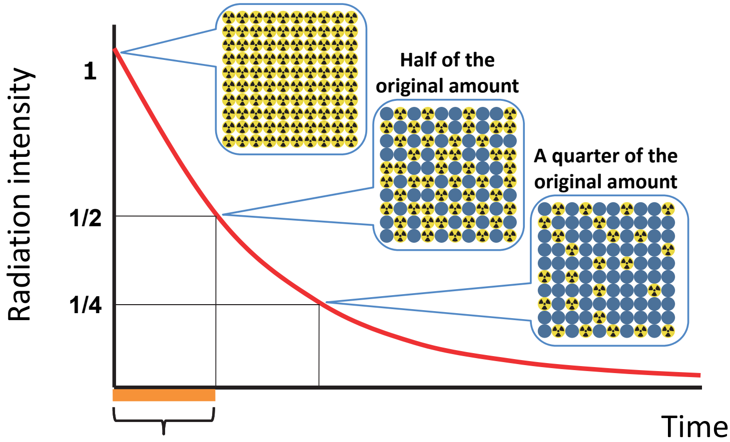
The phenomenon wherein a radionuclide emits radiation and transforms into a different nuclide is called disintegration. A nuclide before disintegration is called a parent nuclide and that after disintegration is called a daughter nuclide.

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 varys depending on their chemical forms and/or particle sizes.
(p.27 of Vol. 1, "Internal Exposure and Radioactive Materials")

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

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.

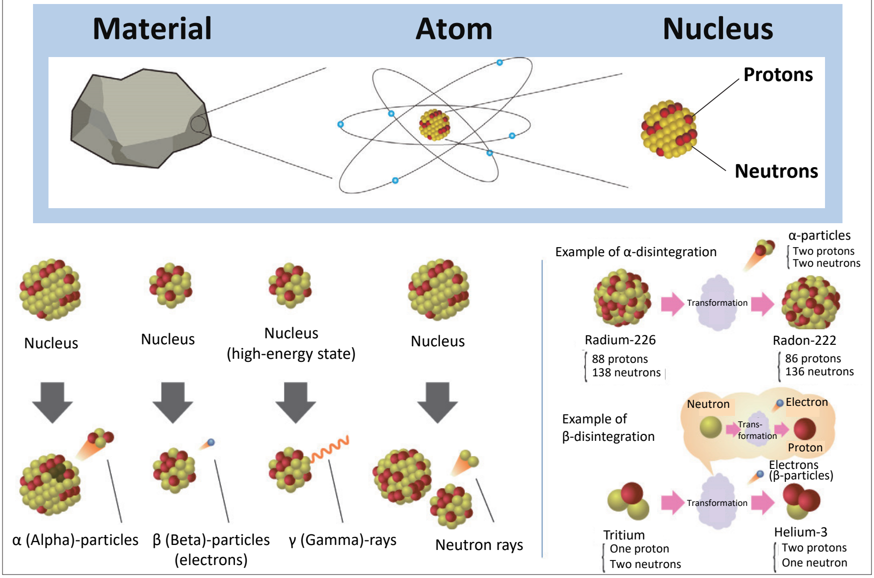
For example, Uranium-238 emits α (alpha)-particles and transforms into Thorium-234, which is also a radionuclide. Thorium-234 further emits β (beta)-particles and transforms into Protactinium-234, which is also a radionuclide. They constitute a series in which the original element transforms into different 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. However, Potassium-40 transforms into stable Calcium-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")

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

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.

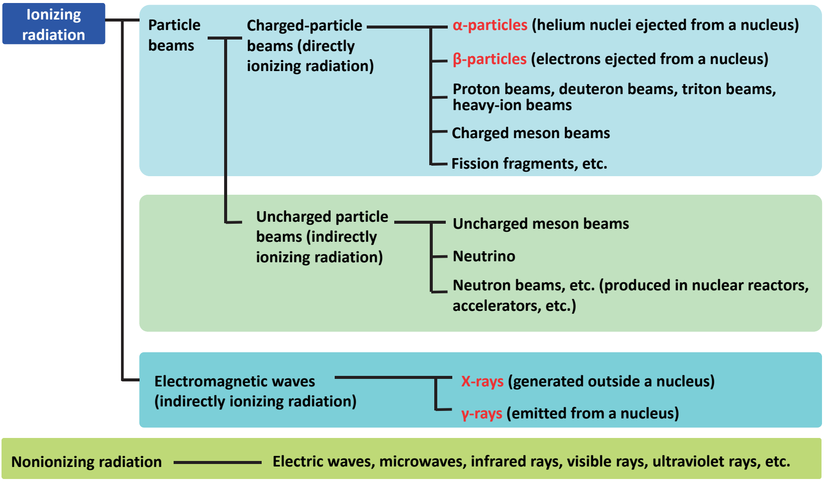
While α-particles, β-particles, and γ-rays are emitted from a nucleus, X-rays are electromagnetic waves that are generated outside a nucleus. Unlike X-rays, γ-rays are generated from a nucleus, but both are electromagnetic waves. A neutron is a particle that constitutes a nucleus. Neutrons that are ejected 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")

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

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)
      - 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.

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")

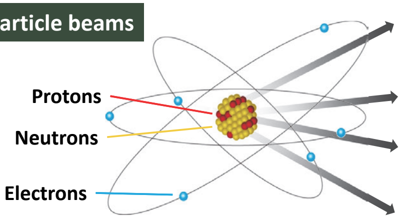
Included in this reference material on March 31, 2013
Updated on March 31, 2016

Radiation

Types of Ionizing Radiation

Ionizing radiation Radiation that causes ionization

Particle beams



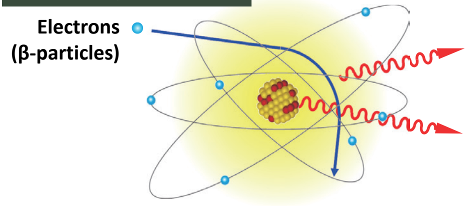
α-particles (helium nuclei ejected from a nucleus)

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)

* X-rays generated when electrons within an atom are caused to travel between orbits by incident electrons are called characteristic X-rays.

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.

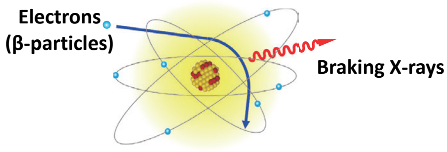
γ-rays and X-rays are types of electromagnetic waves. While α-particles, β-particles, and γ-rays are emitted from a nucleus, X-rays used in X-ray examination for medical checkups and the like are electromagnetic waves generated outside a nucleus. X-rays generated in X-ray tubes are used in X-ray examination. 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")

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

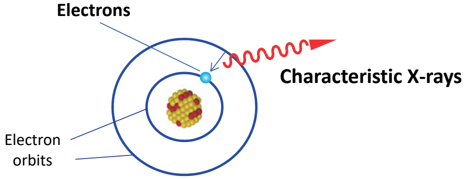
Radiation

X-rays for Medical Use and Generators

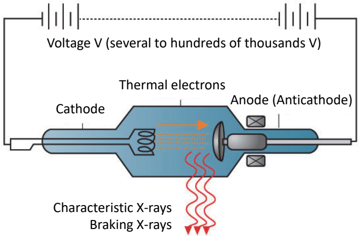
Braking X-rays



Characteristic X-rays



Structural drawing of an X-ray generator



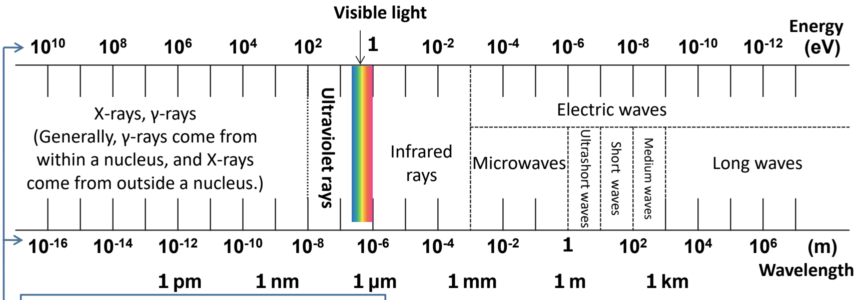
X-ray examination uses X-rays generated in X-ray tubes. A high voltage is applied between a cathode and an anode (tungsten, molybdenum, copper, etc.) inside an X-ray tube so that thermal electrons migrate from the cathode to the anode in a vacuum at high speed. X-rays generated when the direction of 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.

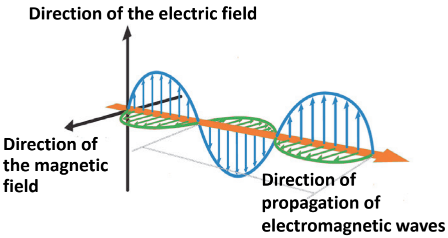
Included in this reference material on March 31, 2016

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).

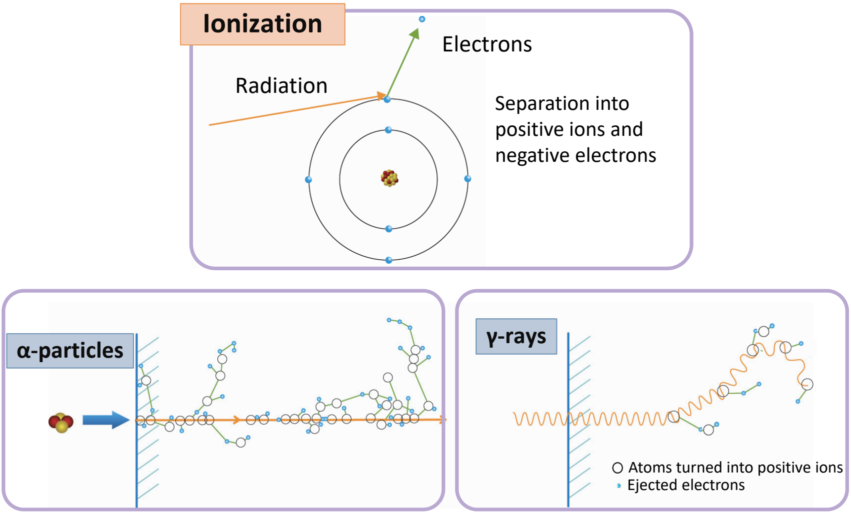
While X-rays and γ-rays differ in the mechanisms of how they are generated, they are both electromagnetic waves with high energy.

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.

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

Radiation

Ionization of Radiation - Property of Ionizing Radiation



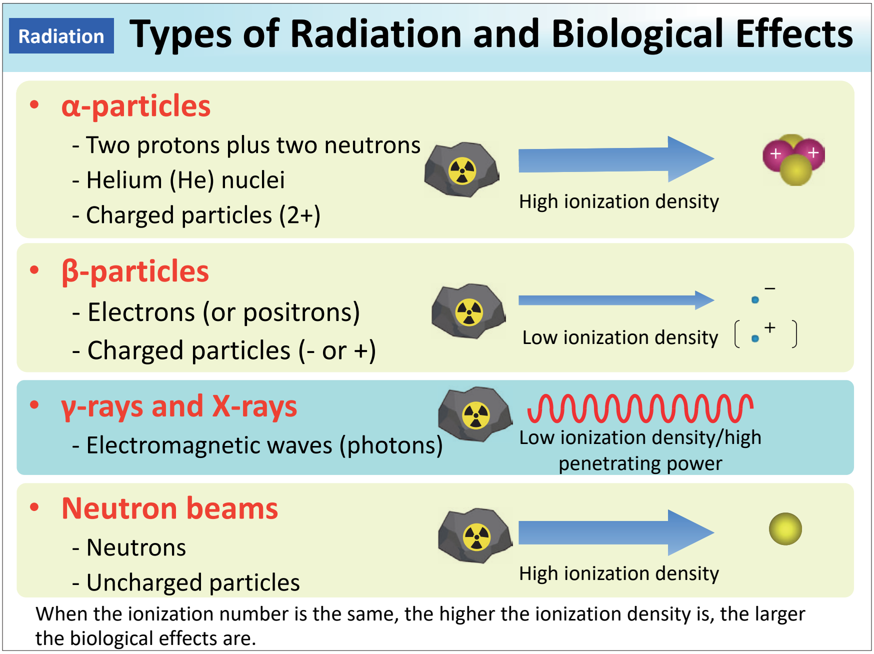
When radiation passes through a substance, its energy causes ejection of orbital electrons of the atoms that make up the substance, separating the atoms into positively charged atoms (or positive ion molecules) and free electrons. This is called ionization.

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

Charged particle beams, such as α-particles and β-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-particles does not cause problems because α-particles 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-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. 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.

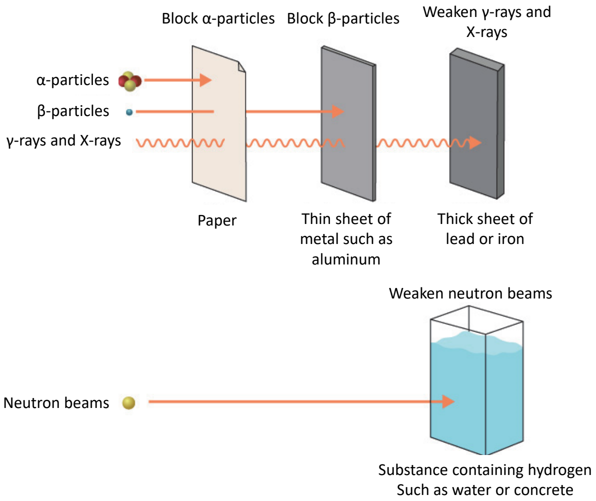
(Related to p.15 of Vol. 1, "Types of Ionizing Radiation," and p.18 of Vol. 1, "Ionization of Radiation - Property of Ionizing Radiation")

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

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-particles cause a large amount of ionization, a sheet of paper is enough to stop them. β-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.

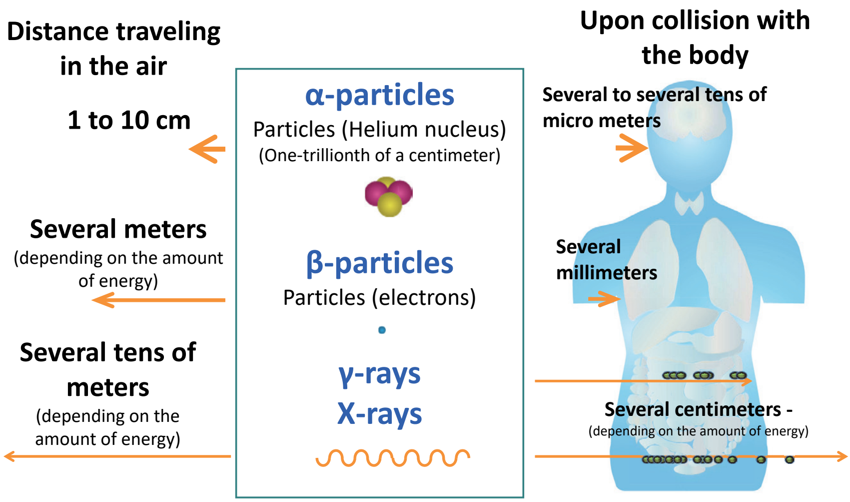
(Related page: p.21 of Vol. 1, "Penetrating Power of Radiation within the Body")

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

Upon collision with the body

1 to 10 cm

α-particles

Particles (Helium nucleus)

(One-trillionth of a centimeter)

Several to several tens of micro meters

Several meters

(depending on the amount of energy)

β-particles

Particles (electrons)

Several millimeters

Several tens of meters

(depending on the amount of energy)

γ-rays

X-rays

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-particles, β-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.

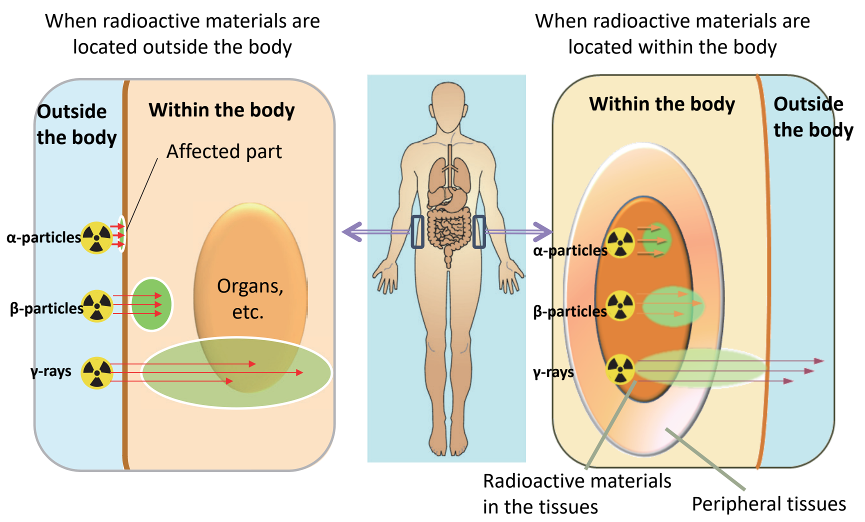
Since β-particles travel only several meters in the air, they hardly contribute to exposure when a radiation source is located away from the body. When the surface of the body is exposed to β-particles, their energy is imparted to the skin and subcutaneous tissues; when β-particles enter the body, their 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, 2015

Radiation Penetrating Power and Range of Effects on the Human Body



In the case of external exposure, α-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-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")

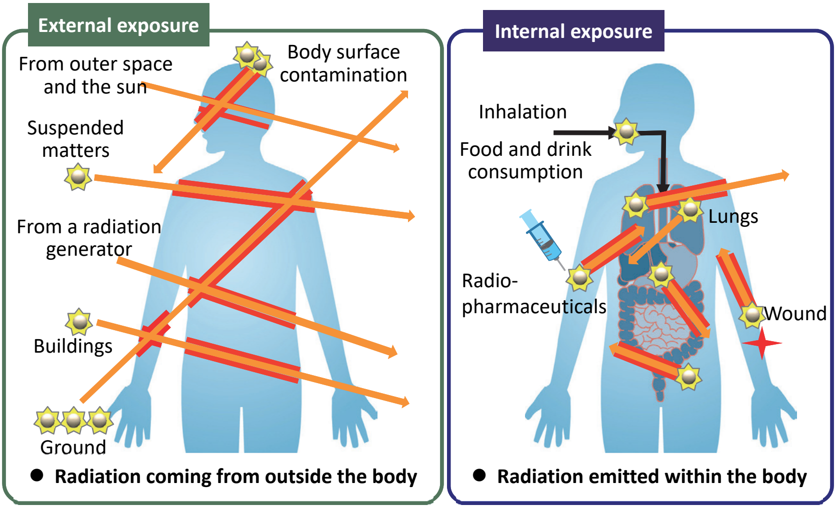
Included in this reference material on March 31, 2013
Updated on March 31, 2015

Chapter 2

Radiation Exposure

Exposure Routes

Internal and External Exposure



The body is equally exposed to radiation in both cases.

Radioactive materials

"Radiation exposure" refers to the situation where the body is in the presence of 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, suspended 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 (biological half-life) 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.61 of Vol. 1, "Exposure Dose from Natural and Artificial Radiation").

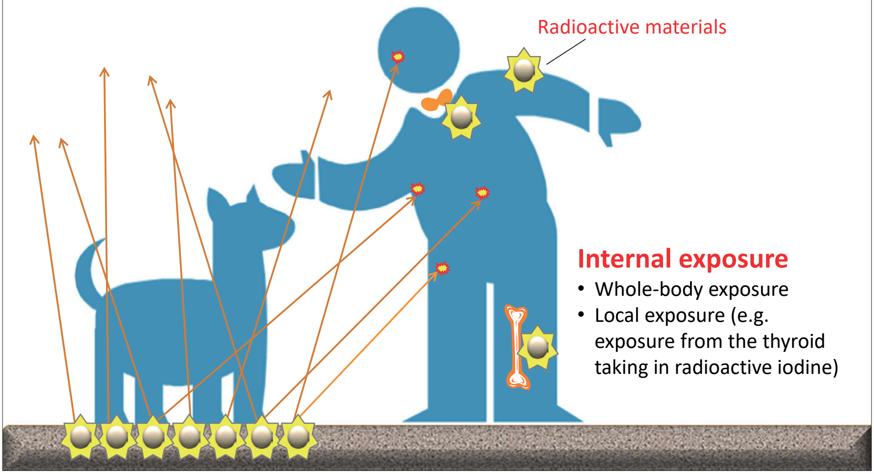
Included in this reference material on March 31, 2013
Updated on February 28, 2018

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.

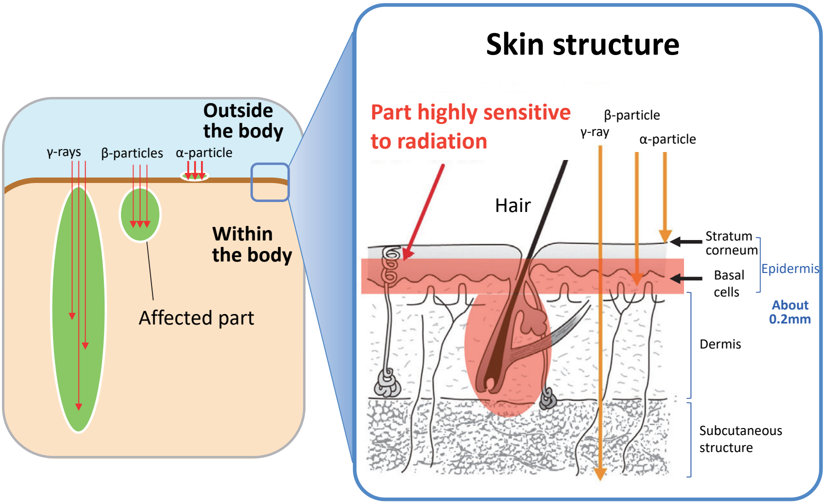
Organs differ in sensitivity to radiation. In local exposure, therefore, the extent of the effects varies greatly depending on whether the exposed part includes organs that are highly sensitive to radiation.

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 Chernobyl nuclear 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'.

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

Exposure Routes

External Exposure and Skin



In external exposure, α-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-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.

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

Exposure Routes

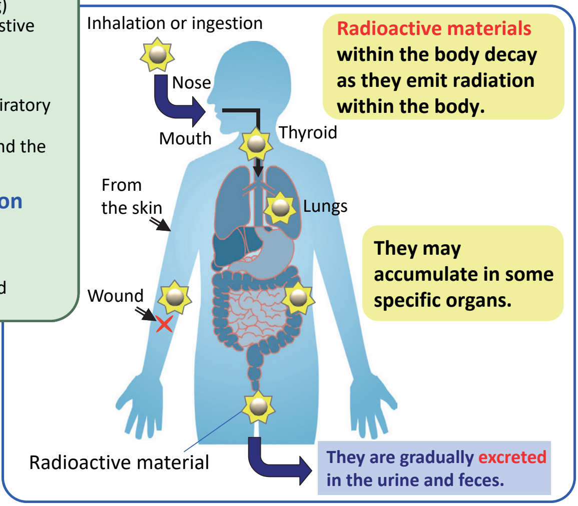
Internal Exposure

(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



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 via four routes: ingestion together with food; inhalation; absorption from the skin; and wound contamination.

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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Exposure Routes

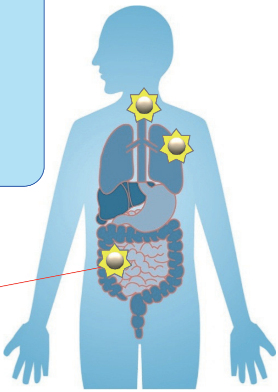
Internal Exposure and Radioactive Materials

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:

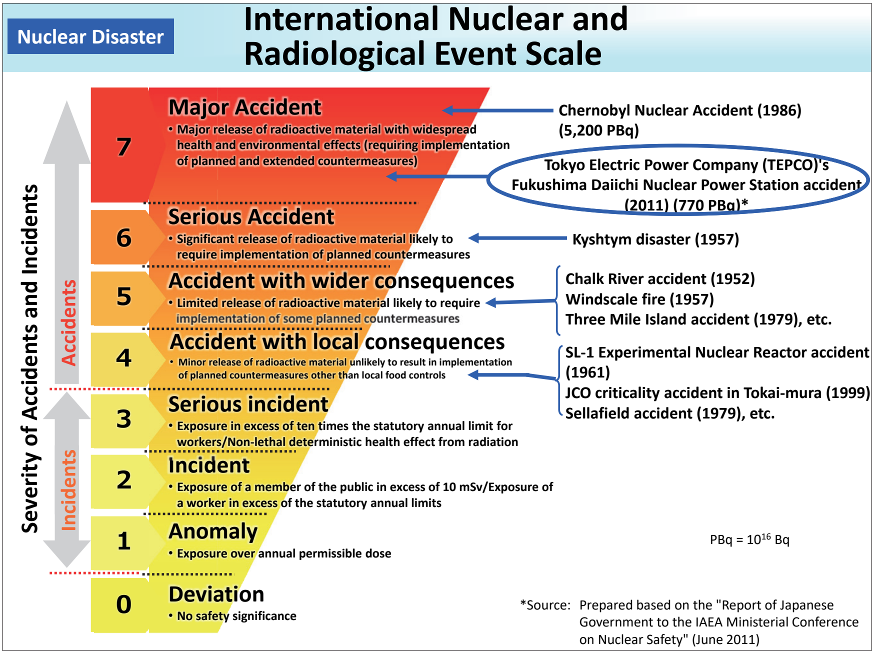
$$1/Te = 1/Tp + 1/Tb$$

A major problem with internal exposure is caused by radioactive materials that have a long half-life and emit α-particles. In terms of the chemical nature and element-specfic 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
Updated on March 31, 2017



Nuclear Disaster

International Nuclear and Radiological Event Scale

7	**Major Accident**	• Major release of radioactive material with widespread health and environmental effects (requiring implementation of planned and extended countermeasures)	Chernobyl Nuclear Accident (1986) (5,200 PBq) Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station accident (2011) (770 PBq)*
6	**Serious Accident**	• Significant release of radioactive material likely to require implementation of planned countermeasures	Kyshtym disaster (1957)
5	**Accident with wider consequences**	• Limited release of radioactive material likely to require implementation of some planned countermeasures	Chalk River accident (1952) Windscale fire (1957) Three Mile Island accident (1979), etc.
4	**Accident with local consequences**	• Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls	SL-1 Experimental Nuclear Reactor accident (1961) JCO criticality accident in Tokai-mura (1999) Sellafield accident (1979), etc.
3	**Serious incident**	• Exposure in excess of ten times the statutory annual limit for workers/Non-lethal deterministic health effect from radiation	
2	**Incident**	• Exposure of a member of the public in excess of 10 mSv/Exposure of a worker in excess of the statutory annual limits	
1	**Anomaly**	• Exposure over annual permissible dose	
0	**Deviation**	• No safety significance	

PBq = 10^{16} Bq

*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.

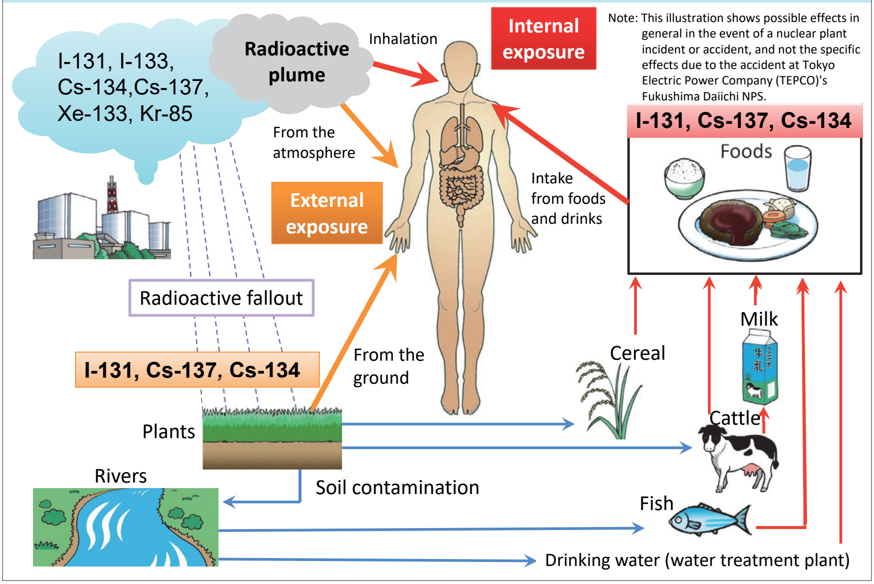
The accident at TEPCO's Fukushima Daiichi NPS was provisionally rated Level 7, indicating that it was the most serious accident because of the amount of radioactive materials released.

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

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

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 may contain radioactive noble gases and particulates such as radioactive iodine or Cesium-137.

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, people receive radiation emitted from radioactive materials contained in a plume passing overhead. This results in "external exposure." Radioactive iodine and cesium are deposited on the ground surface while a plume passes. Therefore, external exposure from deposited radioactive materials may occur even after the plume has passed.

Internal exposure can also occur if one directly inhales radioactive materials while a plume passes or if one consumes drinking water or foods contaminated with deposited radioactive materials.

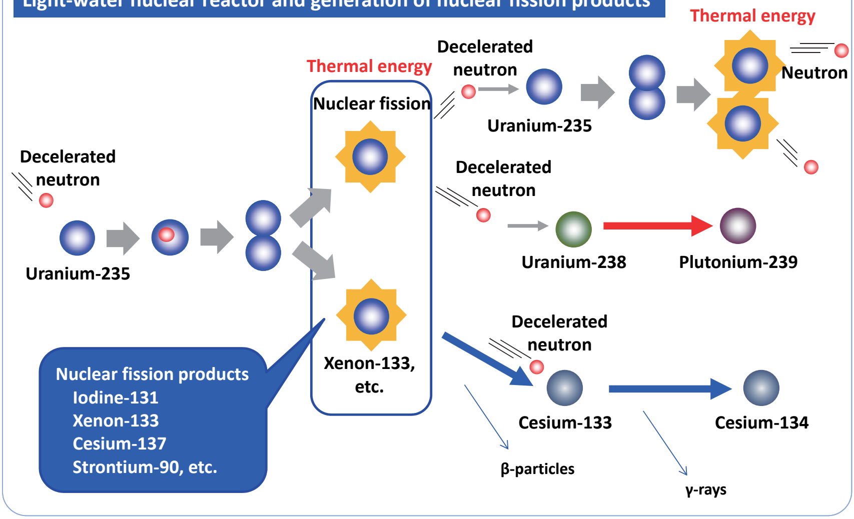
(Related to p.23 of Vol. 1, "Internal and External Exposure," and p.30 of Vol. 1, "Products in Nuclear Reactors")

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

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.

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

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 *4
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: The time required for the amount of radioactive materials in the body to reduce to half through biological excretion (biological half-life) and the physical decay (physical half-life) of the radioactive materials; The values are cited from the "Emergency Exposure Medical Text" (Iryo-Kagaku Sha).
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.

Iodine-131 has a short half-life of about 8 days, but once it enters the body, 10-30% will accumulate in the thyroid. If this happens, the thyroid will continue to be locally exposed to β-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 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 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.
(Related to p.30 of Vol. 1, "Products in Nuclear Reactors")

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

Nuclear Disaster

Comparison of Estimated Amounts of Released Radionuclides between Chernobyl and Fukushima Daiichi NPS Accidents

Nuclides	Half-life[a]	Boiling point[b] ℃	Melting point ℃	Release into the environment: PBq*		Fukushima Daiichi/ Chernobyl
				Chernobyl[d]	Fukushima Daiichi[e]	
Xenon (Xe)-133	5 days	-108	-112	6500	11000	1.69
Iodine (I)-131	**8 days**	**184**	**114**	**～1760**	**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	1380	769	～10	0.14	0.01
Plutonium (Pu)-238	88 years	3235	640	1.5×10^{-2}	1.9×10^{-5}	0.0012
Plutonium (Pu)-239	24100 years	3235	640	1.3×10^{-2}	3.2×10^{-6}	0.00024
Plutonium (Pu)-240	6540 years	3235	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	Chernobyl [f]	Fukushima Daiichi [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 1015Bq.

Sources: a: ICRP Publication 72 (1996); b and c (except for Np and Cm): 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 Chernobyl 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 within the containment vessel 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.

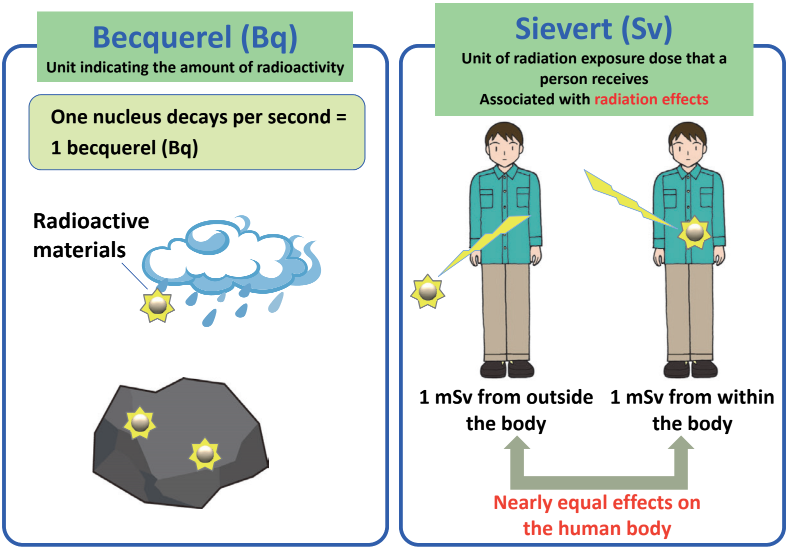
Although it is difficult to directly compare the released amount between the Chernobyl accident and the Fukushima Daiichi NPS accident, the larger amount released at the time of the Chernobyl accident is considered to have been partly due to the fact that the core exploded and was directly exposed to 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, making it possible to curb temperature declines and reduce leaks and 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: approx. 60%; Chernobyl: up to 100%). The large power capacity (Fukushima Daiichi: total of approx. 2,000,000 kW; Chernobyl: 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.

Included in this reference material on March 31, 2017

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

"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.39 of Vol. 1, "Concepts of Doses: Physical Quantities, Protection Quantities and Operational Quantities").

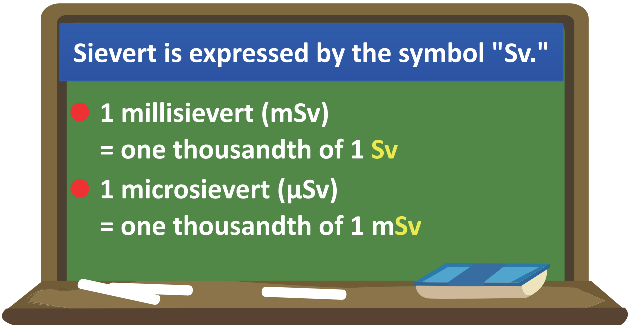
The extent of radiation effects on the human body varies according to the types of exposure, i.e., internal or external exposure, or whole-body or local exposure (p.23-p.27 of Vol. 1, "2.1 Exposure Routes"), and according to the types of radiation (p.13-p.22 of Vol. 1, "1.3 Radiation"). By using sieverts to express all types of exposure, it is possible to compare their effects on human health.

External exposure of 1 mSv and internal exposure of 1 mSv have equal effects on health. 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.

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

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.* 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.

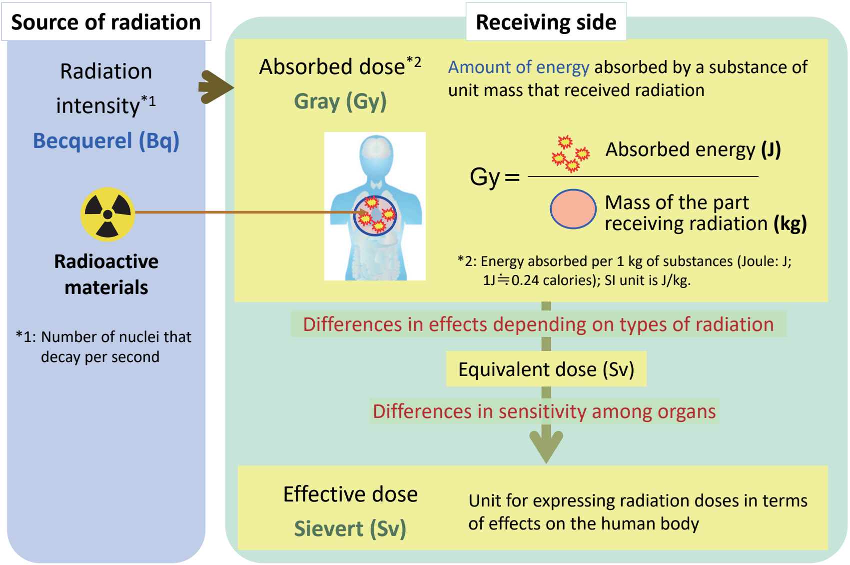
Becquerel (unit of radioactivity), curie (former unit of radioactivity) and gray (unit of absorbed dose) are all named after researchers who made significant contributions to the study of radiation.

* It is said that George Kaye at the National Physical Laboratory played a central role in founding the ICRP.
(Reference: ICRP Publication 109, The History of ICRP and the Evolution of its Policies, ICRP, 2009)

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

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

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

*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

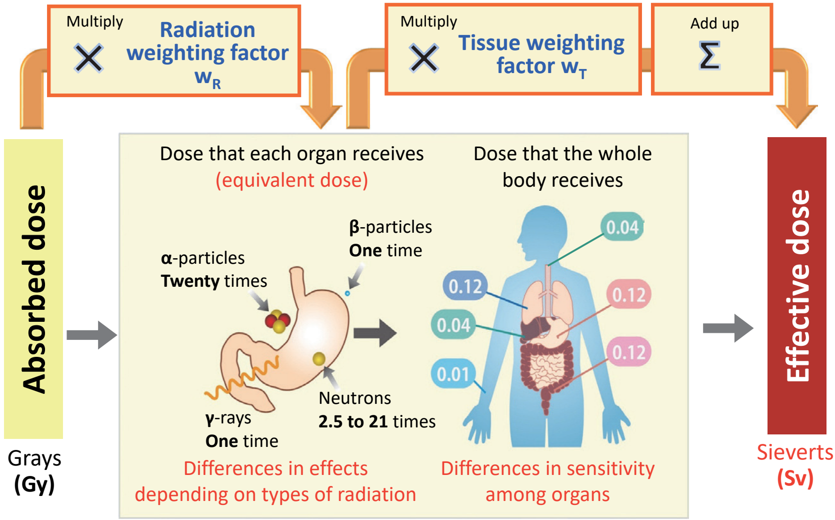
Units of radiation can be broadly divided into units for sources of radiation and units for the receiving side. Becquerel, a unit of radioactivity, is used for sources of radiation. Units for the receiving side are gray and sievert.

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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

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-particles: 20; β-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.37 of Vol. 1, "Various Factors")

Included in this reference material on March 31, 2013
Updated on March 31, 2017

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-particles have 20 times larger effects on the human body than γ-rays and β-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.36 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. 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 hereditary effects of radiation were observed. 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

Calculation of Equivalent Dose and Effective Dose

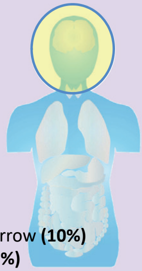
Effective dose (sievert (Sv)) = Σ (Tissue weighting factor × Equivalent dose)

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.

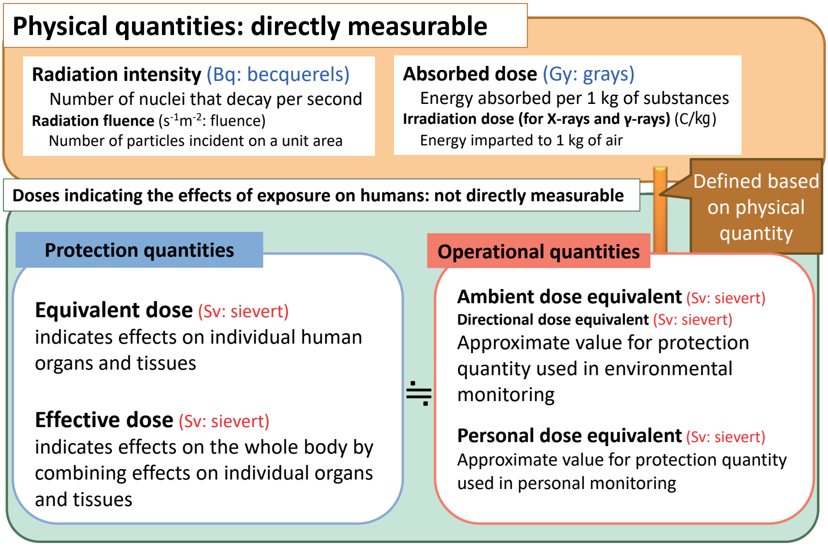
If only the head is exposed to 1 mGy in radiation inspection, the organs and tissues in the head, such as the thyroid, brain and salivary gland, are entirely exposed to radiation, so equivalent doses are 1 mSv for all these organs and tissues. For organs and tissues that are only partly present in the 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.35 of Vol. 1, "Relationship between Units")

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

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

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

Defined based on physical quantity

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.40 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Units of Radiation

Dose Equivalents:

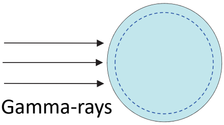
Measurable Operational Quantities for Deriving Effective Doses

Dose equivalent = Absorbed dose at a reference point meeting requirements × Quality factor

To substitute for "effective doses" that cannot be actually measured, "operational quantities" that can be measured 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)

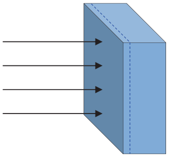
Dose equivalent occurring at a depth of 1cm from the surface of an ICRU sphere, which is 30 cm in diameter and simulates human tissue, placed in a field where radiation is coming from one direction; Ambient dose equivalent is used in measurements of ambient doses using survey meters, etc.



Personal dose equivalent (1cm 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 estimating effective doses that cannot be actually measured (p.39 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 Hp(d) for evaluating personal exposure, and the directional dose equivalent H' (d,α) (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.

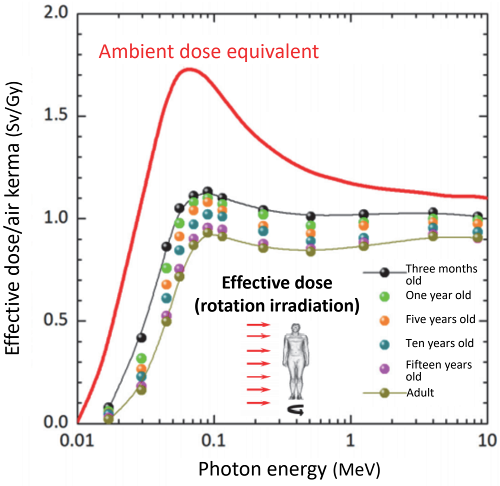
Generally, both the ambient dose equivalent and the personal dose equivalent are also called 1 cm dose equivalents because a depth of 1 cm is used in the case of exposure to γ-rays.

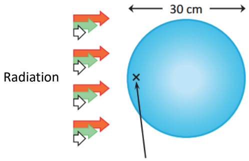
However, while the ambient dose equivalent is measured using measuring instruments that are less affected by directivity, such as a stationary ionization chamber and a survey meter, the personal dose equivalent is measured using a small personal dosimeter worn on the trunk of the body, so incidence from 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.

Included in this reference material on March 31, 2017

Units of Radiation

Difference between Values of Effective Dose and Dose Equivalent





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.

Extract from 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.

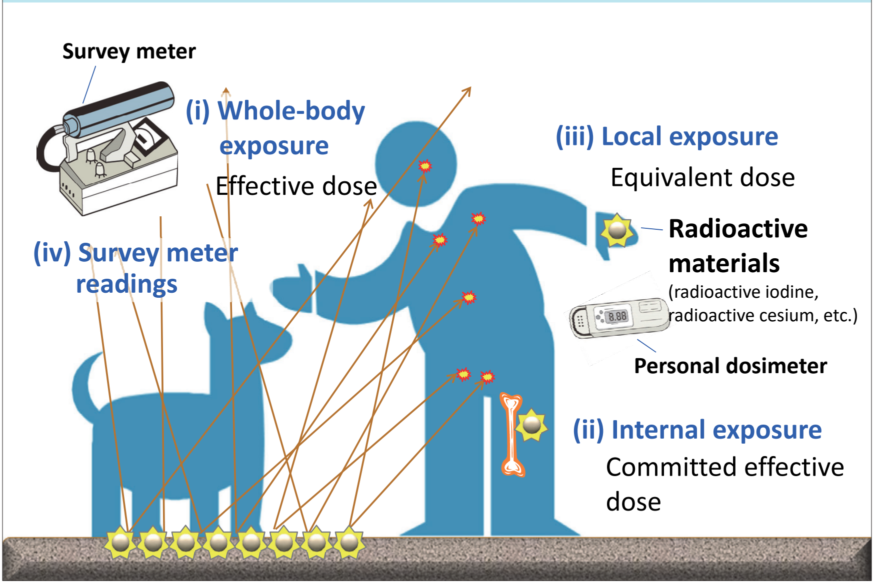
This is also the case for a personal dosimeter when measuring radiation incident only from the front. However, in a setting where a personal dosimeter is worn on the body and radiation sources are evenly distributed, measured value will be close to the value of "effective dose" because of the self-shielding 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.40 of Vol. 1, "Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses")

Included in this reference material on March 31, 2017

Units of Radiation

Doses in Units of Sieverts

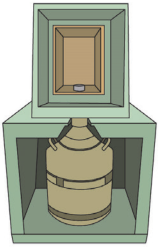


Sievert is used as the unit for (i) radiation dose to the whole body (effective dose) (p.41 of Vol. 1, "Difference between Values of Effective Dose and Dose Equivalent"), (ii) radiation dose due to internal exposure (committed effective dose) (p.53 of Vol. 1, "Committed Effective Doses"), and (iii) dose 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 hereditary effects on individuals or tissues exposed.

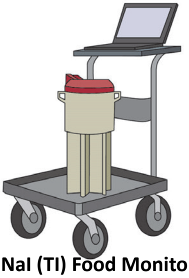
Sievert may also be used for (iv) the readings of survey meters. These values are obtained by multiplying absorbed doses (gray) in the air by a certain factor for conversion to sievert, and are indicated as larger approximations of effective doses received by humans. They may be considered as approximations of effective doses in sieverts when the whole body is evenly exposed to radiation (p.43 of Vol. 1, "Various Measuring Instruments").

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

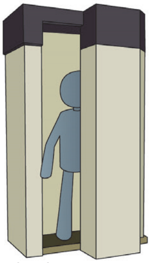
Various Measuring Instruments



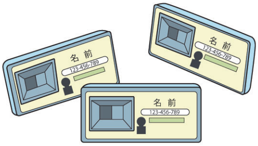
Ge Semiconductor Detector
Used to measure radioactivity in foods or soil; Effective in measuring low levels of radioactivity concentrations



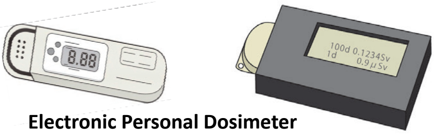
NaI (Tl) Food Monitor
Suitable for efficient radioactivity measurement of foods, etc.



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.44 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.

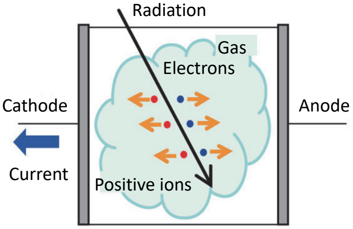
Also commercially available are whole-body counters that use numerous scintillation counters or Ge detectors worn on the body to assess accumulation of γ-ray nuclides in the body, as well as integrating personal dosimeters and electronic personal dosimeters for managing personal exposure. In particular, 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Principles of Radiation Measurement

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

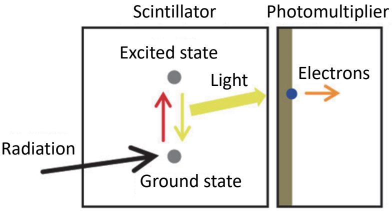
Ionization (with gas atoms)



- 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.

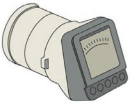
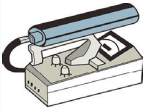
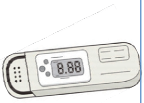
Geiger Muller (GM) counter survey meters and ionization chambers utilize the ionization between radiation and gas atoms. Ionization effect refers to the process in which radiation ejects electrons from nuclei in a substance. Detectors of GM counter survey meters and ionization chambers are filled with 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.

NaI (Tl) scintillation survey meters utilize excitation with substances. Radiation gives energy to electrons of 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. Aside from NaI (Tl) scintillation survey meters, germanium semiconductor detectors also utilize the excitation effect for radiation measurement.

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

Included in this reference material on March 31, 2017

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	Most 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-particles and are thus suitable for inspecting body surface contamination. They are 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 (becquerels), 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Dose Measurement and Calculation

Methods of Measuring Doses

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

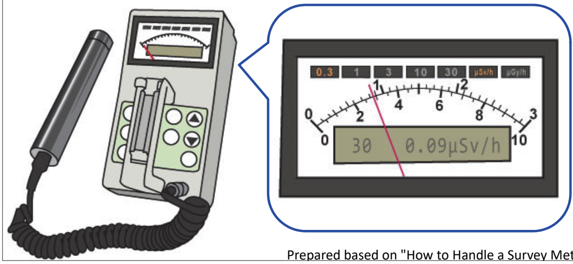
(i) Background measurement

(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, in principle, 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.

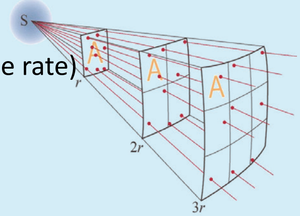
Included in this reference material on March 31, 2017

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 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, 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.

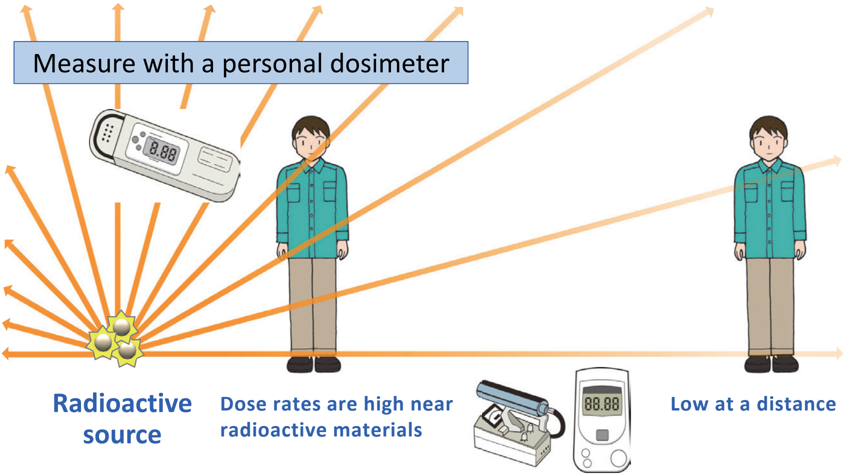
Calculation of external exposure doses is based not on the radioactivity intensity (becquerels) but on the amount of radiation (grays or sieverts) the human body is exposed to.

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.

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

Dose Measurement and Calculation

External Exposure (Measurement)



Measure with a personal dosimeter

Radioactive source

Dose rates are high near radioactive materials

Low at a distance

Survey meter measurement: Ambient dose rate (microsieverts/h) multiplied by the time spent in the relevant location roughly shows an external exposure dose.

Wearing a personal dosimeter on the body is one of the means to measure doses due to external exposure. Personal dosimeters can measure cumulative amounts of radiation exposure for an extended period of time, and provide hourly readings.

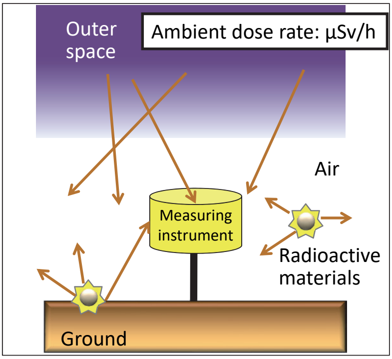
Another means is to measure radiation dose rates in a workplace with a survey meter to estimate the level of exposure supposing that a person stays in that place. Since α-particles and β-particles from outside the body do not reach into the body (p.22 of Vol. 1, "Penetrating Power and Range of Effects on the Human Body"), γ-rays are measured to obtain doses due to external exposure. Many recent instruments provide readings in microsieverts per hour, 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.

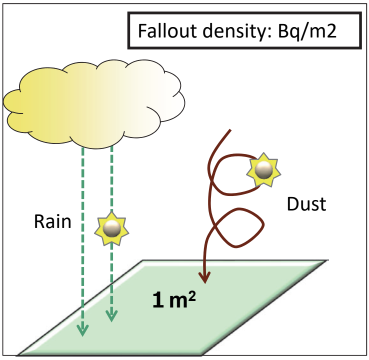
Included in this reference material on March 31, 2013
Updated on February 28, 2018

Dose Measurement and Calculation

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.

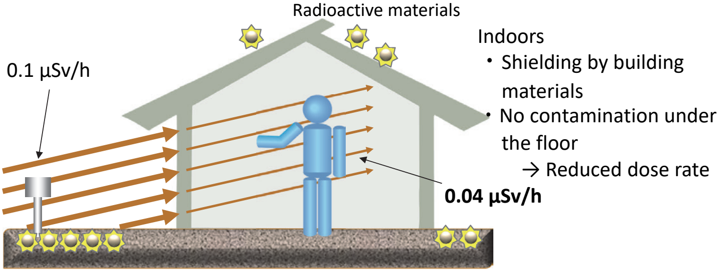
Normally, a measuring instrument is placed at a height of about 1 m from the ground, because most important internal organs are located at this height in the case of an adult.

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.

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

Shielding and Reduction Coefficient



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 450-900m^2 wide	**0.05**
Upper floors of a building with each floor 900m^2 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: "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.45 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. When radioactive materials are mainly on the soil surface, the amount of radiation becomes smaller on higher floors because of increasing distance from the soil.

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

Additional Exposure Doses after an Accident (Example of Calculation)

It is important to subtract values in normal times.

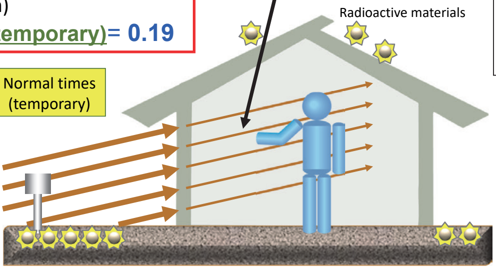
Dose rate (increase due to an accident: µSv/h)
0.23 – 0.04(temporary)= 0.19

Normal times (temporary)

Actual measurement (example)

Reduction coefficient: 0.4

When the time staying outdoors/indoors is 8 hours/16 hours



Derived from an accident

0.19 × 8 hours (outdoors)
+
0.19 × 0.4 × 16 hours (indoors)
(µSv/day)

× 365 days ≒1,000µSv/year

≒ 1.0 mSv/year

The ambient dose rate measured with a survey meter includes γ-rays from nature. 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" (http://www.kankyo-hoshano.go.jp, in Japanese).

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

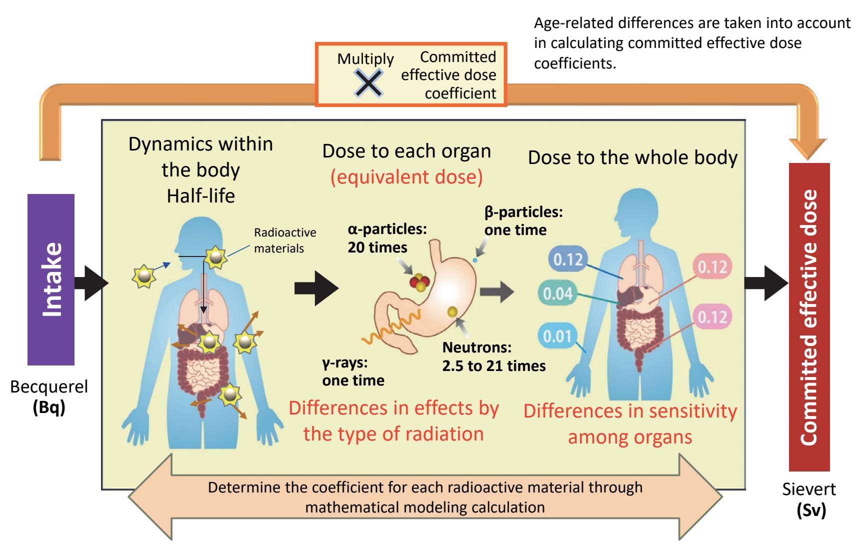
The calculation example above for obtaining additional exposure doses after the accident is under the assumption that a person stays outdoors for eight hours and stays in a traditional Japanese house with a reduction coefficient of 0.4 for 16 hours. A daily additional exposure dose is calculated in this manner and an annual additional exposure dose is further estimated by multiplying it by 365, the number of days in a year.

An ambient dose rate of 0.23 µSv/h, which is the threshold for carrying out decontamination, is derived from an annual additional exposure dose of 1mSv (hourly exposure dose of 0.19 µSv, which will become 1 mSv in annualized terms under the same assumption on the safe side as applied in the calculation example above, plus 0.04 µSv (exposure dose due to natural radiation)).

This calculation example is for external exposure and is rather conservative without considering physical attenuation of radioactive materials and weathering effects due to transfer of radioactive materials by wind and rain, etc.

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

Calculation of Internal Exposure Doses



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.

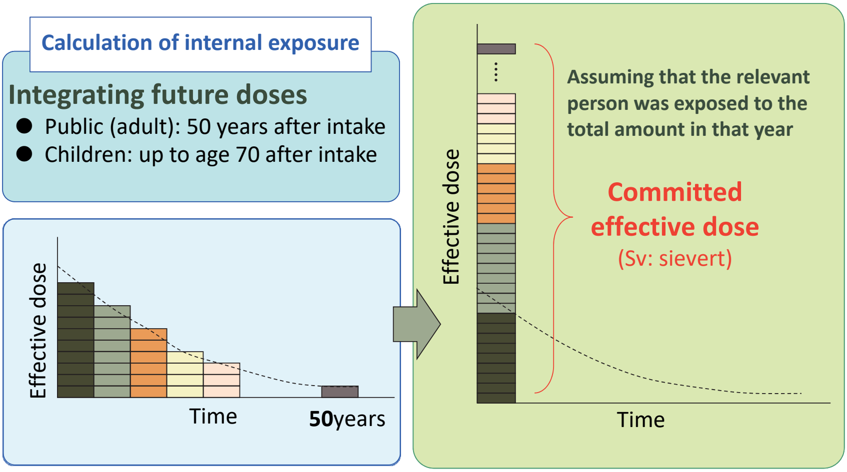
Mathematical model calculation is performed for each of these different conditions to determine the relationship between the intake of radioactive materials and the absorbed dose of each organ and tissue. Then, differences in sensitivity by types of radiation and among different organs are taken into 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.53 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.54 of Vol. 1, "Conversion Factors to Effective Doses").

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

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.

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

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

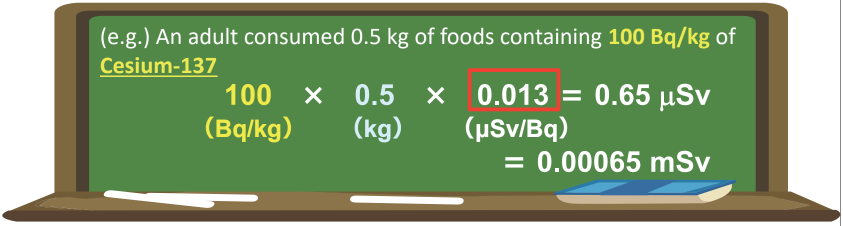
Source: ICRP Publication 119, Compendium of Dose Coefficients based on ICRP Publication 60, 2012, International Commission on Radiological Protection (ICRP)

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.

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

Exposure Doses from Foods (Example of Calculation)



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

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

$$= 0.00065\ \mathrm{mSv}$$

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	$\boxed{0.013}$

Bq: becquerels; μSv: microsieverts; mSv: millisieverts

Source: 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.

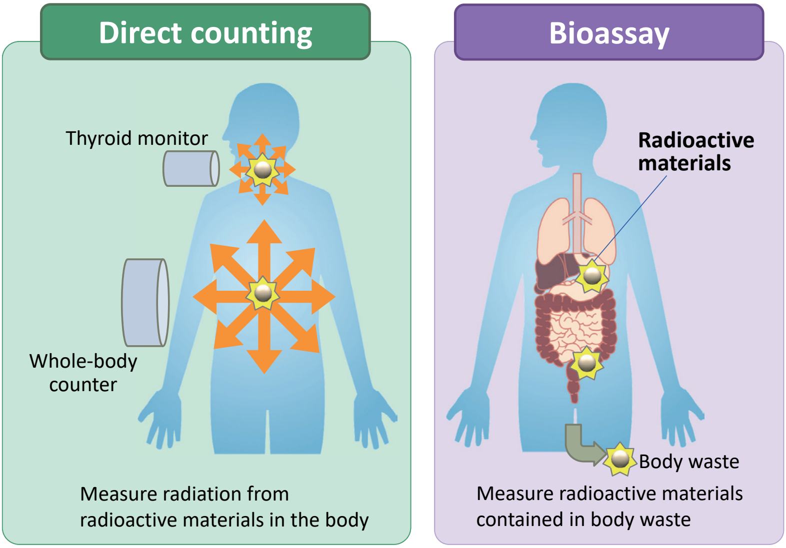
Suppose the person has consumed 0.5 kg of foods containing 100 Bq of Cesium-137 per 1 kg.

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.53 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.54 of Vol. 1, "Conversion Factors to Effective Doses").

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

Methods of Measuring Radioactivity for Estimation of Intake

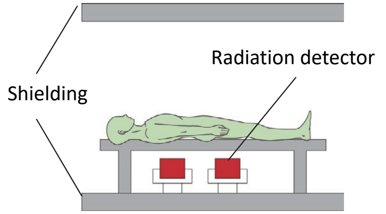
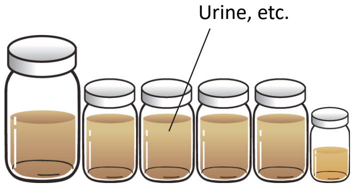


Direct counting methods that directly measure γ-rays coming from within the body or bioassay methods that measure the amount of radioactive materials in urine or feces are used to estimate the intake, which is required for calculating internal exposure doses.

Based on the results obtained using these methods, the time of intake of radionuclides, chemical forms, and intake routes (inhalation or ingestion) are taken into consideration and mathematical models (p.52 of Vol. 1, "Calculation of Internal Exposure Doses") are used to calculate the percentages of radioactive materials remaining in the body or found in body waste to determine the intake of respective radionuclides.

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

Comparison of Methods of Assessing Internal Radioactivity

Direct counting	Bioassay
Directly measure the human body	Indirect measurement
Need to spare time to receive direct measurements	Submit samples (urine, feces, etc.)
Mainly target materials that emit γ-rays	Able to measure all radioactive materials
Short measuring time using the apparatus	Chemical analysis takes time.
Accurate dose assessment	Large margin of error in results of dose assessment
	

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, so if measurements are carried out in locations with high ambient dose rates, sufficient shielding against environmental radiation is required. These instruments cannot measure radioactive materials that do not emit γ-rays.

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

For both methods, if the time when a detected radioactive material was taken in cannot be clearly determined, calculation results will have a larger margin of error.

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

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.

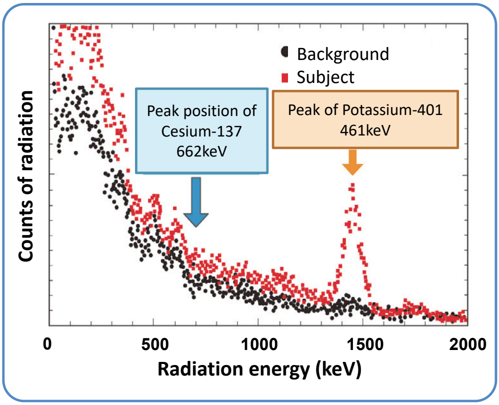
Since radioactive cesium is distributed throughout the body, a whole-body counter is used to measure its amount within the body. If internal exposure by radioactive iodine is suspected, a thyroid monitor is used, as iodine accumulates in the thyroid. A radiation detector is applied to the part of the 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.

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

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.

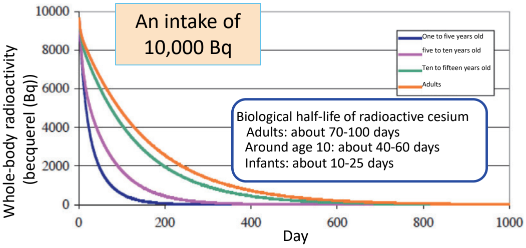
The black round dots in the graph represent values measured while no one is on the bed (background state). When the subject is on the bed, radiation peaks appear, as indicated by the red square dots. The energy of γ-rays is unique for each radioisotope. For example, radioactive potassium, K-40, emits 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").

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

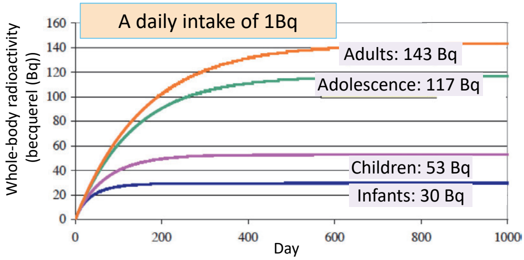
Dose Measurement and Calculation

Internal Radioactivity and Dose Assessment



Biological half-life of radioactive cesium
Adults: about 70-100 days
Around age 10: about 40-60 days
Infants: about 10-25 days

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,
- finite values are unlikely to be obtained for children.
- it is more reasonable to examine adults in order to detect trace intake.

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

Whole-body counters can measure the amount of internal radioactivity on the day of measurement but have a detection limit depending on machines' performance or measuring time, as do other measuring instruments.

Radioactive cesium has a biological half-life of 70-100 days for adults (p.11 of Vol.1, "Half-lives and Radioactive Decay"), so estimation of initial exposure would be effective for no longer than around a year after a nuclear accident. As shown in the upper figure, the radioactivity of cesium taken into the body approaches 0 Bq in a year or so because of its effective half-life, so the internal radioactivity returns to its previous value. Subsequent whole-body counting is performed for the purpose of estimating chronic exposure, mainly from foods (p.59 of Vol. 1, "Data on Internal Exposure Measured by Direct Counting").

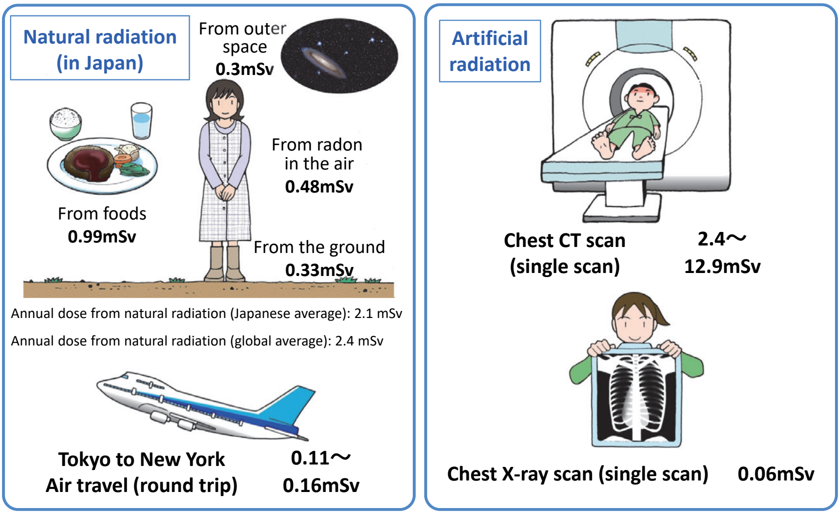
In contrast, children have high metabolism, so estimation of their initial exposure from an intake of a trace amount of radioactive materials would be only effective for around half a year after an accident, and estimation of their chronic internal exposure would often provide values below detection limits because not much of the radioactive materials remain in children's bodies. In such cases, it would be reasonable to examine adults for estimation of exposure, given that committed effective dose coefficients are similar for both children and adults even though their rates of metabolism are different.

To estimate committed effective doses from the measurement results of internal radioactivity, it is necessary to make an appropriate assumption and choose an appropriate model while taking into account whether exposure is acute or chronic, whether radioactive materials were taken in through inhalation or ingestion, the time of intake, and other factors.

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

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; and "Environmental Radiation in Daily Life (2011)," new edition, Nuclear Safety Research Association; ICRP (International Commission on Radiological Protection) 103, etc.

We are exposed to radiation in our daily lives without realizing it.

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.63 of Vol. 1, "Comparison of Exposure Doses per Year").

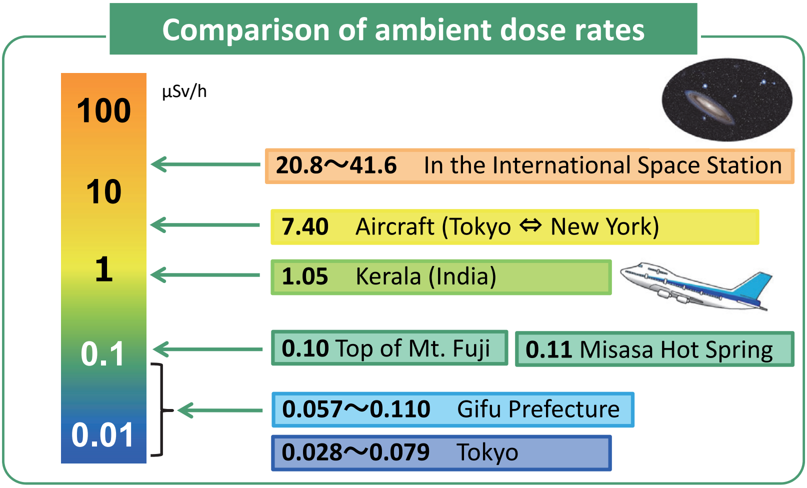
The percentage of medical exposure from radiological examinations is known to be high in Japan. This is considered due to the fact that CT scans, which involve high-dose exposure per examination, are quite common and upper gastro intestinal (UGI) examination is generally utilized for stomach cancer screening in Japan.

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

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)

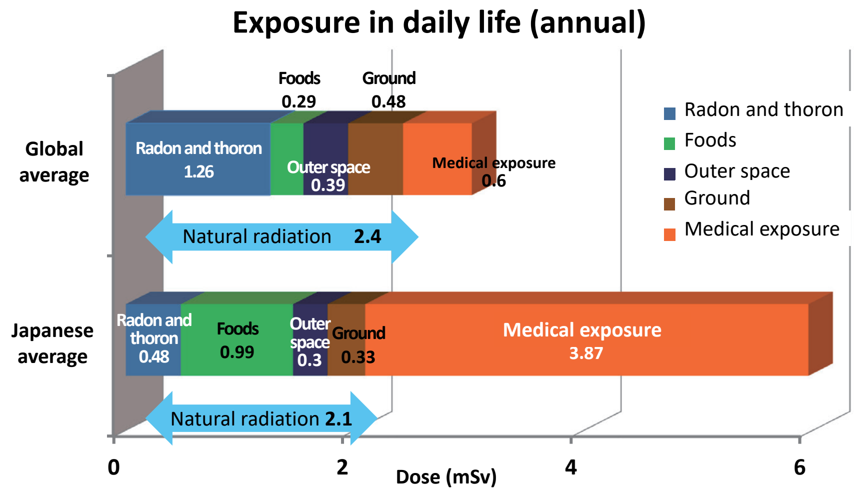
In outer space and aircraft, ambient dose rates are higher because of cosmic rays from galaxies and the Sun. Ambient dose rates are also high at high altitudes such as the top of Mt. Fuji, compared to low altitudes, because the influence of cosmic rays is stronger. At low altitudes, cosmic rays (radiation) 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.65 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. In contrast, ambient dose rates tend to be low in the Kanto Plain, where a loam layer covers the ground, shielding radiation from the ground (p.66 of Vol. 1, "Ground Radiation (Japan)").

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

Comparison of Exposure Doses per Year



Sources: Prepared based on the 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report; and "Environmental Radiation in Daily Life (2011)," Nuclear Safety Research Association

In December 2011, the Nuclear Safety Research Association announced Japan's national doses for the first time in 20 years. The survey shows that the annual average dose of Japanese people is 5.98 millisieverts, of which 2.1 millisieverts 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. In preparing this report, it has been found that 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 intake of fish and seafood (p.64 of Vol. 1, "Breakdown of Natural Exposure Doses (Japanese)").

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.

The above calculation of the national doses does not take into account the influences of the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS caused by the Great East Japan Earthquake. In the future, exposure doses due to the accident at the NPS will be added to the current average exposure doses in normal times.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Breakdown of Natural Exposure Doses (Japanese)

Type of exposure	Breakdown of radiation sources	Effective dose (mSv/year)
External exposure	Cosmic rays	**0.3**
	Ground 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.)	**0.01**
	Others (uranium, etc.)	**0.006**
Internal exposure (ingestion)	Mainly Lead-210 and Polonium-210	**0.80**
	Tritium	**0.0000082**
	Carbon-14	**0.01**
	Potassium-40	**0.18**
Total		**2.1**

Source: "Environmental Radiation in Daily Life (2011)," 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:

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)

They are deposited on the ground or settled in rivers and oceans and are taken into the human body through foods.

One reason why Japanese people's exposure doses from foods are higher compared to the rest of the world is that their diets contain lots of fish, which is rich in Polonium-210. This accounts for Japanese people's large effective doses.

On the other hand, exposure to Radon-222 and Radon-220 (thoron) is smaller among Japanese people, and this is considered to be due to the fact that traditional Japanese houses are well ventilated and Radon-222 and Radon-220 (thoron) that seep indoors from the ground are 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.68 of Vol. 1.

Tritium has smaller effects on the human body compared with other nuclides and exposure doses due to natural tritium are relatively small.

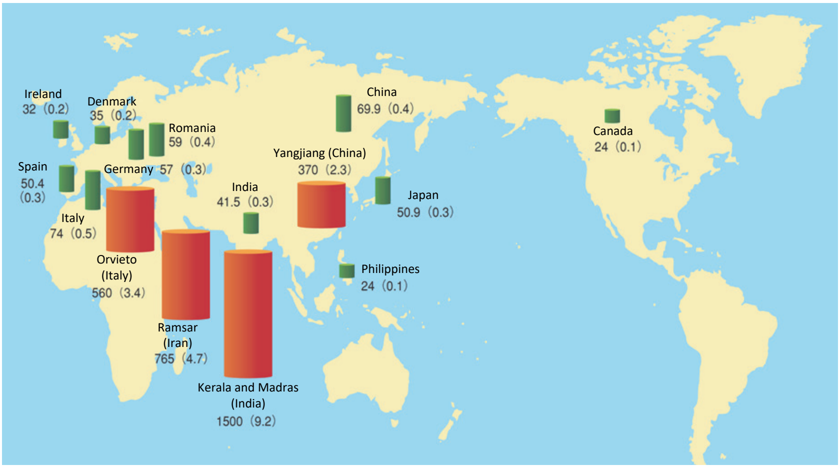
Included in this reference material on March 31, 2013
Updated on February 28, 2018

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 (2011)," Nuclear Safety Research Association

There are regions around the world where natural radiation is two to ten 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.119 of Vol. 1, "Effects of Long-Term Low-Dose Exposure"). In Ramsar, analysis on cancer risks is underway.

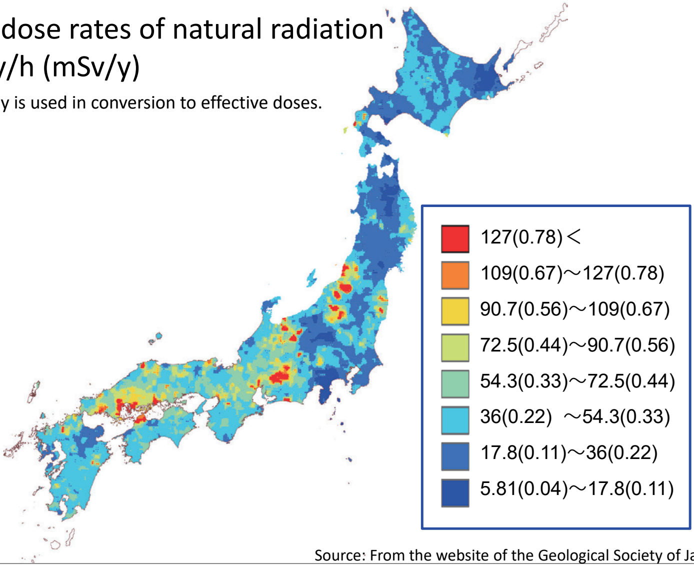
Included in this reference material on March 31, 2013
Updated on March 31, 2015

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.



Source: From the website of the Geological Society of Japan

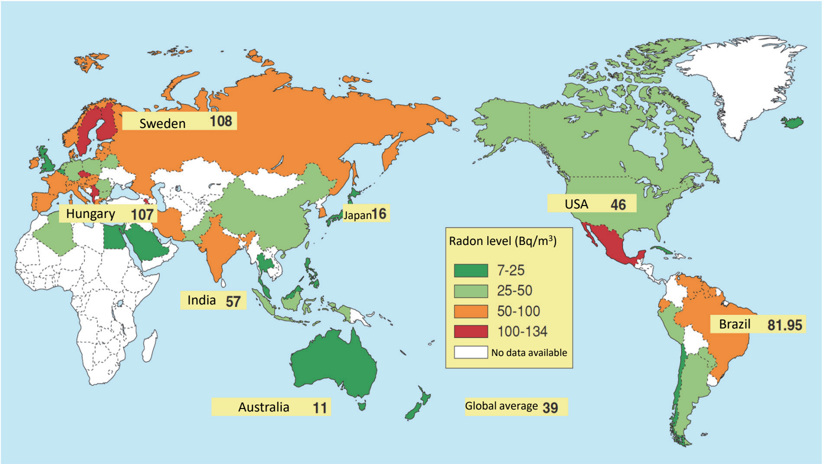
In Japan, like everywhere else, the amount of ground radiation varies from area to area. Comparison of ambient dose rates among different prefectures shows that there is a difference of 0.4 mSv per year between Gifu, where the ambient dose rates are highest, and Kanagawa, where the values are lowest.

In the Kanto Plain, where a loam layer shields radiation from the ground, the amount of ground radiation 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.

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

Indoor Radon

Regional differences in exposure from indoor radon
(arithmetic average: **Bq/m3**)



Bq/m3: becquerels/cubic meter

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

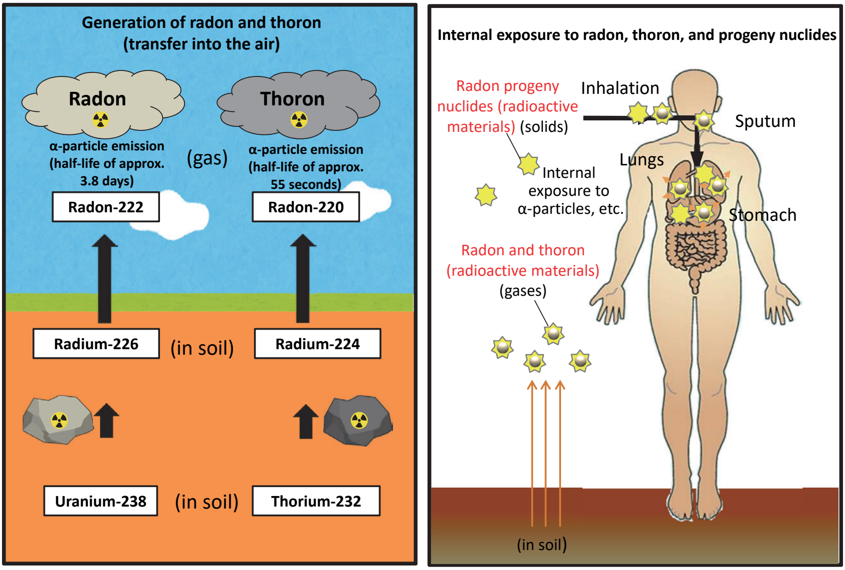
Radon is a radioactive noble gas produced by the alpha-decay of radium, which is universally present under the ground. Since radon is a gas, it is emitted from the ground and seeps into houses (p.68 of Vol. 1, "Internal Exposure to Radon and Thoron through Inhalation").

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/m3, while Japan has an average value of 16 Bq/m3. 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., people inhale radon and thoron in their lives on a daily basis. Inhaled radon reaches the lungs and emits α-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.

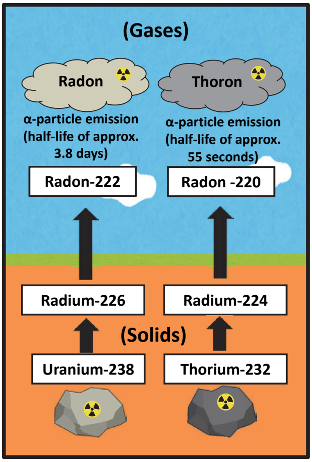
Radon contributes less to internal exposure than its progeny nuclides. This is because radon, being a gas, is easily exhaled, while radon progeny nuclides, i.e., radioactive Polonium-218 and Lead-214 that is created through decay of the former, are solids and therefore not easily expelled out of the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

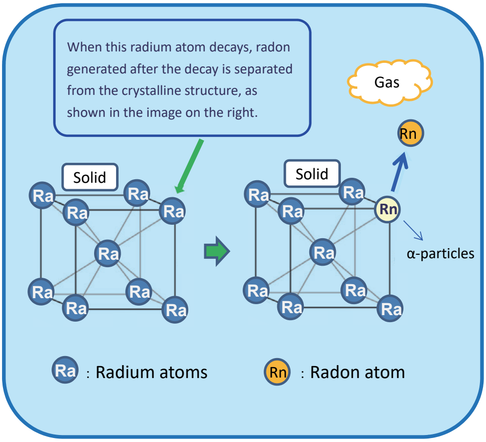
Included in this reference material on March 31, 2015
Updated on March 31, 2016

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-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-particles and γ-rays, causing internal exposure from food intake (p.73 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

Radiation Doses from Medical Diagnosis

Type of examination	Diagnostic reference levels*1	Actual exposure dose*2	
		Dose	Type of dose
General imaging: Front chest	0.3mGy	0.06mSv	Effective dose
Mammography (mean glandular dose)	2.4mGy	Around 2 mGy	Equivalent dose (Mean glandular dose)
Fluoroscopy	IVR (InterVentional Radiology): Fluoroscopic dose rate 20 mGy/sec	Gastric fluoroscopy Around 4.2-32 mSv*3 (varies depending on operators and subjects)	Effective dose
Dental imaging	From 1.1 mGy at the frontal teeth of the mandible to 2.3 mGy at the molar teeth of the maxilla	Around 2-10 µSv	Effective dose
X-ray CT scan	Adult head simple routine: 85 mGy	Around 5-30mSv	Effective dose
	Child (age 6-10), head: 60mGy		
Nuclear scanning	Value for each radioactive medicine	Around 0.5-15mSv	Effective dose
PET scan	Value for each radioactive medicine	Around 2-20mSv	Effective dose

* 1 : "Diagnostic Reference Levels based on the Latest Survey within Japan," J-RIME, etc., June 7, 2015 (partially updated on August 11, 2015) (http://www.radher.jp/J-RIME/)

* 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 (http://www.nirs.qst.go.jp/rd/faq/medical.html)

* 3 : Prepared based on "Gastric Fluoroscopy" in "X-ray Medical Checkup" in "Basic Knowledge on Medical Radiation," (http://www.khp.kitasato-u.ac.jp/hoshasen/iryo/), Kitazato University Hospital, Radiology Department

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

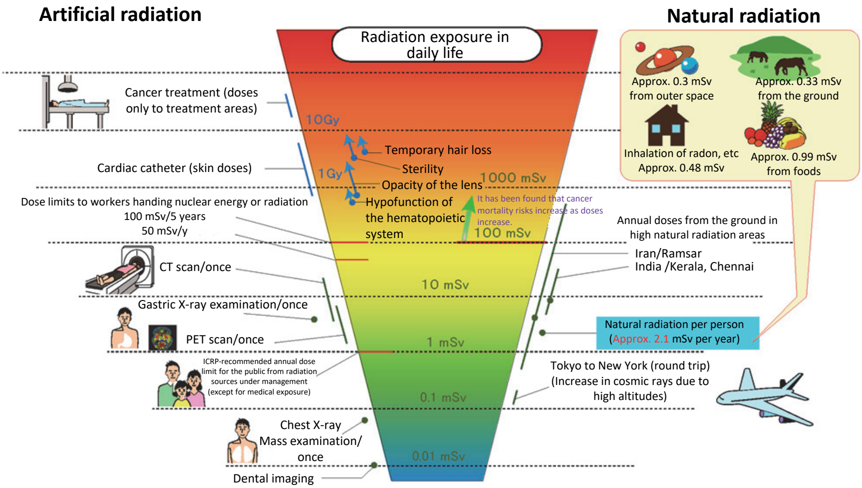
Exposure doses from radiological examinations vary by the types of examinations. Some examinations, such as dental imaging, only involve very slight, local exposure, while some other examinations, such as X-ray CT scans and nuclear scanning, involve relatively high exposure doses. Even with the same type of examination, doses could vary widely depending on the medical institution. It is therefore recommended to use diagnostic reference levels as criteria for determining whether doses might be too high for diagnosis. 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)* created Japan's first diagnostic reference levels based on the results of surveys conducted by participating organizations ("Diagnostic Reference Levels based on the Results of the Latest National Survey," Japan Association on Radiological Protection in Medicine, etc., June 7, 2015 (partially updated on August 11, 2015)).

Note*: 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 (source: website of the National Institute of Radiological Sciences of National Institutes for Quantum and Radiological Science and Technology: http://www.nirs.qst.go.jp/rd/structure/merp/j-rime.html, in Japanese).

Included in this reference material on March 31, 2013
Updated on March 31, 2017

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
- "Life Environmental Radiation (Calculation of the National Dose)," new edition

Prepared by the National Institute of Radiological Sciences based on the sources above (May 2013)

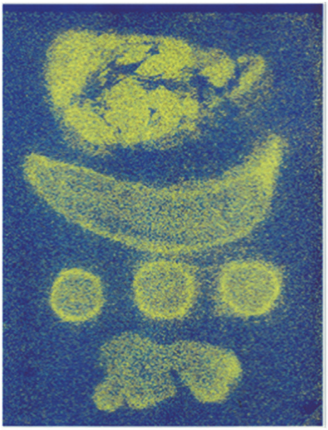
mSv: millisieverts

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.71 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.

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

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 × 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-particles and γ-rays.

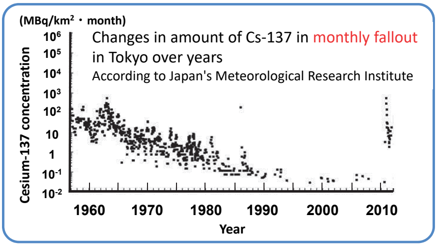
The distribution of potassium can be found by using an imaging plate and detecting β-particles from Potassium-40.

The above image was obtained by placing pieces of pork meat, banana and ginger on an imaging plate and exposing for 25 days while 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.

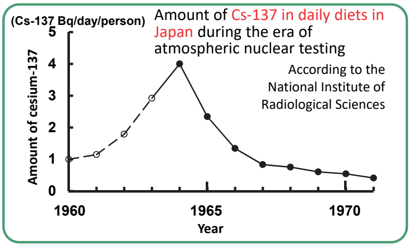
Included in this reference material on March 31, 2013
Updated on March 31, 2015

Effects of Radioactive Fallout due to Atmospheric Nuclear Testing

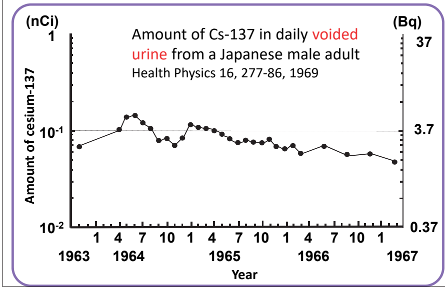
Internal radioactivity: Body weight: 60 kg	**Potassium-40: 4,000 Bq; Carbon-14: 2,500 Bq; Rubidium-87: 520 Bq; Tritium: 100 Bq**


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

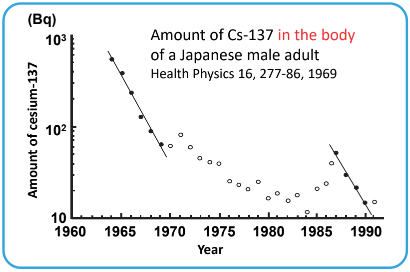
According to Japan's Meteorological Research Institute


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 16, 277-86, 1969

MGq: megabecquerels, nCi: nanocuries※

Large amounts of artificial radionuclides were released into the environment during the era of atmospheric nuclear testing. 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.

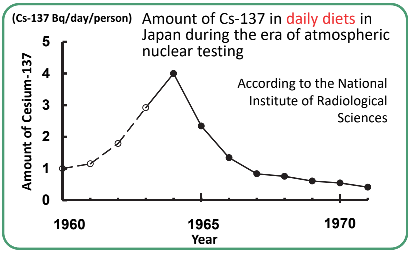
Because there is a time lag between contamination of foods with cesium and their consumption, the amount of radioactive cesium in daily diets was highest in 1964, then dropped sharply by 1967, and has been decreasing relatively slowly since then.

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 Chernobyl nuclear disaster.

*Curie (Ci): Unit of radioactivity; 1 nanocurie (1 nCi) is 10-9 of one curie (1 Ci), i.e., a billionth of one curie.

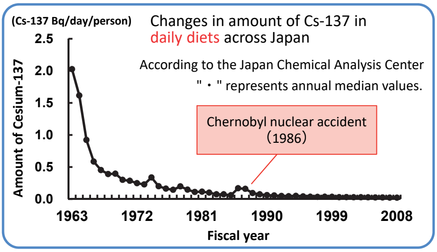
Included in this reference material on March 31, 2013
Updated on February 28, 2018

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:

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

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

Source: "Environmental Radiation in Daily Life (2011)," Nuclear Safety Research Association (2011)

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. 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 Chernobyl 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

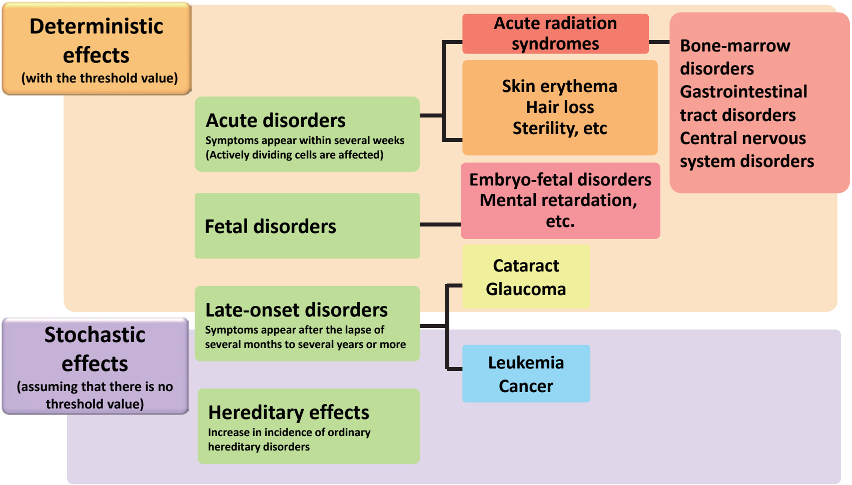
Chapter 3

Health Effects of Radiation

Effects on Human Body

Types of Effects

▶ Consideration is to be given to whether any health effects arise after radiation exposure and what effects, if any, the amount of radiation, parts exposed to radiation (whole-body exposure or local exposure), and exposure modes (acute, chronic or fractionated exposure).



Deterministic effects
(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 deterministic effects and stochastic effects. The above figure compiles these two effects.

Deterministic effects 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. They 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 confirmed among laboratory animals.

(Related to p.79 of Vol. 1, "Classification of Radiation Effects," and p.80 of Vol. 1, "Deterministic Effects and Stochastic Effects")

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

Effects on Human Body

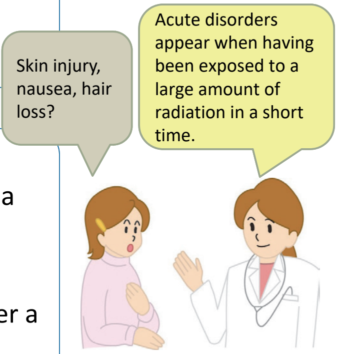
Exposure Modes and Effects

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

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

Acute exposure
(Exposed to a large amount of radiation in a short time)

Chronic exposure
(Exposed to a small amount of radiation over a long period of time)



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.

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

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 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 
	Hereditary 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 on the human body are classified into those appearing in a person exposed to radiation and those 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 and stochastic effects.

Deterministic effects 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 (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 hereditary disorders. Radiation may damage DNA, which may result in genetic mutation (p.84 of Vol. 1, "Radiation Damage to DNA"). Each mutation is unlikely to lead to diseases independently, but theoretically, the possibility of causing cancer or a hereditary disorder cannot be completely denied. Therefore, cancer or hereditary disorders are managed on the safe side under the assumption that there is no threshold dose.
(Related to p.80 of Vol. 1, "Deterministic Effects and Stochastic Effects")

Included in this reference material on March 31, 2013
Updated on March 31, 2017

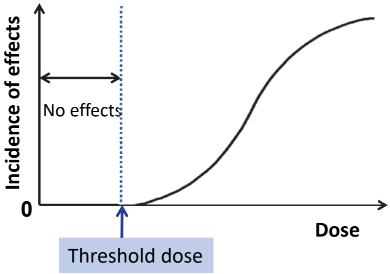
Effects on Human Body

Deterministic Effects and Stochastic Effects

Deterministic effects

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

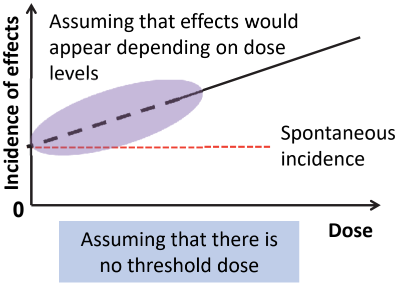
When a number of people were exposed to the same dose of radiation and certain symptoms appear in 1% of them, said dose is considered to be the threshold dose.
(2007 Recommendations of the International Commission on Radiological Protection (ICRP))



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 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.

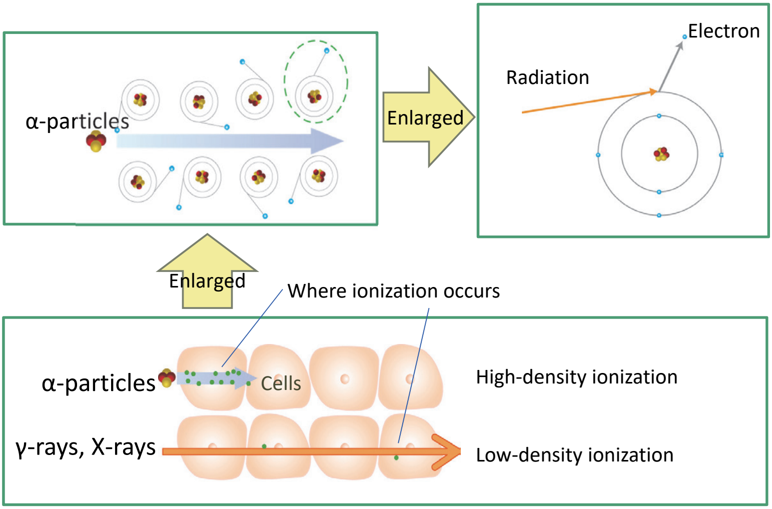
On the other hand, in radiological protection, it is assumed that there is no threshold dose for stochastic effects. Under this assumption, the possibility that radiation exposure even at extremely low doses may exert some effects can never be eliminated. It is very difficult to epidemiologically detect 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).

When assessing cancer risks due to low-dose exposures, results of the epidemiological surveys 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. 150 mSv. However, it is not clear whether risks also increase linearly in the case of radiation exposure at doses below 150 mSv. Additionally, 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 when the total exposure doses are the same.

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

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.

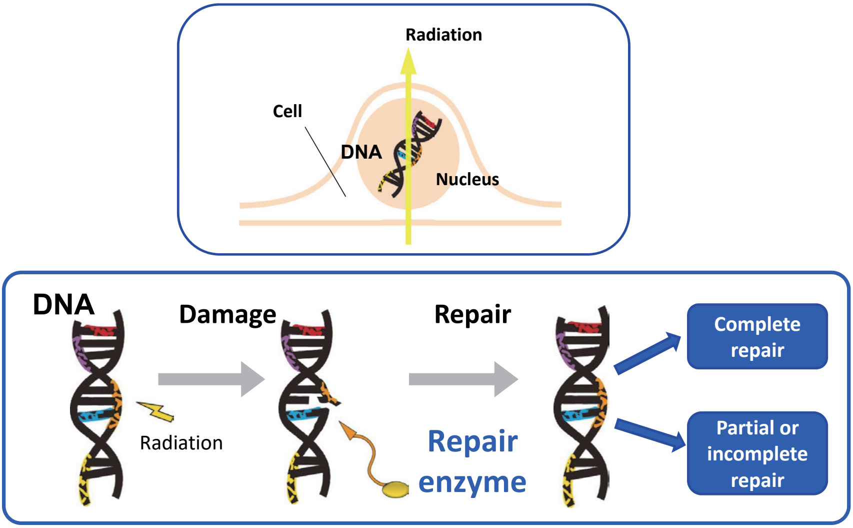
The density of energy provided by radiation differs by the type of radiation. Compared with β-particles and γ-rays, α-particles provide energy more intensively to substances in an extremely small area. Due to such difference in the ionization density, damage to cells differs even with the same absorbed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

The process in which radiation directly damages biomolecules is called direct action. As approximately two-thirds of a cell consists of water, radiation also causes the ionization of water. Radical components, which are created through the ionization and facilitate chemical reactions, damage biomolecules. This process is called indirect action (p.83 of Vol. 1, "DNA→Cells→Human Body").

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

Mechanism of Causing Effects on Human Body

Damage and Repair of DNA



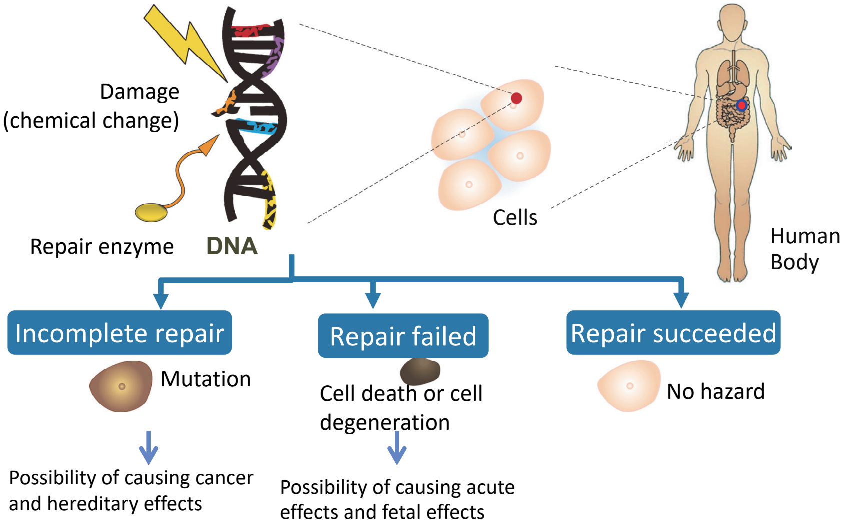
Cells have DNA, the blueprint of life. DNA consists of two chains of sugar, phosphate and four different bases. As the genetic information is incorporated in the arrangement of these bases, bases are combined firmly to mutually act as a template in order to maintain the arrangement. When DNA is irradiated, it may be partially damaged depending on the amount of radiation (p.84 of Vol. 1, "Radiation Damage to DNA").

DNA is damaged not only by radiation but also by carcinogens in foods, tobacco, chemical substances in the environment and active 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.83 of Vol. 1, "DNA→Cells→Human Body").

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

Mechanism of Causing Effects on Human Body

DNA→Cells→Human Body



When radiation hits a cell, it may damage DNA (genes) inside the cell, but such damage is repaired by inherent human body systems.

Minor damage is successfully repaired and DNA is 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 will appear, such as hair loss, cataract, skin injury or other acute disorders, as well as fetal disorders (p.85 of Vol. 1, "Lapse of Time after Exposure and Effects," and p.86 of Vol. 1, "Deterministic Effects").

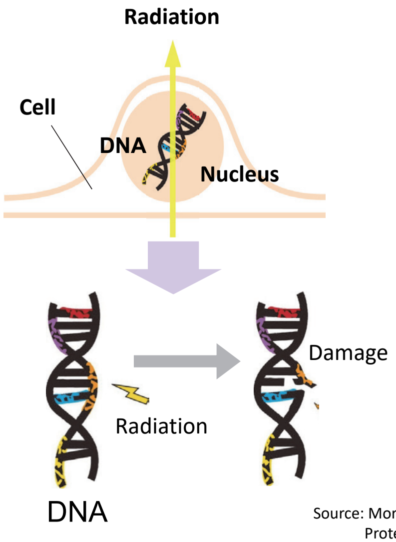
When a cell in which genes were not completely repaired survives, cell genes may mutate and cause stochastic effects such as cancer or hereditary disorders.

DNA is damaged not only by radiation but also by carcinogens in foods, tobacco, chemical substances in the environment and active 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. Approx. 85% of radiation effects are caused by active oxygen, etc. created by radiation and approx. 15% is direct damage by radiation.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Mechanism of Causing Effects on Human Body

Radiation Damage to 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)

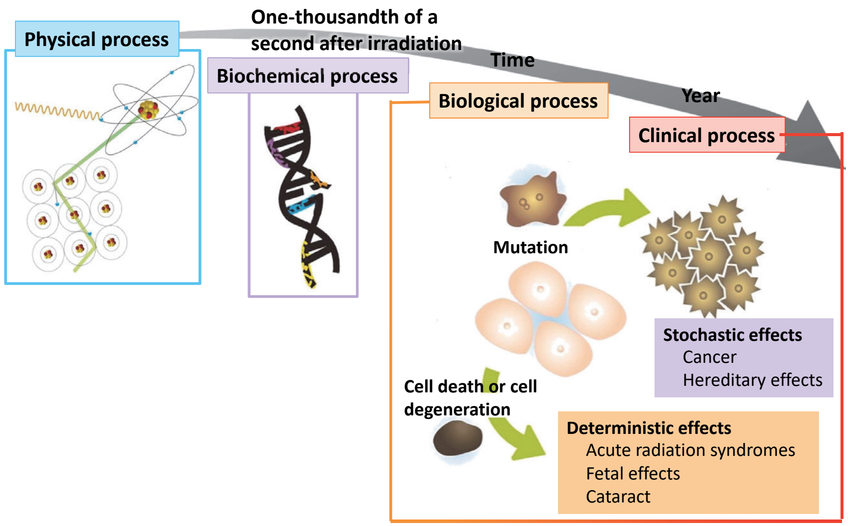
When radiation hits DNA, part of the DNA may break depending on the amount of radiation.

It is said that exposure to 1 mGy of X-rays causes a single-strand break at one location per cell on average. This amount of radiation is equivalent to 1 mSv. Double-strand breaks occur less frequently, at 0.04 locations per cell, which means that if 100 cells are evenly exposed to 1 mGy of X-rays, double-strand breaks occur in four cells.

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

Mechanism of Causing Effects on Human Body

Lapse of Time after Exposure and Effects



Physical process

One-thousandth of a second after irradiation

Biochemical process

Time

Biological process

Year

Clinical process

Mutation

Cell death or cell degeneration

Stochastic effects
Cancer
Hereditary effects

Deterministic effects
Acute radiation syndromes
Fetal effects
Cataract

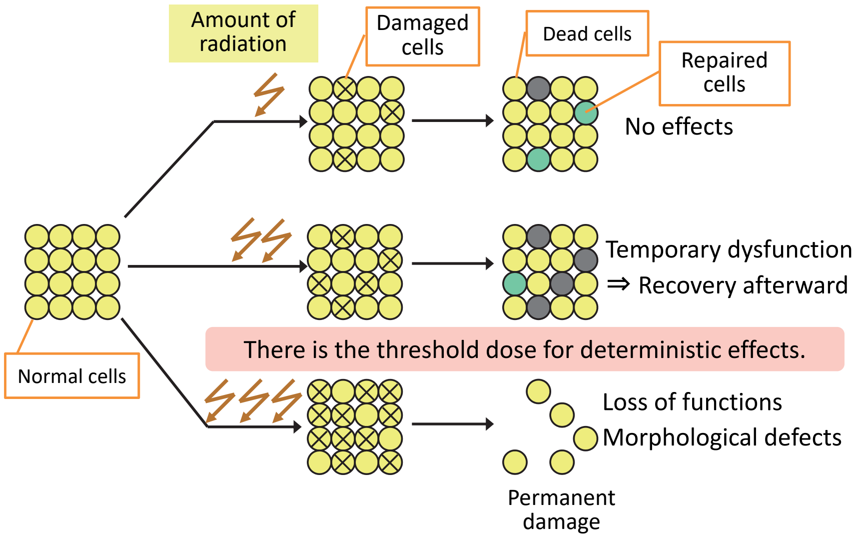
In as short a time as one-thousandth of a second after irradiation, DNA breaks and base damage occur. In a second after irradiation, DNA repair starts, and if repair fails, cell deaths and mutation occur within an hour to one day. It takes some time until such reaction at the cell level develops into 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.107 of Vol. 1, "Mechanism of Carcinogenesis")

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

Mechanism of Causing Effects on Human Body

Deterministic Effects



Amount of radiation

Damaged cells

Dead cells

Repaired cells

No effects

Normal cells

Temporary dysfunction
⇒ Recovery afterward

There is the threshold dose for deterministic effects.

Loss of functions
Morphological defects

Permanent damage

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.

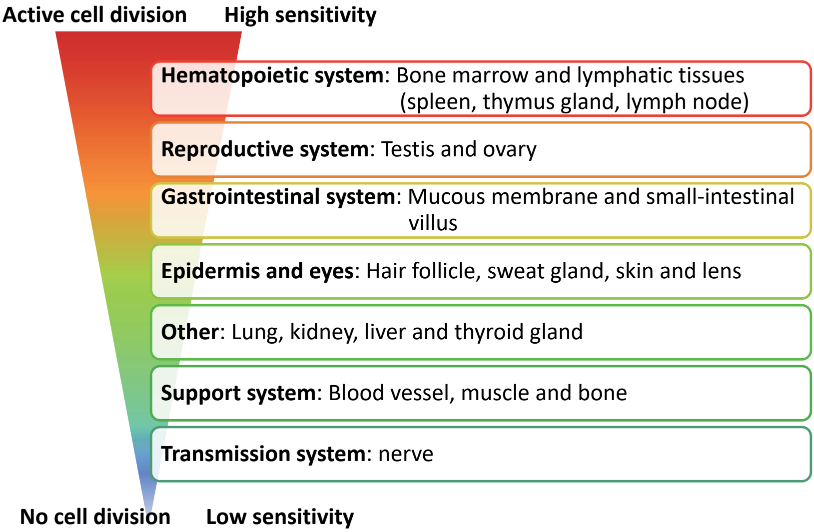
When cells in tissues or organs are damaged severely due to a large amount of radiation, this may lead to permanent cell damage or morphological defects.

In this manner, for deterministic effects 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.91 of Vol. 1, "Threshold Values for Various Effects").

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

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.

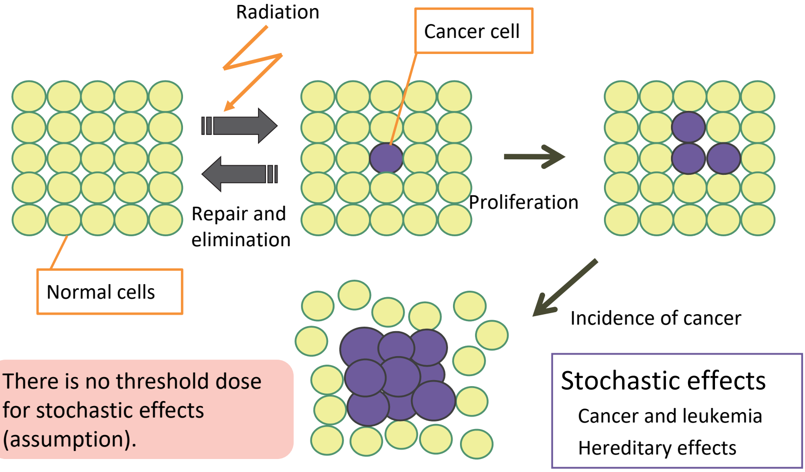
As a result, the supply of blood cells is suspended and the number of various types of cells in blood decreases. In addition, the epithelium of the digestive tract is constantly metabolized and is also highly sensitive to radiation.

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.

Included in this reference material on March 31, 2013

Mechanism of Causing Effects on Human Body

Stochastic Effects



Radiation

Cancer cell

Repair and elimination

Proliferation

Normal cells

Incidence of cancer

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

Stochastic effects

Cancer and leukemia

Hereditary effects

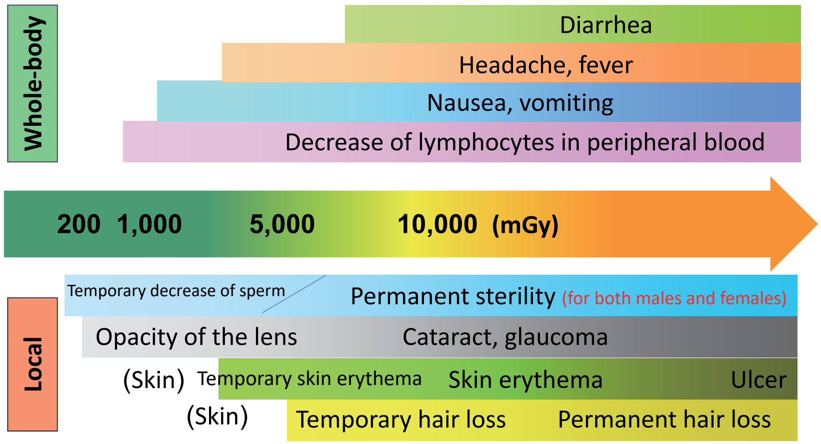
Risks of effects of cellular mutation are considered to increase even if mutation occurs in a single cell.

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, 2015

Deterministic Effects

Whole-body Exposure and Local Exposure



Whole-body

Diarrhea

Headache, fever

Nausea, vomiting

Decrease of lymphocytes in peripheral blood

200 1,000 5,000 10,000 (mGy)

Local

Temporary decrease of sperm

Permanent sterility (for both males and females)

Opacity of the lens

Cataract, glaucoma

(Skin) Temporary skin erythema

Skin erythema

Ulcer

(Skin) Temporary hair loss

Permanent hair loss

Source: Rearranged 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 symptoms naturally heal.

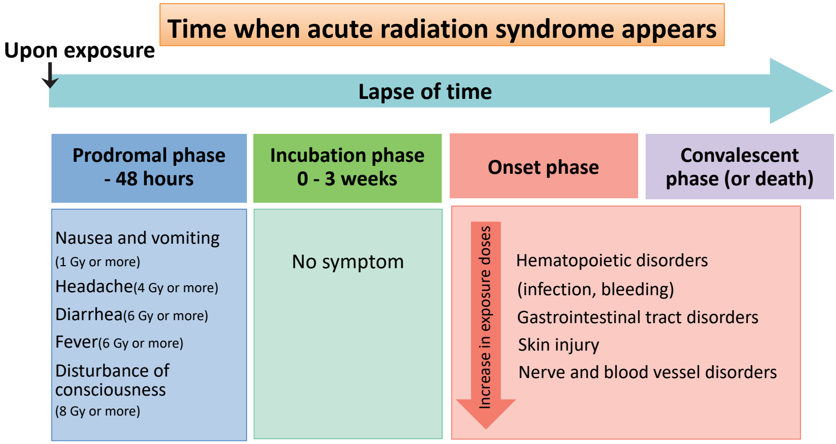
On the other hand, radiation exposure at levels exceeding 2,000 mGy (= 2 Gy) at one time often causes clinical symptoms that require proper treatment.

In the case of local exposure, disorders appear in the exposed organs.
(Related to p.82 of Vol. 1, "Damage and Repair of DNA")

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

Deterministic Effects

Acute Radiation Syndromes



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	Hematopoietic disorders (infection, bleeding) Gastrointestinal tract disorders Skin injury Nerve and blood vessel disorders	

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

Gy: Grays

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

Whole-body exposure to radiation exceeding 1 Gy (1,000 mGy) at one time 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. Exposure to radiation exceeding 1 Gy may cause loss of appetite, nausea and vomiting, and exposure to radiation exceeding 4 Gy may cause headaches, etc. When exposure doses exceed 6 Gy, such symptoms as diarrhea and fever may appear.

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

Skin covers a large area of 1.3 to 1.8 m2 of the whole body of adults. Epidermis, which is the result of repeated division 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* 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 sometimes appears immediately after exposure depending on radiation intensity, but skin injury generally appears after the lapse of a few weeks (p.25 of Vol. 1, "External Exposure and Skin").

*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)

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

Deterministic Effects

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

Sensitivity to radiation differs by organ. The testes are most sensitive.

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.

When bone marrow is exposed to radiation exceeding 0.5 Gy (500 mGy), the number of blood cells decreases due to deterioration of hemopoietic capacity.

Some deterministic effects 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.

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

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

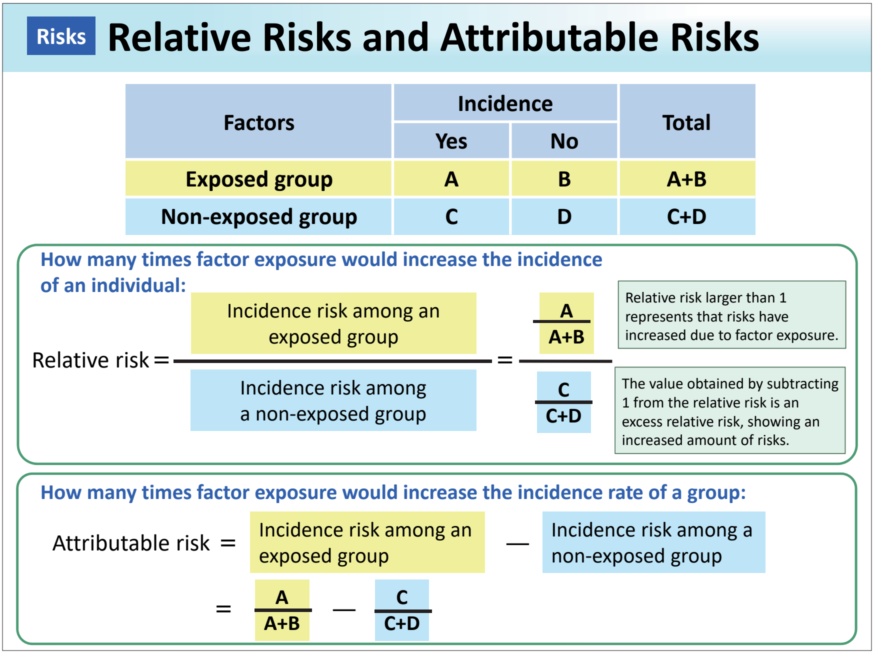
The term "risk" generally means "dangerousness" or "degree of hazard." However, more strictly, the term is used to refer to "the magnitude of the influence of damage," "the possibility of any damage (probability)," or "the combination of the magnitude of the influence and the possibility (probability)." 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.

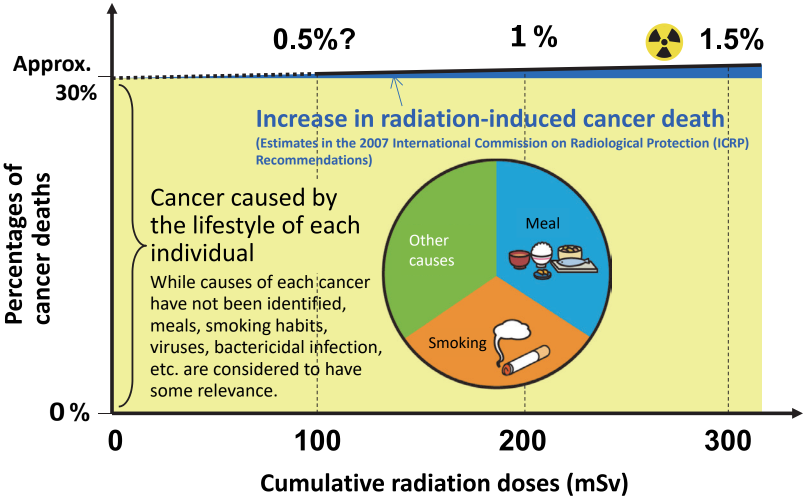
Suppose a group is exposed to some risk factor while another group is not, and there are 2 patients of a certain disease among one million people in the non-exposed group, while there are 3 patients among one million people in the exposed group.

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.

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

Risks Risks of Cancer Death from Low-Dose Exposure



The 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.

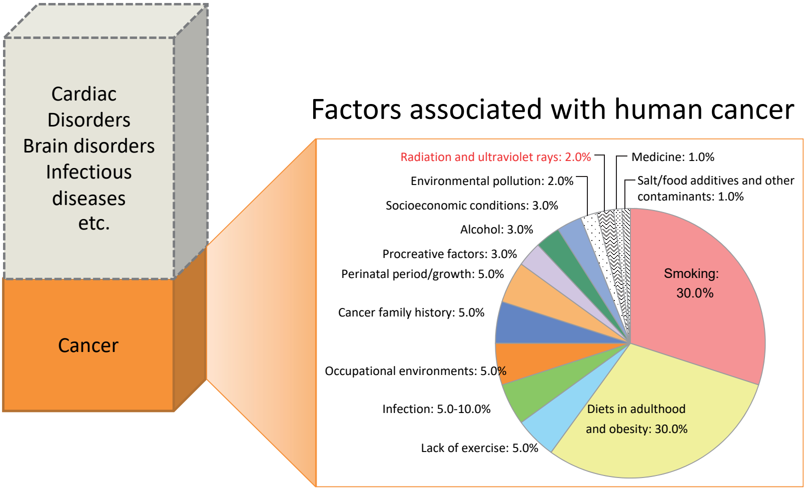
Currently, the leading cause of deaths among Japanese people is cancer, with around 30% of the entire population dying of cancer. That is, 300 people in a group of 1,000 will die of cancer. If the probability of death from radiation-induced cancer is added, it can be estimated that in a group of 1,000 people each 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,* and no methods using pathological diagnosis or other means have yet to be established 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.

*: 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Risks Factors Associated with Carcinogenesis

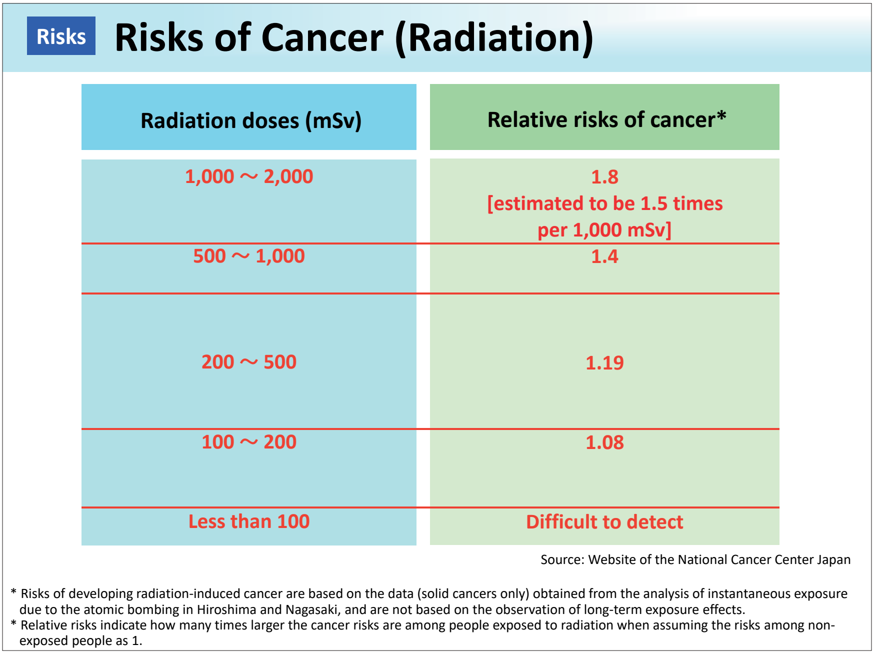


Source: Prepared based on Cancer Causes Control 1996.7.S55-S58

We are surrounded by various cancer causes in our lives. The pie chart above provides U.S. data, which gives an idea that foods and smoking habits are closely associated with the development of cancer. As there are already these negative factors, it is best to avoid radiation exposure from a biological viewpoint.

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.96 of Vol. 1, "Risks of Cancer (Radiation)," and p.97 of Vol. 1, "Risks of Cancer (Life Habits)")

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



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: 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 exposed to radiation when assuming the risks among non-exposed people as 1.

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

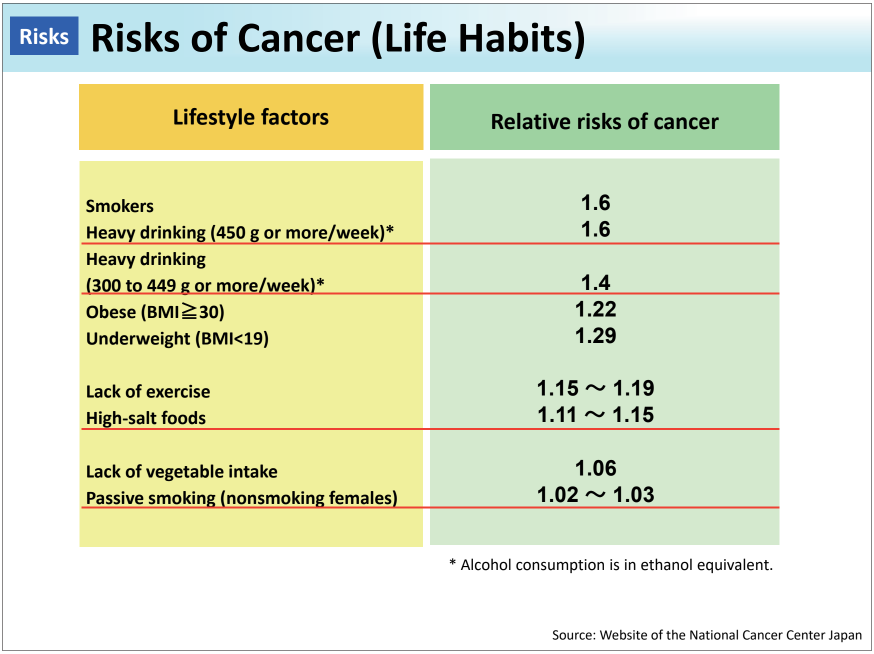
It is estimated that the relative risk increases by 1.8 times due to radiation exposure doses of 1,000 to 2,000 mSv, by 1.4 times due to doses of 500 to 1,000 mSv and by 1.19 times due to doses of 200 to 500 mSv.

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.97 of Vol. 1, "Risks of Cancer (Life Habits)")

Included in this reference material on March 31, 2013

Updated on March 31, 2017



Risks

Risks of Cancer (Life Habits)

Lifestyle factors	Relative risks of cancer
Smokers	1.6
Heavy drinking (450 g or more/week)*	1.6
Heavy drinking (300 to 449 g or more/week)*	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

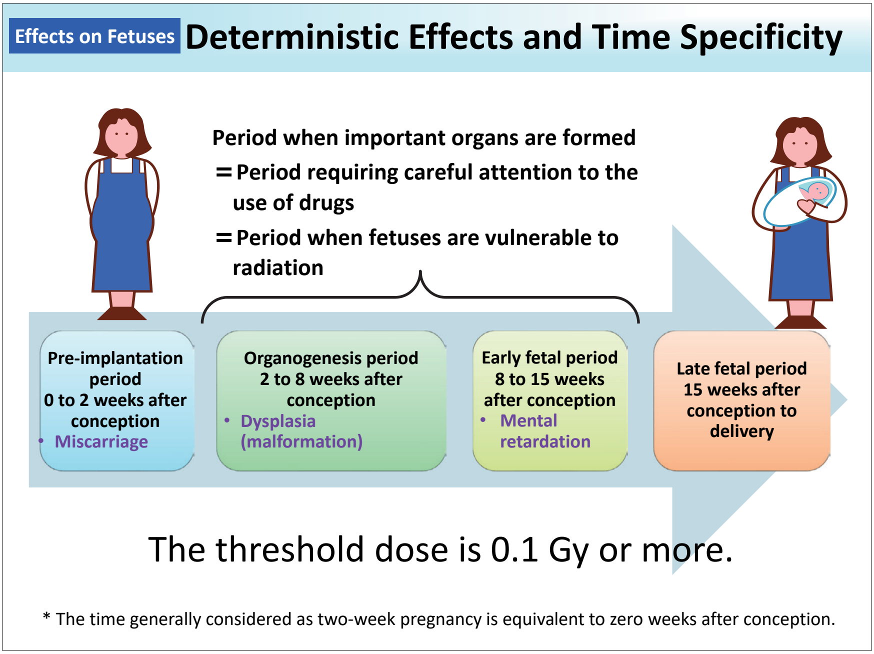
* Alcohol consumption is in ethanol equivalent.

Source: Website of the National Cancer Center Japan

The table above shows the relationship between life habits and relative risks of cancer 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 related to life habits, 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.95 of Vol. 1, "Factors Associated with Carcinogenesis," and p.96 of Vol. 1, "Risks of Cancer (Radiation)")

Included in this reference material on March 31, 2013
Updated on March 31, 2017



Effects on Fetuses

Deterministic Effects 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 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.99 of Vol. 1, "Mental Retardation").

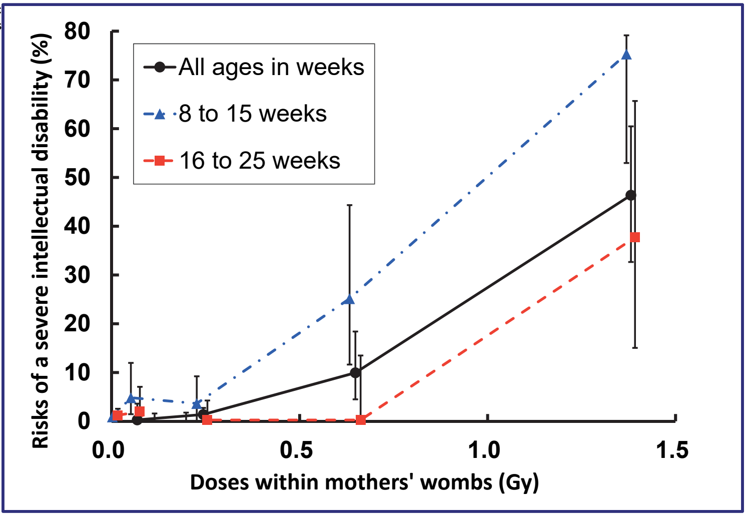
The period when fetuses are highly sensitive to radiation coincides with the period during which pregnant women are advised not to take drugs carelessly. During this period before the stable period, fetuses are vulnerable to both drugs and radiation. Fetal effects are caused by radiation exposure exceeding 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 hereditary disorders also increase depending on exposure dose levels.

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

Effects on Fetuses

Mental Retardation

Data on Atomic Bomb Survivors



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.

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

Effects on Fetuses

Effects on Children - Chernobyl Nuclear Accident -

Survey on children born from mothers who were pregnant at the time of the Chernobyl 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: 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 Chernobyl 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 absorbed doses to the thyroid 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 stress evaluation index survey targeting parents revealed clear correlation between incidence of parents' anxiety disorders and children's emotional disorders.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Effects on Fetuses

Knowledge on Malformation Induction

- Chernobyl Accident -

Has the Chernobyl accident increased malformation?

Comparison of European congenital malformation/twin registry database between before and after the Chernobyl 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

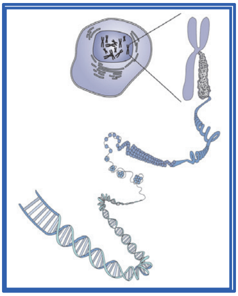
There have been various reports on what impact radiation could have on newly born children and on the incidence of congenital anomalies before and after the Chernobyl accident. Comparison of databases of the European Surveillance of Congenital Anomalies (EUROCAT), and of Finland, Norway, and Sweden showed no change in incidence of malformations.

In the Polissia county in the northern half of the Rivne province of Ukraine, there are people who live a self-sufficient life in a contaminated area. As their name "Polishchuks (forest residents)" suggests, they live off collecting wild strawberries and mushrooms, hunting and fishing in the forests. 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.

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

Hereditary Effects

Risks of Hereditary 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 hereditary 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 hereditary 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, hereditary 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, follow-up death surveys, clinical health checks, and surveys on various molecular levels have been conducted. Results of these surveys have made it clear that risks of hereditary 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.

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

Hereditary 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%)

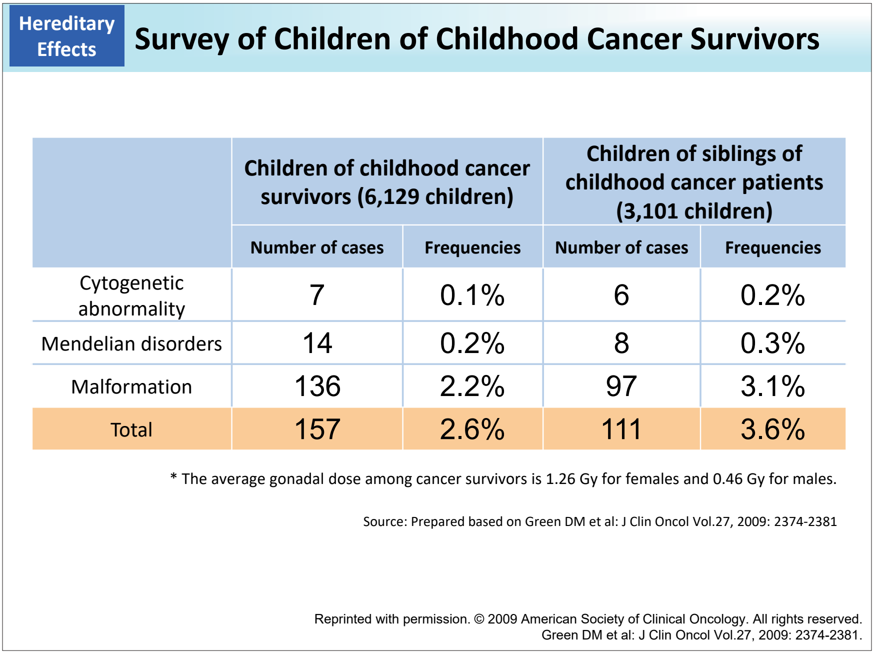
Source: "Chromosomal Aberrations among Children of Atomic Bomb Survivors (1967 - 1985 surveys)" on the website of the Radiation Effects Research Foundation (https://www.rerf.or.jp/programs/roadmap/health_effects/geneefx/chromeab/)

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.

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



Hereditary Effects

Survey of Children of Childhood Cancer Survivors

	Children of childhood cancer survivors (6,129 children)		Children of siblings of childhood cancer patients (3,101 children)	
	Number of cases	Frequencies	Number of cases	Frequencies
Cytogenetic abnormality	7	0.1%	6	0.2%
Mendelian disorders	14	0.2%	8	0.3%
Malformation	136	2.2%	97	3.1%
Total	157	2.6%	111	3.6%

* The average gonadal dose among cancer survivors is 1.26 Gy for females and 0.46 Gy for males.

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

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

This is a Japanese translation of Table 7 contained in the report on 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 hereditary 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: Green DM et al: J Clin Oncol Vol.27, 2009: 2374-2381

Included in this reference material on February 28, 2018

Hereditary 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.104 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

*Source:
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

Included in this reference material on February 28, 2018

Hereditary Effects

Other Epidemiological Surveys of Children of Atomic Bomb Survivors

- Deaths from leukemia or possibly hereditary 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: Y. Yoshimoto et al.: Am J Hum Genet 46: 1041-1052, 1990.)

- Deaths from 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).

（Sourse ： S. Izumi et al.: Br J Cancer 89: 1709-13, 2003.）

- Incidence 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 incidence rates of lifestyle-related diseases (the survey is still underway).

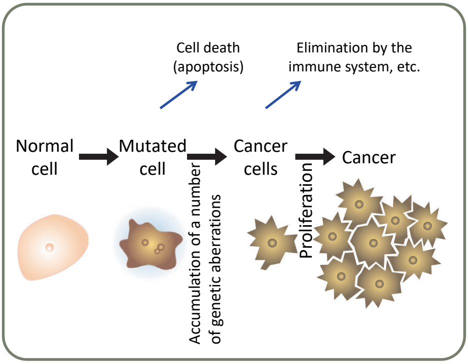
（Source ： S Fujiwara et al.: Radiat Res 170: 451-7, 2008.）

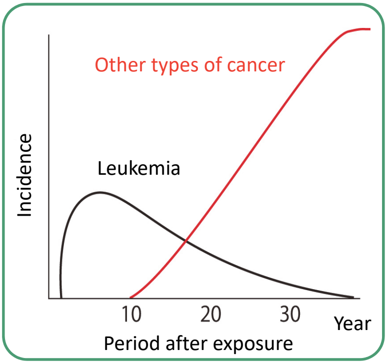
The Radiation Effects Research Foundation has been conducting follow-up surveys to ascertain whether parents' radiation exposure increases their children's incidence rates of lifestyle-related diseases, which are multifactorial disorders. The Foundation has so far conducted a survey of childhood cancer and leukemia,*1 a survey of solid tumors,*2 and a survey of lifestyle-related diseases,*1 but none of them revealed specific radiation effects.

*Source:
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: S Fujiwara et al.: *Radiat Res* 170: 451-7, 2008

Included in this reference material on February 28, 2018

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.

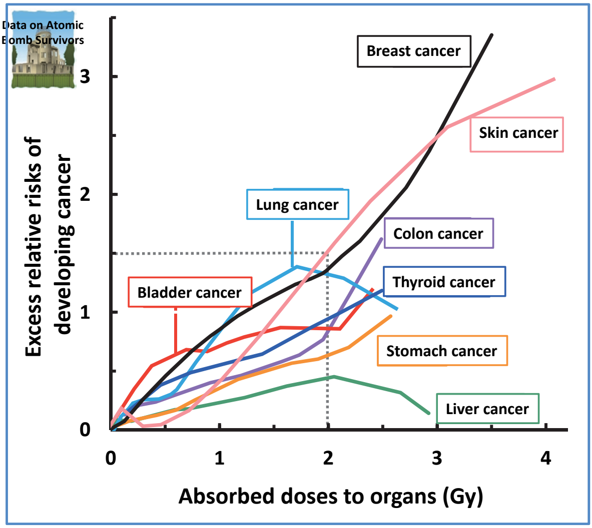
Not only radiation but also various chemical substances and ultraviolet rays, etc. damage DNA. However, cells have a mechanism to repair damaged DNA and DNA damage is mostly repaired quickly. Even if repair was not successful, the human body has a function to eliminate cells wherein DNA damage has not been completely repaired (p.82 of Vol. 1, "Damage and Repair of DNA").

Nevertheless, cells with incompletely repaired DNA survive as mutated cells in very rare cases. Such cancer germ repeatedly appears and disappears.

In the process, genetic aberrations may be accumulated in cells that happen to survive and these cells develop into cancer cells. However, this process requires a long period of time. After the atomic bombing, 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.85 of Vol. 1, "Lapse of Time after Exposure and Effects")

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

Tissues and Organs Highly Sensitive to Radiation



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

Tissue	Tissue weighting factor_{WT}*
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.

This figure shows how cancer risks have increased depending on where in the body was exposed to how much doses of radiation, 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 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.93 of Vol. 1, "Relative Risks and Attributable Risks")

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

Difference in Radiosensitivity by Age

Children are not small adults.

	Committed effective dose coefficients for I-131*1 (mSv/Bq)	Committed effective doses when having taken in 100 Bq of I-131 (mSv)	Equivalent doses to the thyroid when having taken in 100 Bq of I-131*2 (mSv)
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**

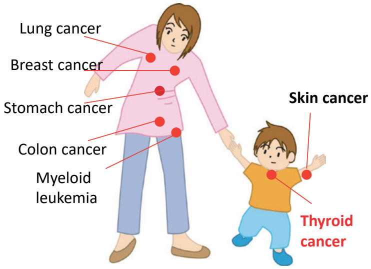
*1: Committed effective dose coefficients are larger for children due to difference in metabolism and physical constitution.

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

Source: 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.

mSv/Bq: microsieverts/becquerel



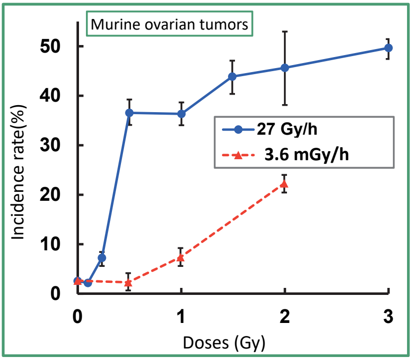
In the case of adults, bone marrow, colon, mammary gland, lungs and stomach easily develop cancer due to radiation exposure, while it has become clear that risks of developing thyroid cancer and skin cancer are also high in the case of children.

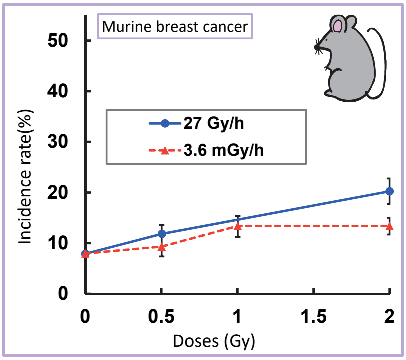
In particular, children's thyroids are more sensitive to radiation and committed effective doses per unit intake (Bq) are much larger than adults. Therefore, the exposure dose to the thyroids of 1-year-old children is taken into account as the standard when considering radiological protection measures 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.114 of Vol. 1, "Relationship between Ages at the Time of Radiation Exposure and Oncogenic Risks")

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

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 the high-dose 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 high-dose 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.

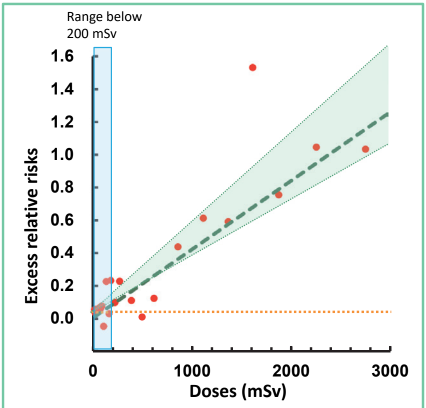
Dose and dose-rate effectiveness factors are correction values used in the case of estimating risks of low-dose exposures, for which no concrete data is available, on the basis of risks of high-dose exposures (exposure doses and incidence rates), or estimating risks of chronic exposures or repeated exposures 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.

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

Cancer due to Acute External Exposure

Relationship between Solid Cancer Deaths and Doses

Deaths from solid cancer (results among atomic bomb survivors)



Source: Prepared based on Ozasa et al., Radiat Res., 177, 229, 2012

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 developing solid cancer and between exposure doses exceeding 200 mSv and the risk of death from solid cancer.

However, there is no consensus among researchers concerning a relationship between cancer risks and exposure doses below 100 to 200 mSv. It is expected that studies will be further continued into the future to clarify 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 (p.158 of Vol. 1, "Disputes over the LNT Model").

*Source:
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)

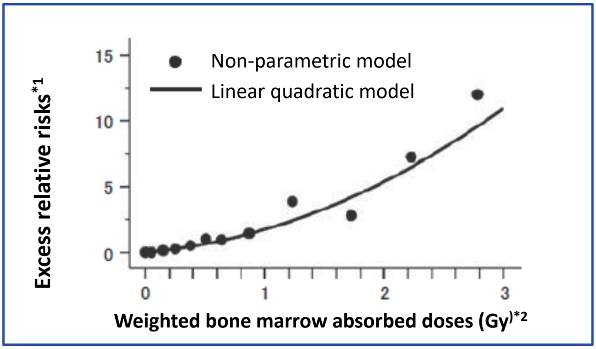
Included in this reference material on March 31, 2013
Updated on February 28, 2018

Cancer due to Acute External Exposure

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.93 of Vol. 1, "Relative Risks and Attributable Risks")

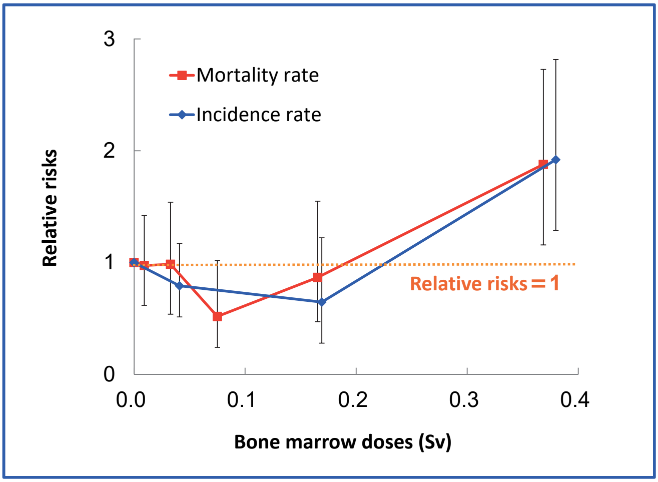
Included in this reference material on March 31, 2013
Updated on February 28, 2018

Cancer due to Acute External Exposure

Risks of Developing Leukemia

Data on Atomic Bomb Survivors

Risks of developing leukemia among atomic bomb survivors



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.93 of Vol. 1, "Relative Risks and Attributable Risks")

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

Cancer due to Acute External Exposure

Relationship between Ages at the Time of Radiation Exposure and Oncogenic Risks

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.109 of Vol. 1, "Difference in Radiosensitivity by Age," and p.115 of Vol. 1, "Ages at the Time of Radiation Exposure and Cancer Types")

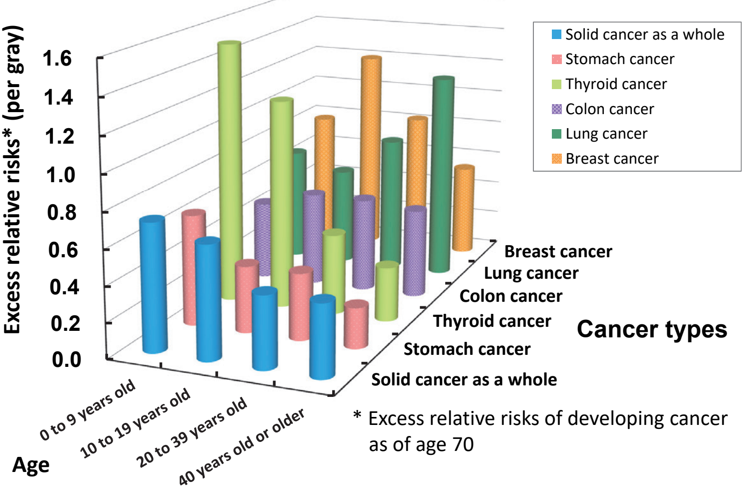
Included in this reference material on March 31, 2013
Updated on February 28, 2018

Cancer due to Acute External Exposure

Ages at the Time of Radiation Exposure and Cancer Types

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

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

This figure shows a comparison of 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 by age at the time of radiation exposure and by type of cancer, using the results of the surveys targeting atomic bomb survivors. Risks of thyroid cancer, stomach cancer and solid cancer as a whole are higher among people who were younger at the time of radiation exposure, risks of lung cancer are high among people aged 40 or older, risks of breast cancer are high during puberty, and risks of colon cancer do not show notable differences by age. In this manner, the figure suggests that the periods showing high radiosensitivity vary by type of cancer.

The excess relative risks in the figure show oncogenic risks due to exposure to respective organs when the survey targets become 70 years old.

(Related to p.116 of Vol. 1, "Oncogenic Risks by Age at the Time of Radiation Exposure," and p.93 of Vol. 1, "Relative Risks and Attributable Risks")

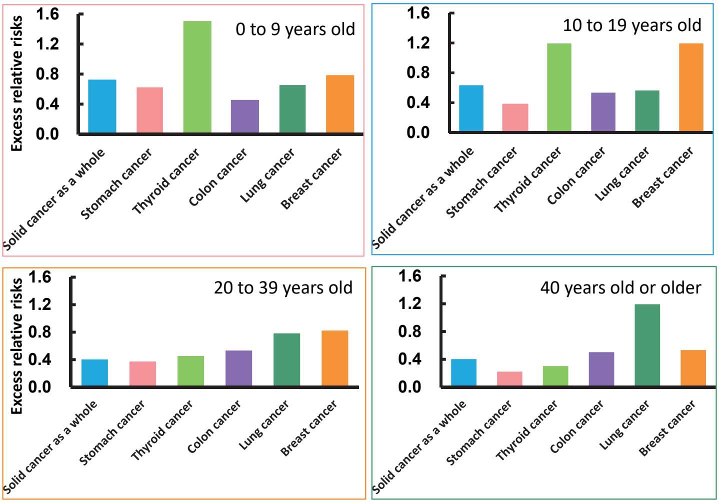
Included in this reference material on March 31, 2013
Updated on February 28, 2018

Cancer due to Acute External Exposure

Oncogenic Risks by Age at the Time of Radiation Exposure

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) in respective organs due to radiation exposure when the survey targets become 70 years old.

It can be observed that types of cancer with higher risks differ by age at the time of radiation exposure.

(Related to p.115 of Vol. 1, "Ages at the Time of Radiation Exposure and Cancer Types," and p.93 of Vol. 1, "Relative Risks and Attributable Risks")

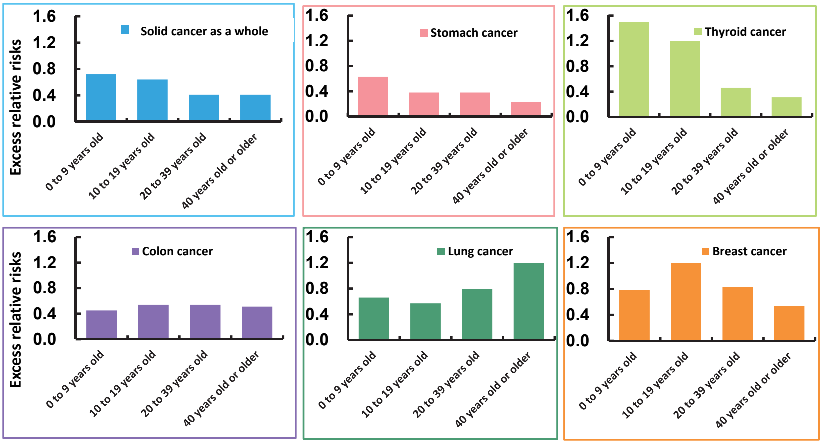
Included in this reference material on March 31, 2013
Updated on February 28, 2018

Cancer due to Acute External Exposure

Ages at the Time of Radiation Exposure and Risks by Type of Cancer

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) by age for each type of cancer, 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.

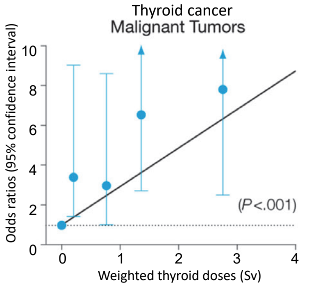
(Related to p.93 of Vol. 1, "Relative Risks and Attributable Risks")

Included in this reference material on March 31, 2013

Updated on February 28, 2018

Cancer due to Acute External Exposure

Incidence of Thyroid Cancer among Atomic Bomb Survivors



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.
Odds of p / Odds of q = p / (1-p) ÷ 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.

No significant difference was found by a survey only targeting micro papillary thyroid cancer.* The odds ratio remains low until the weighted thyroid dose exceeds 100 mGy, but the ratio slightly exceeds 1 when the weighted thyroid dose becomes 100 mGy or larger. (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.)

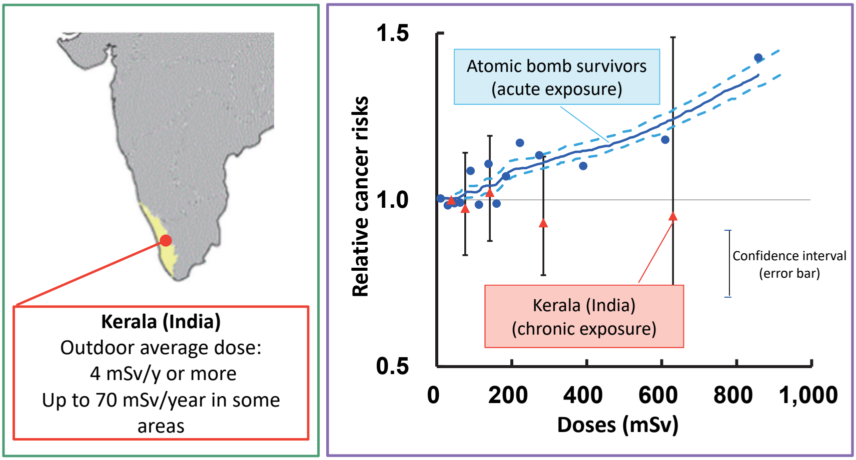
* Source:
M. Imaizumi, et.al., "Radiation Dose-Response Relationships for Thyroid Nodules and Autoimmune Thyroid Diseases in Hiroshima and Nagasaki Atomic Bomb Survivors 55-58 Years After Radiation Exposure" JAMA 2006;295(9):1011-1022
Y. Hayashi, et.al., "Papillary Microcarcinoma of the Thyroid Among 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, 2017

Carcinogenesis due to Chronic Exposure

Effects of Long-Term Low-Dose Exposure

Carcinogenesis among residents in high natural radiation area in India



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.
(Related to p.93 of Vol. 1, "Relative Risks and Attributable Risks")

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

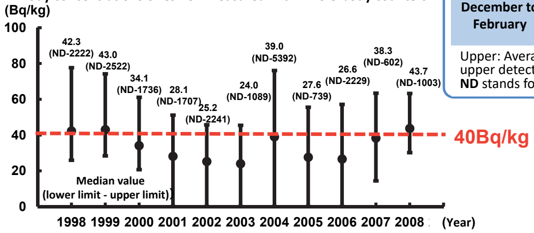
Internal Exposure due to Cesium at the Time of the Chernobyl Accident

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.

Body concentrations of Cs-137 measured with whole-body counters



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

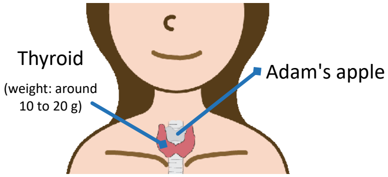
Due to the Chernobyl accident in 1986, much larger amounts of radioactive materials were released compared with those released by the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. At first, the government of the former Soviet Union did not publicize the accident nor did it 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 suggests that exposure to Cs-137 due to the Chernobyl accident has been continuing over years.

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

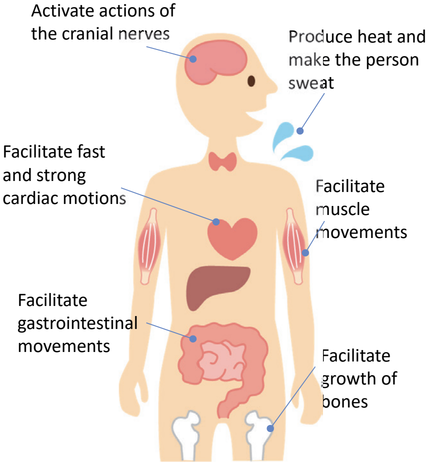
Basic Information on Thyroid

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)	10～20mg
Boiled kelp roll (3 to 10 g)	6～20mg
Hijiki seaweed (5 to 7 g)	1.5～2mg
Wakame seaweed soup (1 to 2 g)	0.08～0.15mg
Half sheet of dried laver seaweed (1 g)	0.06mg
Stock made from kelp (0.5 to 1 g)	1～3mg
Agar (1 g)	0.18mg

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 (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.

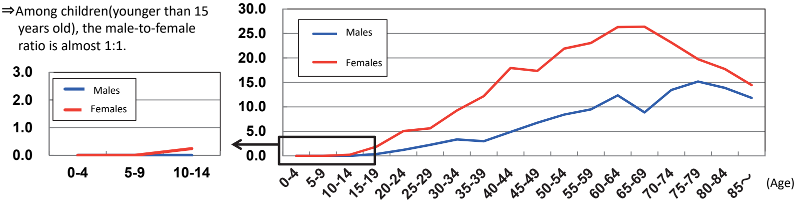
Included in this reference material on March 31, 2017

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: <u>11.5</u> (people); Males: <u>4.5</u> (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.

- **There is also occult thyroid cancer that does not exert any effects on people's health throughout their lifetime.**
- **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

(Source: "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.

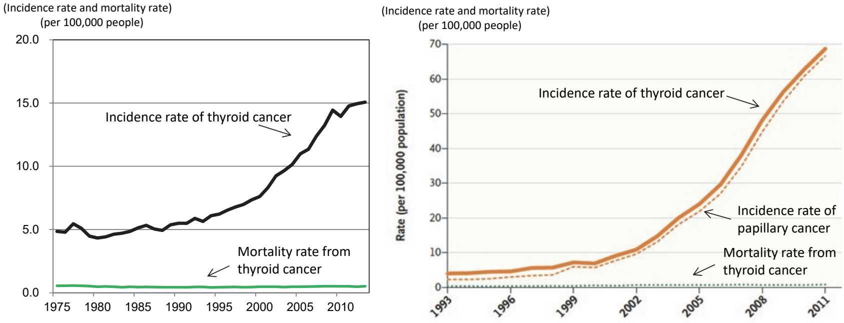
It is known that breast cancer is most frequently detected in females in their 40s and 50s and the incidence rate of stomach cancer is higher among both males and females over 60 years old. On the other hand, thyroid cancer is characteristically found broadly in all age groups from teenagers to people in their 80s.

Furthermore, thyroid cancer has long been known as a type of cancer, most of which are occult cancers without exerting any effects on people's health throughout their lifetime. 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.

Included in this reference material on March 31, 2017
Updated on February 28, 2018

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]

*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 cancer) that have no symptoms and are non-fatal.

As the mortality rate has remained almost unchanged despite sharp increases in the incidence rate, the possibility of overdiagnoses (detection of many cases of such non-fatal micro papillary cancer) is pointed out.*

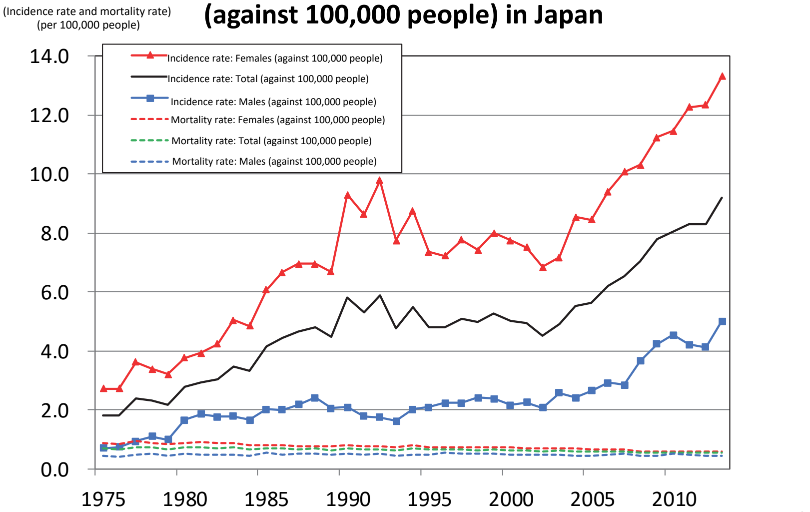
Increases in the incidence rate of thyroid cancer are global trends observed in such countries as America, Australia, France and Italy, but are especially notable in South Korea. In South Korea, official assistance for thyroid cancer screening was commenced in 1999 to enable people to receive the most-advanced 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.

* Source:
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

Incidence Rates of Thyroid Cancer: Japan

Annual changes in age-adjusted incidence rates and mortality rates (against 100,000 people) in Japan



(Source: "Cancer Registration and Statistics," Cancer Information Service, National Cancer Center Japan))

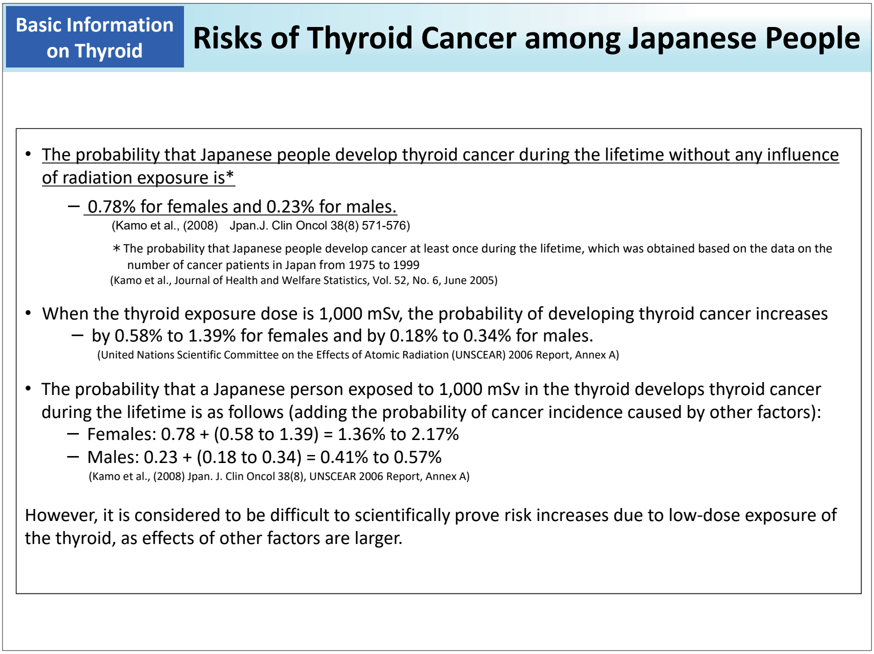
This figure shows annual changes in incidence rates (percentage of patients against the population during a certain period of time) and mortality rates concerning thyroid cancer in Japan.

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 2013. 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.124 of Vol. 1, "Incidence Rates of Thyroid Cancer: Overseas").

In Japan, palpation by doctors has long been conducted broadly as thyroid cancer 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.

* Source: Hiroki Shimura, Journal of the Japan Thyroid Association, 1 (2), 109-113, 2010-10

Included in this reference material on March 31, 2017



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) Jpan.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)

- The probability that a Japanese person exposed to 1,000 mSv in the thyroid develops thyroid cancer during the lifetime is as follows (adding the probability of cancer incidence caused by other factors):
  - Females: 0.78 + (0.58 to 1.39) = 1.36% to 2.17%
  - Males: 0.23 + (0.18 to 0.34) = 0.41% to 0.57%

(Kamo et al., (2008) Jpan. J. Clin Oncol 38(8), UNSCEAR 2006 Report, Annex A)

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.

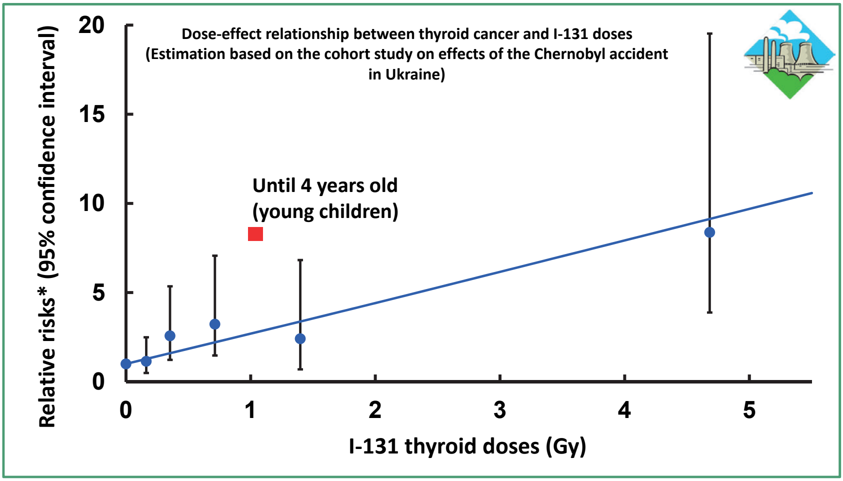
Exposure to 1,000 mSv in the thyroid increases the probability of developing thyroid cancer by 0.58% to 1.39% for females and by 0.18% to 0.34% for males, and after adding the probability of cancer incidence caused by other factors, the probability would increase by 1.36% to 2.17% for females and by 0.41% to 0.57% 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Relationship between Thyroid Cancer and Doses

- Chernobyl Accident -



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 Chernobyl accident are as shown in the figure above.

That is, exposure to 1 Gy in the thyroid doubles the probability of developing thyroid cancer. This study concludes that the double increase in risks is the average of children up to 18 years old, and for younger children up to 4 years old, risk increase would be sharper (indicated with 🟥 in the figure).

(Related to p.93 of Vol. 1, "Relative Risks and Attributable Risks")

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

Basic Information on Thyroid

Thyroid Cancer and Iodine Intake

- Chernobyl 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 Chernobyl, where the relevant data was obtained, are located inland away from the sea and iodine concentration in soil is low. Additionally, people there do not habitually eat seaweed and salt-water fish that are rich in iodine.

Compared to areas around Chernobyl, 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 Chernobyl is not necessarily applicable in Japan.
(Related to p.93 of Vol. 1, "Relative Risks and Attributable Risks")

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

Exposure of a Group of Evacuees

- Chernobyl 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 Chernobyl accident and the average is estimated to be approx. 490 mGy. The average thyroid 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 average thyroid exposure dose for people who resided outside evacuation areas in the former Soviet Union was approx. 20 mGy, while that for people who resided in the contaminated areas was approx. 100 mGy. Both values were much higher than the average dose (approx. 1 mGy) for people in other countries in Europe.

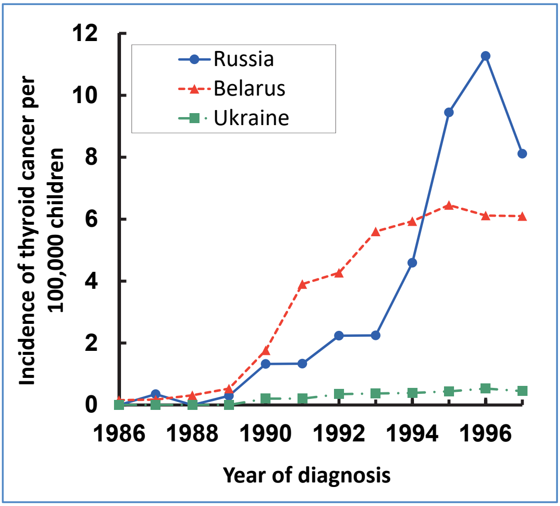
The effective dose from internal exposure in organs other than the thyroid and from external exposure was approx. 31 mSv on average. The average effective dose was approx. 36 mSv in Belarus, approx. 35 mSv in Russia, and approx. 30 mSv in Ukraine. It is known that the average effective dose is larger in Belarus than in Ukraine and Russia as in the case of the average thyroid exposure dose.

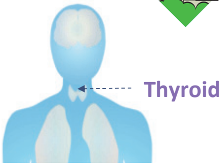
(Related to p.130 of Vol. 1, "Time of Developing Childhood Thyroid Cancer - Chernobyl Accident -")

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Time of Developing Childhood Thyroid Cancer
- Chernobyl Accident -

Childhood thyroid cancer (Chernobyl 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 Chernobyl accident, a large amount of radioactive materials was released and broadly spread out due to an explosion. The major cause of health hazards is said to be radioactive iodine.

Some of the children who inhaled radioactive iodine that fell onto the ground or had 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 due 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.

However, 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 (UNSCEAR 2000 Report, Annex).
(Related to p.129 of Vol. 1, "Exposure of a Group of Evacuees - Chernobyl Accident -")

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

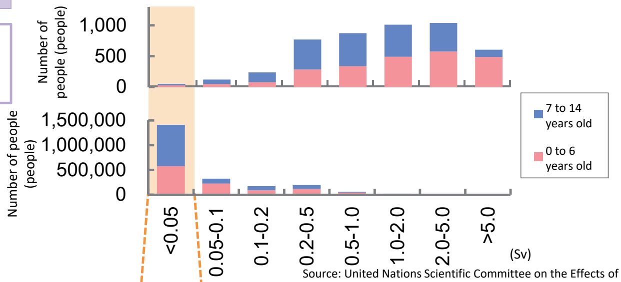
Comparison between the Chernobyl Accident and the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (Thyroid Doses)

Children's thyroid exposure doses

Chernobyl accident

A group of people who evacuated in Belarus in 1986

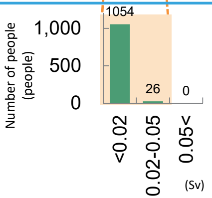
All people in Belarus (excluding evacuees)



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 Chernobyl 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.

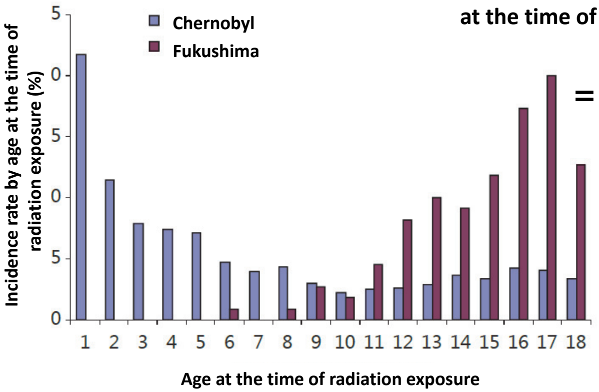
(Related to p.132 of Vol. 1, "Comparison between the Chernobyl Accident and the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (Ages at the Time of Radiation Exposure)")

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Comparison between the Chernobyl Accident and the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (Ages at the Time of Radiation Exposure)

- **Distribution of age at the time of radiation exposure of childhood thyroid cancer patients observed in Chernobyl 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: 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 Chernobyl accident and those in three years after the accident at 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 Chernobyl 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). In Chernobyl, 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.

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 Chernobyl and that the maximum estimated thyroid exposure doses among children is much smaller in Japan (66 mGy in Fukushima and 5,000 mGy in Chernobyl).

(Related to p.131 of Vol. 1, "Comparison between the Chernobyl Accident and the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (Thyroid Doses)")

Included in this reference material on March 31, 2017

Evaluation of the Interim Report on Thyroid Cancer Compiled by the Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident

The Expert Meeting* compiled the Interim Report (December 2014), wherein it considered the following points concerning the thyroid cancer cases found through the Initial Screening 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 accident.

ii) In the case of the Chernobyl 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 Initial Screening in Fukushima.

iii) Increases in thyroid cancer cases after the Chernobyl 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 Initial Screening 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 Initial Screening 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."

However, 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. (Interim Report by the Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident; December 2014)
- "The possibility of radiation effects may be small but cannot be completely denied at this point in time. Additionally, it is necessary to accumulate information in the long term for accurate evaluation of the effects. Therefore, the Thyroid Ultrasound Examination should be continued, while meticulously explaining the disadvantages of receiving the examination and obtaining the understanding of examinees." (Interim Report by the Prefectural Oversight Committee Meeting for Fukushima Health Management Survey; March 2016)
- "Continuing the Fukushima Health Management Survey and the Thyroid Ultrasound Examination for children based on the present protocol is positioned as one of the major priorities in scientific studies." (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2013 Report)

Included in this reference material on February 28, 2018

Psychological Effects

Stress Factors for Disaster Victims

- Future uncertainty
- Uncertainty about residence and workplace security
- Social prejudice
- Media influences
- Differences of climates and customs

+

Characteristics unique to radiation disasters

- 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 victims of disasters 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.135 of Vol. 1, "Radiation Accidents and Health Concerns").

In particular, concerns over future radiation effects cause a huge stress as victims have to be worried for a long time about the possibility that they might someday develop cancer.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

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.

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

Source:
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)

Included in this reference material on March 31, 2013
Updated on March 31, 2017

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 Chernobyl 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.

Regarding a questionnaire on the emotions and behavior of children in Fukushima

Tendencies found through a survey using SDQ (Strengths and Difficulties Questionnaire) as an index to evaluate the mental health of children:

- The percentage of respondents whose SDQ score was 16 or higher was 9.5% in a previous study targeting the general Japanese population unaffected by any disasters. Compared with this, the survey revealed that the percentages of those scoring 16 or higher were high in both the 4-6 age and 6-12 age groups.
- However, the same percentages tend to be lower in both the 4-6 age and 6-12 age groups in the survey conducted in FY2014, compared to that in FY2011, i.e., the year of the accident.

SDQ：Strengths and Difficulties Questionnaire

Source:
・A debriefing report from "Mental Health and Lifestyle Survey," Fukushima Health Management Survey in FY2014, Fukushima Medical University, June 2016
・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 Chernobyl 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.

The Radiation Medical Science Center in Fukushima conducts the Mental Health and Lifestyle Survey with the aim of handing down to the following generations accumulated knowledge on better mental care in an emergency or in the event of a natural disaster.

The survey uses the Strengths and Difficulties Questionnaire (SDQ)* as an index to evaluate children's mental health. The higher the percentage of those scoring high (16 or higher), the more support is needed. The survey conducted in FY2011 showed rather bad results (high scores) but considerable improvements are observed in the results of the one conducted in FY2014, which have come close to the results of the surveys conducted outside the affected regions (see p.141 of Vol. 2, "Mental Health and Lifestyle Survey: What Has Become Clear (4/4)" for details).

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

Response to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station (NPS) 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 characterisation 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.

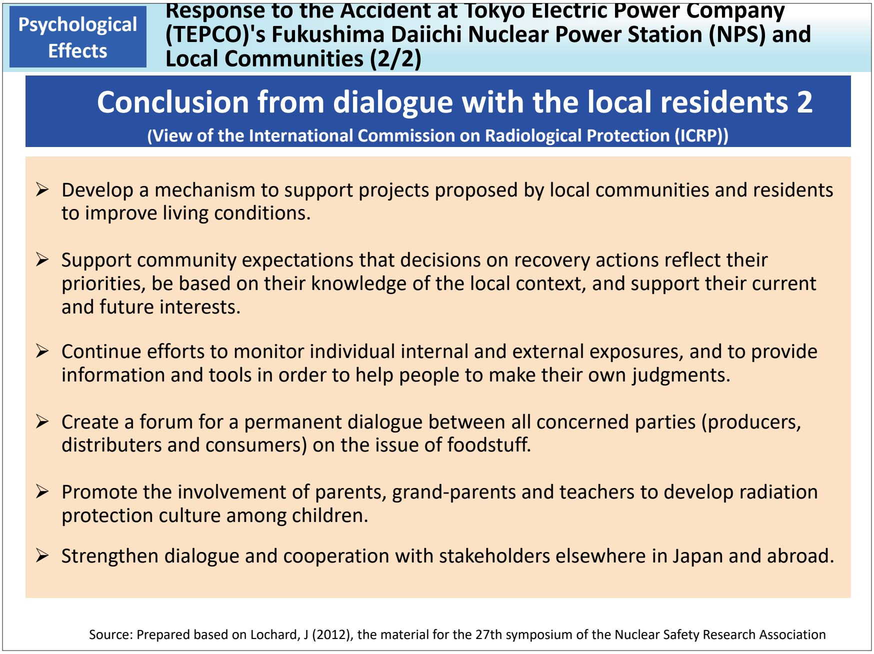
Source: Prepared based on Lochard, J (2012), the material for the 27th symposium of the Nuclear Safety Research Association

Providing useful information for helping disaster victims 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 Chernobyl NPS accident, as well as after the TEPCO's Fukushima Daiichi NPS accident, experts and local residents had dialogues. If disaster victims are able to solve radiation issues by themselves with experts' support, that is considered quite effective in reducing their psychological stress.

Included in this reference material on March 31, 2013
Updated on March 31, 2017



Psychological Effects

Response to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power Station (NPS) 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 victims of the accident at 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Psychological Effects

Overview of Health Effects - Chernobyl Accident -

Summary of effects on mental health

World Health Organization (WHO) Report issued in 2006 upon the 20th anniversary of the Chernobyl 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 Chernobyl 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 Chernobyl 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 Chernobyl 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Psychological Effects

Summary by WHO - Chernobyl 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.

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

Views of Expert Groups - Chernobyl 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 Chernobyl 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 Chernobyl 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, 2017

Psychological Effects

View Different from the 2006 WHO Report

- Chernobyl 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 Chernobyl 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 Chernobyl accident or other effects, or their combinations.

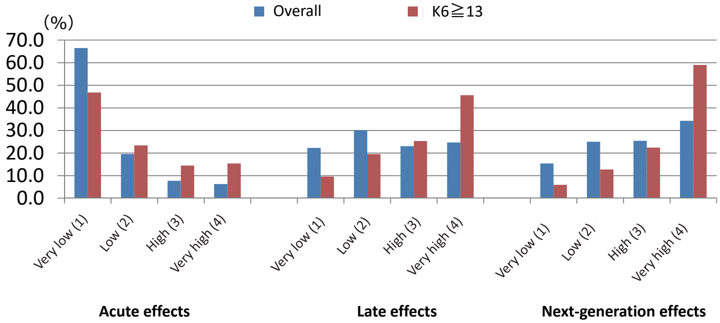
(Related to p.101 of Vol. 1, "Knowledge on Malformation Induction - Chernobyl Accident -")

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

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.

Prepared based on Suzuki Y, et. al., Bull World Health Organ, 2015
(http://dx.doi.org/10.2471/BLT.14.146498)

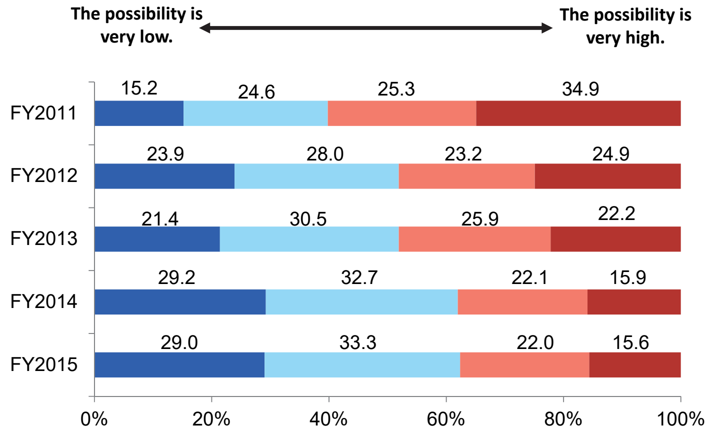
As part of the Fukushima Health Management Survey, Fukushima Prefecture conducts the Mental Health and Lifestyle Survey targeting disaster victims every year (see p.135 to p.141 of Vol. 2, "10.5 Mental Health and Lifestyle Survey" for details). The 2011 survey asked about the perception of (i) acute effects (hair loss and bleeding), (ii) late effects (thyroid cancer and leukemia), and (ii) any next-generation effects of radiation. As a result, the following were found.

- There are very few disaster victims 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 disaster victims 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

Changes in Perception of Radiation Risks (Next-generation Effects)



Prepared based on the materials of the 29th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey

As shown on p.143 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 40% as of FY2015, showing little change from FY2014.

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. As shown in the survey results, if disaster victims 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 disaster victims.

Included in this reference material on February 28, 2018

Increase in Induced Abortions in Europe

- Chernobyl Accident -

The Chernobyl 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: Proceedings of the Symposium on the effects on pregnancy outcome in Europe following the Chernobyl accident. Biomedicine & Pharmacotherapy 45/No 6, 1991

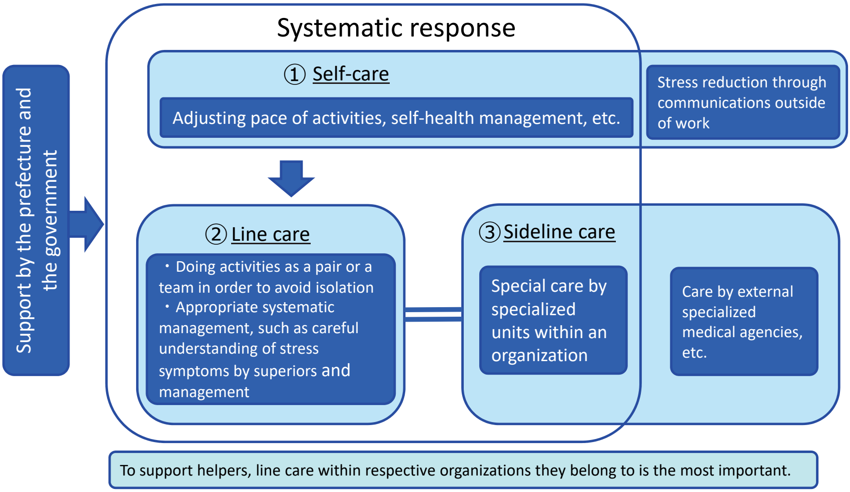
Excessive concern over the health effects of radiation could be harmful both physically and mentally.

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 Chernobyl accident. There is also a report that induced abortions increased even in areas remote from the Chernobyl plant. In Greece, the effect of the Chernobyl 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.

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

Support for Helpers: Three Stages of Care



Systematic response

Support by the prefecture and the government

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

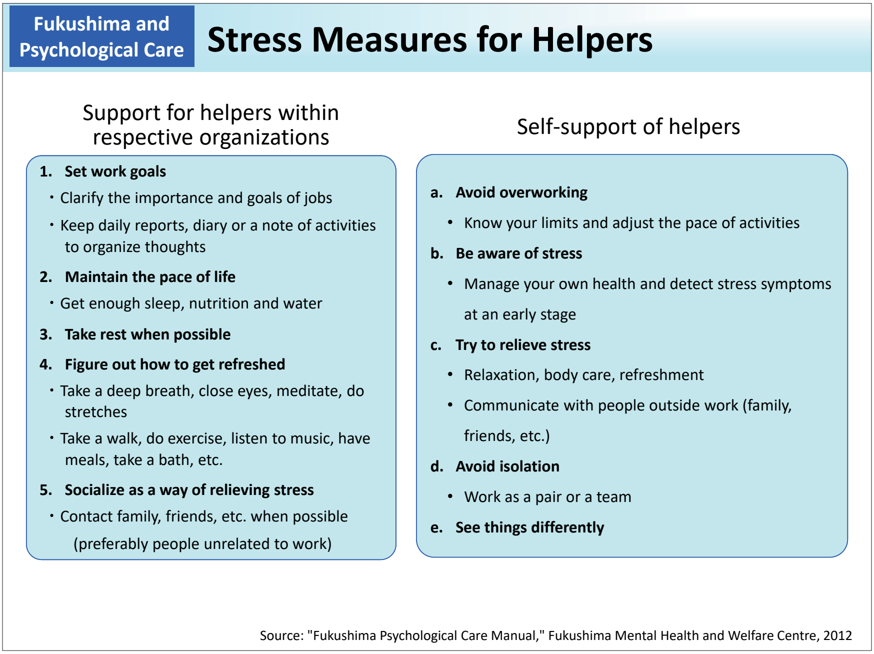
Support service providers to disaster victims, such as civil servants and medical personnel, are often in positions to closely witness the agony of the disaster victims and tend to feel helpless or guilty as no immediate solutions are available.

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 disaster victims directly and indirectly through psychological care support projects for the disaster victims, etc.

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: "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 disaster victims 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.

Included in this reference material on March 31, 2016

Fukushima and Psychological Care

When Feeling Depressed or Anxious

Consult a public health nurse, a nurse or a special institution nearby if you are aware of any change as follows in yourselves. It is important to share everything and be listened to.

Signs of depression - Signs you can notice yourselves

- Feel sad, gloomy, down
- Easy to get tired, feeling unwell (lethargic)
- Hard to sleep, get up earlier than usual in the morning
- Feel worse in the morning than in the evening
- Unable to overcome failure, sorrow, disappointment
- Disinterested in everything, have no fun
- Feel weaker, less motivated, less focused (dull)
- Less appetite, in no mood to meet people
- Unable to get rid of worries, paranoid
- Blame yourself, feel worthless, etc.

("Do you know what depression is like?" (pamphlet for the general public (draft)), Ministry of Health, Labour and Welfare; http://www.mhlw.go.jp/shingi/2004/01/s0126-5d.html)

Below are consultation services you can turn to when you have problems with yourselves or your family, such as worries, anxiety, loneliness and alcohol problems.

Consultation service	Phone number	Business hours
Fukushima Mental Care Centre Telephone Counselling Service for Disaster Victims, Fukukoko Line	024-925-8322	9:00-12:00 and 13:00-17:00 from Mon. to Fri. (except national holidays and the year-end and New Year holidays)
Telephone Mental Health Counselling Service (For people residing in Fukushima Prefecture) (For people residing outside Fukushima Prefecture)	024-535-5560 0570-064-556	9:00-17:00 from Mon. to Fri. (except national holidays)
Fukushima Counselling Service	024-536-4343	10:00-22:00 every day (open 365 days a year)
Fukushima Mental Health and Welfare Centre	024-535-3556	9:00-17:00 from Mon. to Fri. (except national holidays and the year-end and New Year holidays)

Child counseling (under age 18): If you have any concerns, turn to the nearest health center in your municipality.

Source: Prepared based on the "List of Other Counseling Services," Radiation Medical Science Center for the Fukushima Health Management Survey, Fukushima Medical University

Depression is considered to be caused when the part of the brain associated with emotions and willingness becomes underactive.

We are exposed to a lot of stress as we have worries or are under pressure in our daily lives. Getting enough sleep or a good rest can reduce such stress to some extent. This is because our bodies have natural healing power.

However, if we keep worrying or are under pressure for a long time or if we continue overwork, we may become more likely to develop depression. The symptoms of depression or symptoms suspected of being related to depression are as follows:

(i) Symptoms related to emotions and willingness, such as feeling down, unmotivated, having a hard time concentrating, losing the power to think;

(ii) Symptoms related to sleep, such as having a hard time falling asleep, waking up in the middle of the night, having a hard time getting a good night's sleep or waking up earlier than usual in the morning;

(iii) Symptoms related to appetite, such as having no appetite, food not tasting good, having an upset stomach.

If you have any of the above, it is important to call a specialized institution or counselling service without hesitation.

Reference: "Depression and Depressive States," Fukushima Mental Care Centre, supervised by Misato Oe

Included in this reference material on March 31, 2017

Psychological Care

Reference Materials on General Psychological Care (1/3)

General Information on Psychological Care

	Title	Issued by	Issued in	URL
(i)	Psychological First Aid (PFA) Field Guide	World Health Organization (WHO) Japanese translation: National Center of Neurology and Psychiatry, Care Miyagi, (Public Interest Incorporated Foundation) Plan Japan	2011	http://saigai-kokoro.ncnp.go.jp/pdf/who_pfa_guide.pdf
(ii)	Guidelines for Local Mental Health Care Activities after a Disaster	Ministry of Health, Labour and Welfare, Health and Labour Science Research Grants Health and Labor Science Special Research Program	Updated in March 2011	http://saigai-kokoro.ncnp.go.jp/document/medical_personnel05.html
(iii)	Roadmap for Local Mental Health Care Activities after a Disaster	National Center of Neurology and Psychiatry, National Information Center of Disaster Mental Health	Updated in March 2011	http://saigai-kokoro.ncnp.go.jp/document/pdf/mental_info_map.pdf
(iv)	Mental Health Manual for Disaster Rescuers and Helpers	National Center of Neurology and Psychiatry, National Information Center of Disaster Mental Health	Updated in March 2011	http://saigai-kokoro.ncnp.go.jp/document/pdf/mental_info_saigai_manual.pdf
(v)	Guide for Providing Psychological Support in the Event of a Nuclear Disaster - How to Respond to Local Residents -	(Public Interest Incorporated Foundation) Nuclear Safety Research Association (Project commissioned by the Ministry of Education, Culture, Sports, Science and Technology)	March 2009	http://saigai-kokoro.ncnp.go.jp/document/pdf/mental_info_nuclear.pdf

This table shows reference materials on general psychological care as well as the health effects of disasters and radiation.

(i) is a guide for Psychological First Aid (PFA) translated in Japanese. It provides points that supporters should consider in practicing PFA, such as what to do and what not to do.

(ii) is a guideline on how to manage stress after a disaster. It is directed to doctors, public health nurses, nurses, psychiatric social workers, other professionals, and administrative officials and explains specific measures to deal with the psychological effects of disasters on local residents.

(iii) is a roadmap showing psychiatric health activities that should be implemented immediately after a disaster and over mid and long terms. It is directed to health and medical personnel and explains the psychological and mental reactions of disaster victims and corresponding activities.

(iv) is a manual on how disaster helpers should manage stress. It is directed to health and medical personnel and explains the mental and physical reactions of helpers and how to manage stress.

(v) is a guide showing how to provide psychological care in the event of a nuclear disaster. It provides examples of typical psychological reactions after a disaster and first-aid methods for people with anxiety, and recommends consulting with doctors promptly if helpers notice such reactions. It also recommends using a check sheet to check symptoms that are likely to be seen in helpers, and taking appropriate measures.

Included in this reference material on March 31, 2015
Updated on February 28, 2018

Reference Materials on General Psychological Care (2/3)

Post-Disaster Care to Children

	Title	Purpose and Target	Issued by	Issued in	URL
(i)	Child-friendly Space Guidebook, Part 1 (Key concepts)	・Purpose: To create a space where children can stay safe with peace of mind in an emergency and explain how to make preparations therefor and actual procedures to be followed ・Target: Children	(Public Interest Incorporated Foundation) UNICEF Japan National Center of Neurology and Psychiatry, National Information Center of Disaster Mental Health	Updated in December 2016	https://www.unicef.or.jp/kinkyu/japan/pdf/cfs.pdf
(ii)	To Those who Support Child Disaster Victims - About Acute Psychological Support-	・Purpose: To provide psychological support to children immediately after the disaster ・Target: Children	The Japanese Society for Child and Adolescent Psychiatry, Disaster Contingency Planning Committee	March 2011	http://saigai-kokoro.ncnp.go.jp/document/pdf/mental_info_childs_02.pdf
(iii)	To Those who Support Child Disaster Victims - About Mid- and Long-term Psychological Support -	・Purpose: To provide mid- and long-term support to child disaster victims ・Target: Children	The Japanese Society for Child and Adolescent Psychiatry, Disaster Contingency Planning Committee	July 2011	http://child-adolesc.jp/wp-content/uploads/tebiki_chuuchouki.pdf
(iv)	To Helpers - Guideline on How to Deal with Disabled Children after a Disaster	・Purpose: To deal with physical, psychological and behavioral issues in supporting disabled children after a disaster ・Target: Disabled children and their guardians	The Japanese Society for Child and Adolescent Psychiatry	March 2011	http://saigai-kokoro.ncnp.go.jp/document/pdf/mental_info_handicapped_child.pdf

The table shows reference materials on general psychological care for disasters, mainly on child care.

(i) is an emergency guidebook. It is directed to staff of evacuation centers, private organizations and municipalities, as well as people in the fields of medicine, welfare, and education, and summarizes what should be understood and basic strategies to keep in mind when creating a space where children can stay safe with peace of mind. Additionally, it provides examples of preparations necessary for creating a child-friendly space and actual procedures to be followed.

(ii) and (iii) show how to provide psychological care to children, immediately after a disaster (ii) and over mid- and long-terms (iii), directed to nurses, public health nurses, psychologists, and school nurses.

(iv) is a guideline on how health and medical personnel support disabled children. It summarizes how to deal with physical, psychological, and behavioral issues. It also contains how to support guardians.

Included in this reference material on March 31, 2015
Updated on February 28, 2018

Psychological Care

Reference Materials on General Psychological Care (3/3)
Post-disaster Psychological Care for Each Disease

	Title	Purpose and Target	Issued by	Issued in	URL
(i)	A Manual on How to Promote Measures against Depression - for Prefectural and Municipal Officials -	・Purpose: To appropriately treat depression ・Target: Local residents	Ministry of Health, Labour, and Welfare Regional Anti-Depression Committee	January 2004	http://www.mhlw.go.jp/shingi/2004/01/s0126-5.html#1
(ii)	A Manual on How to Deal with Depression - for Health and Medical Personnel -	・Purpose: To appropriately treat depression ・Target: Local residents	Ministry of Health, Labour, and Welfare Regional Anti-Depression Committee	January 2004	http://www.mhlw.go.jp/shingi/2004/01/s0126-5.html#2
(iii)	Drinking Problems after Disasters	・Purpose: To treat people suffering from alcoholism ・Target: Alcohol addicts after a disaster	National Center of Neurology and Psychiatry, National Information Center of Disaster Mental Health	Updated in April 2011	http://saigai-kokoro.ncnp.go.jp/document/pdf/mental_info_alcohol.pdf
(iv)	To Support People Inclined toward Suicide - Guideline for Counselors -	・Purpose: To confirm the basic knowledge and action guideline required for counseling and supporting activities ・Target: People inclined toward suicide, including survivors of suicide attempts, suicide repeaters, and people contemplating suicide	Ministry of Health, Labour and Welfare, Health and Labour Science Research Grants Mental Health Science Research Program	January 2009	http://www.mhlw.go.jp/bunya/shougaihoken/jisatsu/dl/02.pdf
(v)	A Guideline on Evaluating and Supporting Social Recluses	・Purpose: It is created as a practical guideline on how to evaluate and support social recluses. ・Target: People who fall under the category of social recluses	Ministry of Health, Labour and Welfare, Health and Labour Science Research Grants Mental Health Science Research Program	May 2010	http://www.zmhwc.jp/pdf/report/guidebook.pdf
(vi)	A Manual on How to Support Disaster Victims Suffering from Dementia and Their Family (for Medical Purposes)	・Purpose: For medical purposes ・Target: People with dementia living in evacuation centers and their family	Japan Society for Dementia Research	April 2016	http://dementia.umin.jp/iryou419.pdf
(vii)	A Manual on How to Support Disaster Victims Suffering from Dementia and Their Family (for Nursing Purposes)	・Purpose: For nursing purposes ・Target: People with dementia living in evacuation centers and their family and nursing personnel	Japan Society for Dementia Research	April 2016	http://dementia.umin.jp/kaigo419.pdf

The table shows reference materials on general psychological care after disasters, particularly in relation to depression, stress, drinking habits, suicide, social recluses, dementia, etc.

(i) and (ii) are manuals for regional administrative officials and health and medical personnel to implement general anti-depression measures. They provide precautions in making conversation with people with anxiety, and specific examples of how to explain or ask questions.

(iii) explains how health and medical personnel should deal with alcohol addicts after disasters.

(iv) assumes people inclined toward suicide, including survivors of suicide attempts, suicide repeaters and people contemplating suicide as targets. It provides the basic knowledge and action guideline required for workers in healthcare centers and mental health welfare centers, municipal officials, case workers and children's social workers in providing counseling and support activities.

(v) is a guideline providing examples of social recluses, which is a practical material for use by institutions specialized in mental health, medical care, welfare and education in evaluating and supporting social recluses.

(vi) and (vii) are manuals on people with dementia living in evacuation centers and their family. (vi) is directed to medical personnel such as doctors and nurses treating dementia in disaster-stricken areas. (vii) is aimed at supporting nursing personnel.

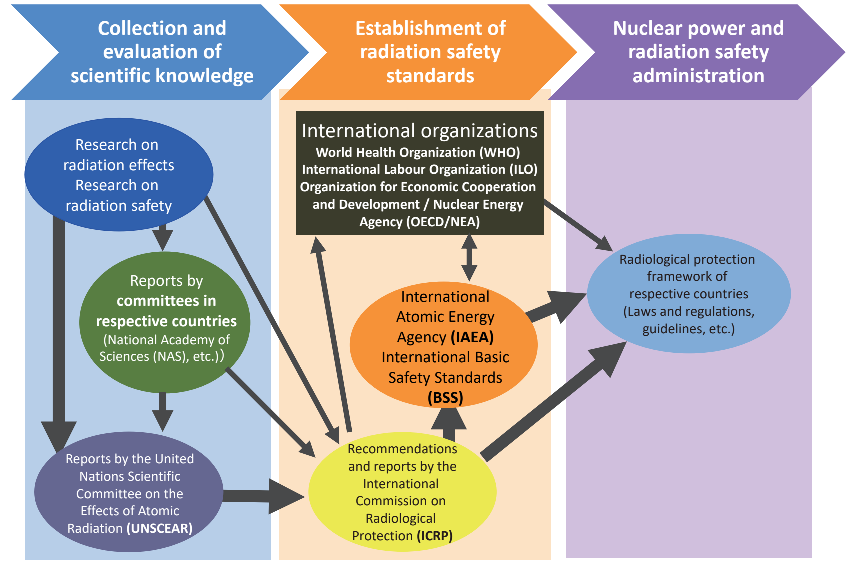
Included in this reference material on March 31, 2015
Updated on February 28, 2018

Chapter 4

Concept of Radiological Protection

Principles of Radiological Protection

Radiological Protection System



Collection and evaluation of scientific knowledge

Establishment of radiation safety standards

Nuclear power and radiation safety administration

Research on radiation effects
Research on radiation safety

Reports by **committees in respective countries** (National Academy of Sciences (NAS), etc.))

Reports by the United Nations Scientific Committee on the Effects of Atomic Radiation **(UNSCEAR)**

International organizations
World Health Organization (WHO)
International Labour Organization (ILO)
Organization for Economic Cooperation and Development / Nuclear Energy Agency (OECD/NEA)

International Atomic Energy Agency **(IAEA)**
International Basic Safety Standards **(BSS)**

Recommendations and reports by the International Commission on Radiological Protection **(ICRP)**

Radiological protection framework of respective countries (Laws and regulations, guidelines, etc.)

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

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

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

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

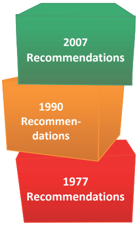
International Commission on Radiological Protection (ICRP)

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 five standing Committees (radiation effects, doses from radiation exposures, protection in medicine, application of the Commission's recommendations, and protection of the environment).

(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.155 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.165 of Vol. 1, "ICRP Recommendations and Responses of the Japanese Government").

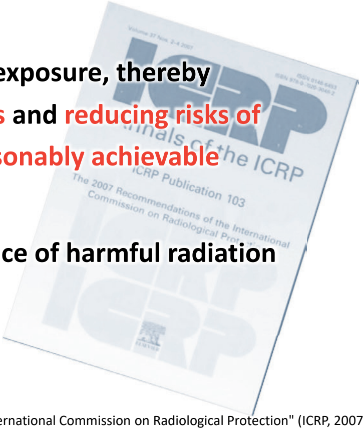
ICRP Recommendations are based on wide-ranging scientific knowledge, such as that obtained through epidemiological studies on atomic bomb survivors, and its radiological protection system has been maintained since 1990 on the basis of its position that comprehensive estimation of deterministic effects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

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

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 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: 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.

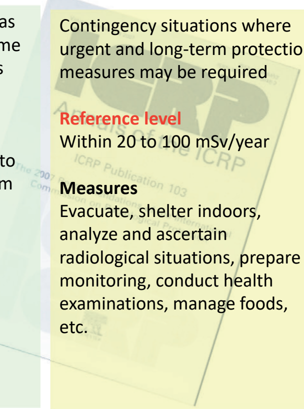
The major aim of the ICRP Recommendations has been the protection of human health, but the aim to protect the environment was newly added in the 2007 Recommendations.

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

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: 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 500 to 1,000 mSv may sometimes be adopted as a rough indication depending on the circumstances.

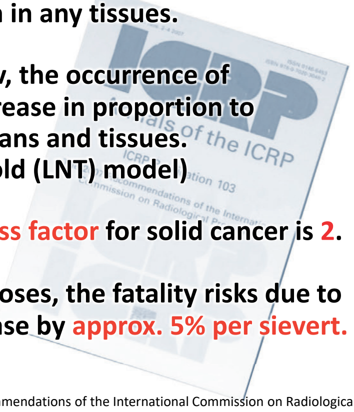
Then, in the recovery and reconstruction period (existing exposure situations), a reference level is to be set within the range of 1 to 20 mSv/year, which is lower than the reference level in an emergency but higher than the dose limits applicable in normal times.
(Related to p.165 of Vol. 1, "ICRP Recommendations and Responses of the Japanese Government")

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

Principles of Radiological Protection

Biological Aspect

Health effects of radiation have deterministic effects 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 hereditary effects increase by approx. 5% per sievert.**

Source: 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. 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. 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.

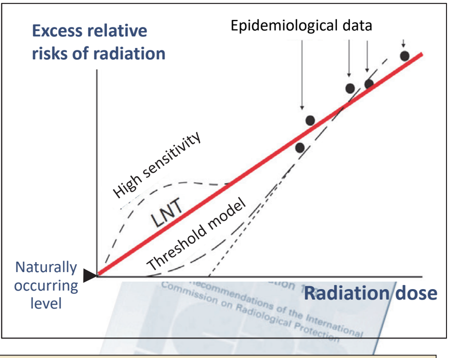
(Related to p.80 of Vol. 1, "Deterministic Effects and Stochastic Effects")

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

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.

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

The ICRP Recommendations are intended to achieve a practical aim of radiological protection, i.e., the provision of a simpler and more reasonable assumption for the management of risks of low-dose exposure, by adopting the LNT model and defining the dose and dose-rate effectiveness factor as 2. On the other hand, the Recommendations also state that it is judged inappropriate for public health planning to estimate hypothetical incidences of cancer or hereditary diseases among a large number of people due to long-term exposure to very low doses of radiation in consideration of the uncertainties concerning low-dose exposure.
(Related to p.80 of Vol. 1, "Deterministic Effects and Stochastic Effects")

*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)

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

Principles of Radiological Protection

Three Fundamental Principles of Radiological Protection

ICRP's three fundamental principles of radiological protection

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

ICRP

Annals of the ICRP

ICRP Publication 103

The 2007 Recommendations of the International Commission on Radiological Protection

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

In cases of cancer and hereditary effects, effects appear stochastically. At present, the linear non-threshold (LNT) model is adopted in radiological protection even for low doses (p.158 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.160 of Vol. 1, "Justification of Radiological Protection," p.161 of Vol. 1, "Optimization of Radiological Protection," and p.163 of Vol. 1 "Application of Dose Limits").

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

Justification of Radiological Protection

Justification of Radiological Protection

Justification

Benefits

Risks

○ Adopt

Benefits

Risks

× Do not adopt

Source: 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.

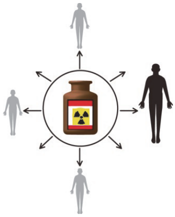
Included in this reference material on March 31, 2013
Updated on March 31, 2015

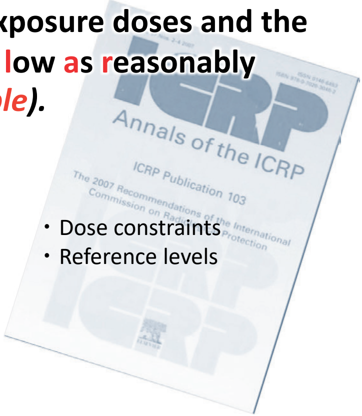
Principles of Radiological Protection

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).*





Annals of the ICRP

ICRP Publication 103

The 2007 Recommendations of the International Commission on Radiological Protection

- Dose constraints
- Reference levels

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

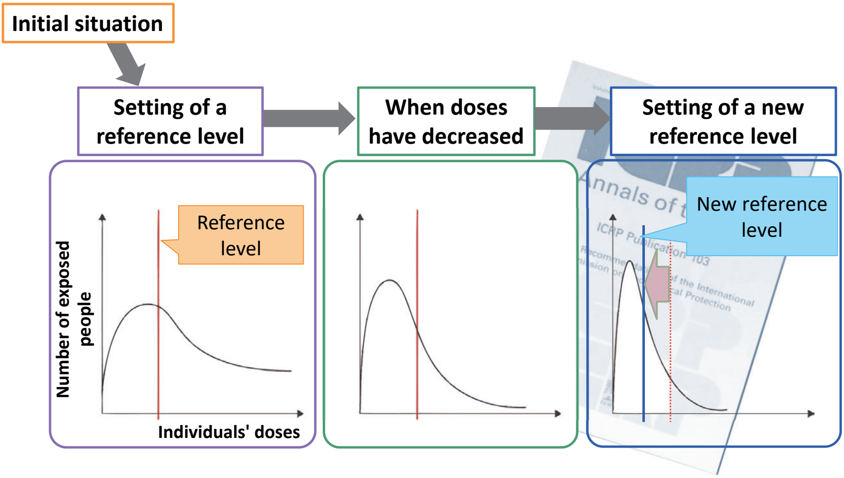
The second principle is the optimization of radiological protection. When merits of an act of using radiation outweigh radiation risks, it is decided to use radiation by taking measures to reduce exposure doses as low as reasonably achievable. This is called the ALARA principle. The optimization of radiological 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.

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

Reduction of Exposure Doses Using Reference Levels

Optimization of radiological protection using reference levels



Source: 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 the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. 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).

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.

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

Principles of Radiological Protection

Application of Dose Limits

Dose limits are applied under planned exposure situations.

○ **Occupational exposure (effective dose)**

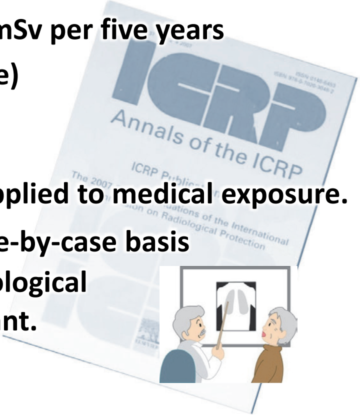
50 mSv per year and 100 mSv per five years

○ **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: 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.

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

Dose Limits

Comparison between ICRP Recommendations and Domestic Laws and Regulations

		Occupational exposure		Public exposure	
		2007 Recommendations of the ICRP	Laws and regulations concerning the prevention of radiation hazards (Japan), as of March 2012	2007 Recommendations of the ICRP	Laws and regulations concerning the prevention of radiation hazards (Japan), as of March 2012
Effective dose limits		The average annual dose for the prescribed five years should not exceed 20 mSv and the annual dose for any one year should not exceed 50 mSv.	Same as the Recommendations	1 mSv/year (Exceptionally, if the average annual dose for five years does not exceed 1 mSv, exposure exceeding the limit for a single year may be sometimes permitted.)	Dose limits are not specified, but doses at the boundaries of business establishments, including those due to exhaust gas and water, are regulated not to exceed the dose limit of 1 mSv/year.
Equivalent dose limits	**Eye lenses**	150m Sv/year	150 mSv/year	15 mSv/year	—
	Skin	500 mSv/year	500 mSv/year	50 mSv/year	—
	Fingers and toes	500 mSv/year	—	—	—
Dose limits for female radiation workers		The equivalent dose of a fetus during gestation after reporting pregnancy (exposure in utero) should not exceed 1 mSv.	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	—	—

Source: Prepared based on the 2007 Recommendations of the ICRP and Japanese laws and regulations concerning the prevention of radiation hazards (as of March 2012)

mSv: millisieverts

Present laws and regulations in Japan have not yet incorporated 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).

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

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	**Up to 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.

Included in this reference material on March 31, 2013
Updated on March 31, 2017

Comparison of Regulation Values for Foods

Indices concerning radioactive materials in foods (Bq/kg)

Radionuclide	Japan	Codex Alimentarius Commission	EU	US
Radioactive cesium	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: Prepared based on "Food and Radiation Q&A," Consumer Affairs Agency

In Japan, new standard limits for radioactive materials in foods were established and were put into force on April 1, 2012. The new standard limits were set by classifying foods into four categories and the standard limit for drinking water, which is most frequently taken by people, was set at 10 Bq/kg.

The standard limit for milk, which children generally drink a lot of, was reduced to 50 Bq/kg. Additionally, a new category, "infant foods," was made for ensuring safety for infants and the standard limit therefor was set at 50 Bq/kg, the same as that for milk. The standard limit for other general foods is 100 Bq/kg.

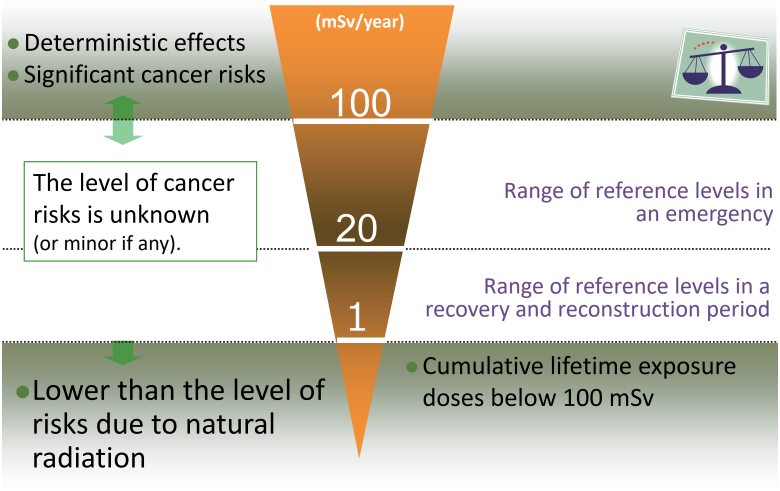
All foods other than infant foods were categorized as general foods based on the idea to minimize gaps in additional doses caused by differences in individuals' eating habits. The value was set with sufficient room to ensure safety no matter what foods people eat as long as radioactive Cs concentrations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

Regulation values 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.43 of Vol. 2, "Standard Limits Applied from April 2012")

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

Dose Limits

Relation between Exposure Doses and Health Risks



- Deterministic effects
- Significant cancer risks

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 increase 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.156 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.

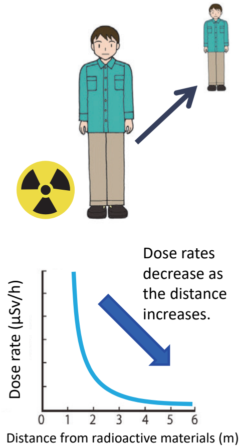
It is not that radiation exposure up to 1 mSv per year is permissible. Principally, radiation exposure should be reduced as low as practically achievable in light of various circumstances.

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

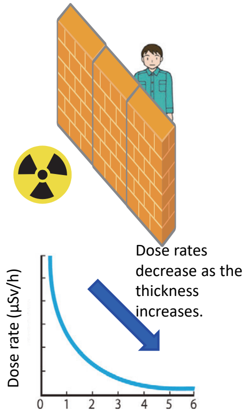
Dose Reduction

Three Principles of Reduction of External Exposure

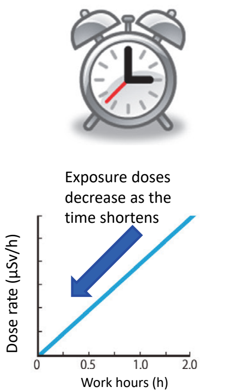
(i) Keep away (distance)



(ii) Place something heavy in between (shielding)



(iii) Shorten time while being close to radioactive materials (time)



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.47 of Vol. 1, "Characteristics of External Exposure Doses")

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

Dose Reduction

Internal Exposure - Responses Immediately after a Nuclear Hazard -

○ Prevent radioactive materials from entering the body through the mouth, nose or wounds, in principle.

○ Be careful not to lose nutritional balance, being excessively worried about a small amount of radioactive materials below the standard limit.

○ Be aware of information on the release of radioactive materials.

○ Wash off soil immediately from the body, shoes and clothes.

As causes of internal exposure, both inhalation and ingestion of foods need to be taken into consideration. For example, when calculating exposure doses for children engaging in outdoor activities at places with high ambient doses, doses due to internal exposure account for only around 2% to 3% and exposure doses are mostly due to radiation from outside of the body. Therefore, people do not have to be too nervous about exposure through inhalation and proper daily hygienic control (taking a bath, getting a haircut, washing hands, cleaning, and doing the laundry, etc.) is effective in reducing internal exposure to some extent.

In the meantime, regarding the possibility of internal exposure caused by ingestion of foods, attention needs to be paid to wild foods or other foods whose safety cannot be confirmed. In particular, special attention is required for ferns and mushrooms, which have a property to concentrate cesium.

Unlike ambient dose rates, internal exposure doses cannot be easily checked personally, so it is recommendable to refer to measurement results, etc. released by relevant ministries and agencies. Data on radioactivity concentrations in foods is released by the Ministry of Health, Labour and Welfare and the Ministry of Agriculture, Forestry and Fisheries.

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

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 (%)
Rice	Polishing - Washing - Cooking	66～72
Leaf vegetables (spinach, etc.)	Washing - Boiling	7～78
Bamboo shoots	Boiling	26～36
Marron	Boiling - Peeling astringent skin	11～34
Japanese radish	Peeling	24～46
Japanese plum	Salting	34～43
Cherry leaves	Salting	78～87
Dried *shiitake* mushrooms	Reconstituting (do not use soaking water)	51～54
Beef meat	Boiling sliced meat (*Shabu-shabu*)	55～69
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: "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 adsorbed 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 breaks and comes out into the boiling water. 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.

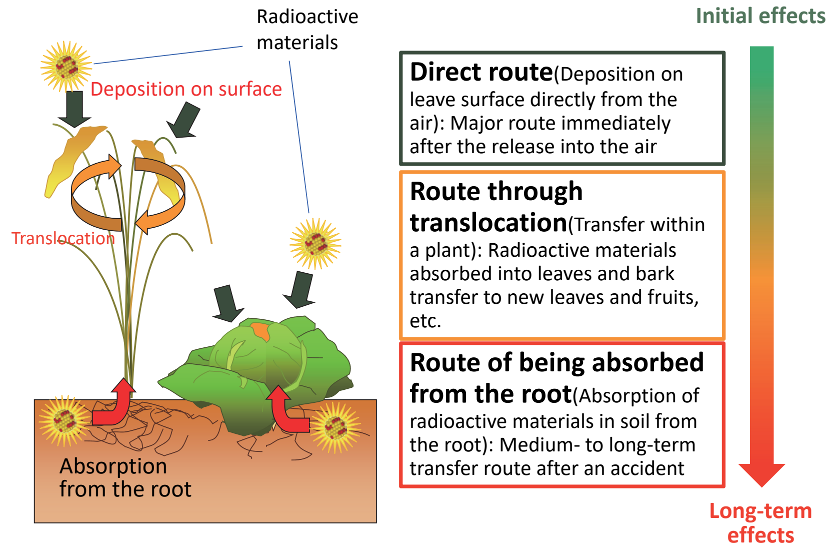
When cooking meat or fish, the amount of radioactive materials can be halved by discarding the cooking liquid. It is known that the removal rate is higher when boiling or cooking than grilling them.

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

Included in this reference material on March 31, 2017

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, 2015

Distribution of Radioactive Cesium in Soil

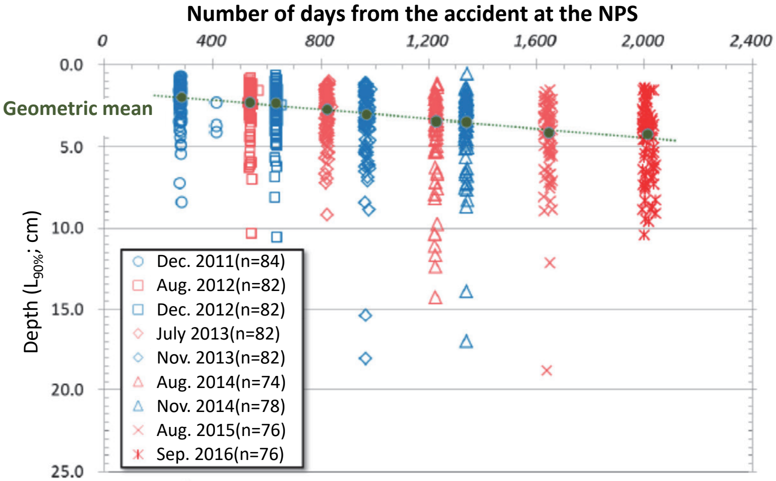


Figure: Data on changes over time in L90%＊ since December 2011 (85 locations at uncultivated land in Fukushima Prefecture, the southern part of Miyagi Prefecture and the northern part of Ibaraki Prefecture)

(Reference) Depth (L90%): 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 FY2016 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 increased gradually over time, but the geometric mean as of September 2016 was less than 5 cm at 4.2 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.

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 Chernobyl nuclear reactor 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 Chernobyl Forum Expert Group (2006), International Atomic Energy Agency).

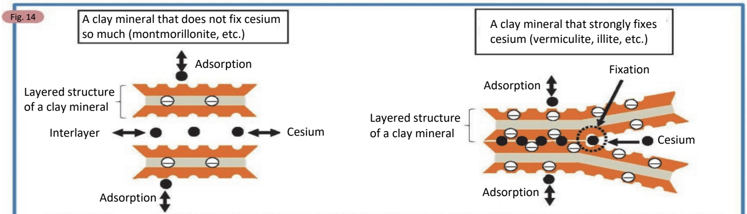
Included in this reference material on March 31, 2017

Long-term Effects

Behavior of Radioactive Cesium in the Environment: Adsorption and Fixation by Clay Mineral

Adsorption and fixation of cesium

Fig. 14



[Explanation]

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

Table 4

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

(Note) Anchoring power of these components vary 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: http://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.

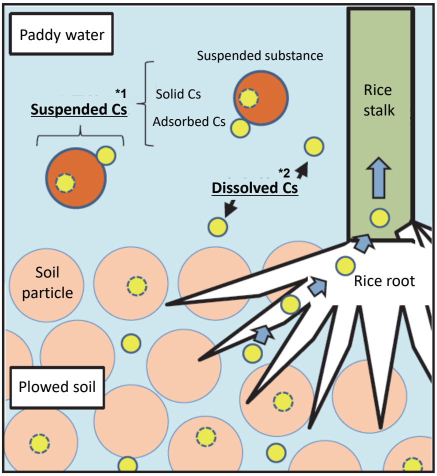
* Source: Outcome report of the FY2014 project, "Compilation of Data on Distribution of Radioactive Materials Released due to the Accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS and Development of Transfer Model" commissioned by the Secretariat of the Nuclear Regulation Authority

Included in this reference material on March 31, 2017

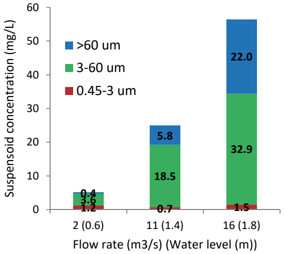
Long-term Effects

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**



Relation between flow rates (water levels) and suspensoid concentrations in the downstream of the Ukedo River (Ukedogawa Bridge) (2014)

Concentrations of dissolved Cs and suspended Cs at each flow rate in the downstream of the Ukedo River (Ukedogawa Bridge) (2014)

River flow rate (m3/s)	2	16
Concentration of dissolved Cs-137 (Bq/L)	0.3	0.3
Concentration of suspended Cs-137 (Bq/L)	0.1	2.2
Percentage of suspended Cs-137	25%	88%
Total concentration of Cs-134 and Cs-137 (Bq/L)	0.6	3.3

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/initiatives/cat01/pdf1511/2-4_iijima.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 suspensoid concentration also becomes high, but suspended substances strongly adsorb radioactive cesium (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/L) 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

Behavior of Radioactive Cesium in the Environment: Outflow from Forest Soil

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

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

Watershed area	Kawamata Town			Mt. Tsukuba	Marumori Town
	Around Mt. Iboishi[*1]	Around Mt. Ishihira[*1]	Around Mt. Kodaishi[*1]	Around Kasumigaura[*2]	Upstream of the Udagawa River[*2]
Survey period	44 to 45 days[*3]			21 months	15 months
Amount of Cs-137 deposited on soil (kBq/m^3)	544	298	916	13	170-230
Amount of outflow of Cs-137[*4] (kBq/m^3)	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.

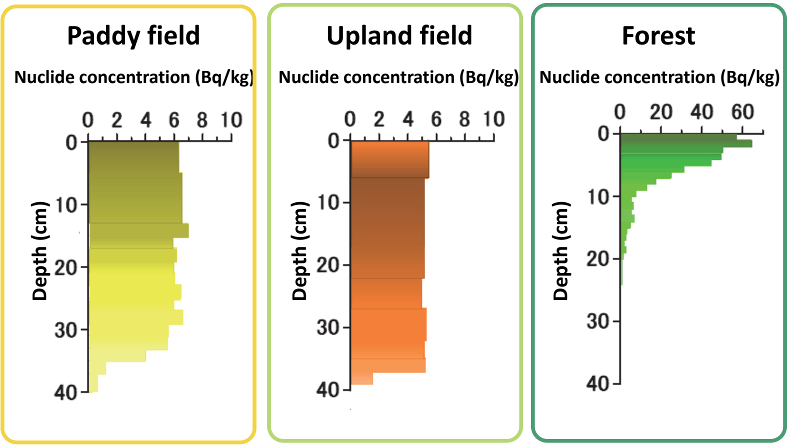
Surveys conducted so far revealed that the annual outflow rate of Cs-137 from forest soil is around 0.02% to 0.3% of the total amount of Cs-137 deposited on nearby watershed soil.

* Prepared based on the material for the 16th meeting of the Environment Recovery Committee

Included in this reference material on March 31, 2017

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.74 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.172 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

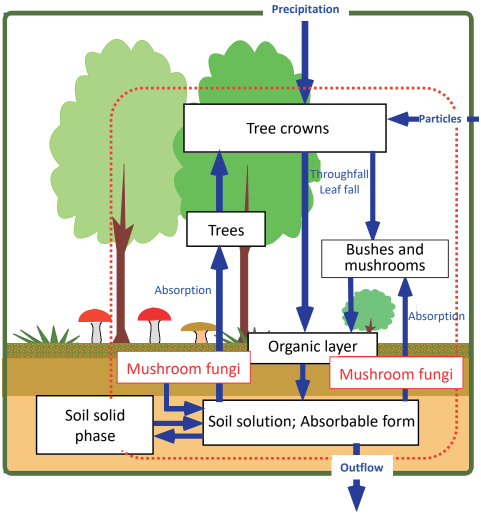
Distribution changes over time (years).

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. For example, mushrooms often contain cesium at relatively high concentrations. This is partly due to the nature of the relevant mushrooms, but is also considered to have something to do with the fact that mushroom fungi grow well in organic-rich soil with less clay minerals.

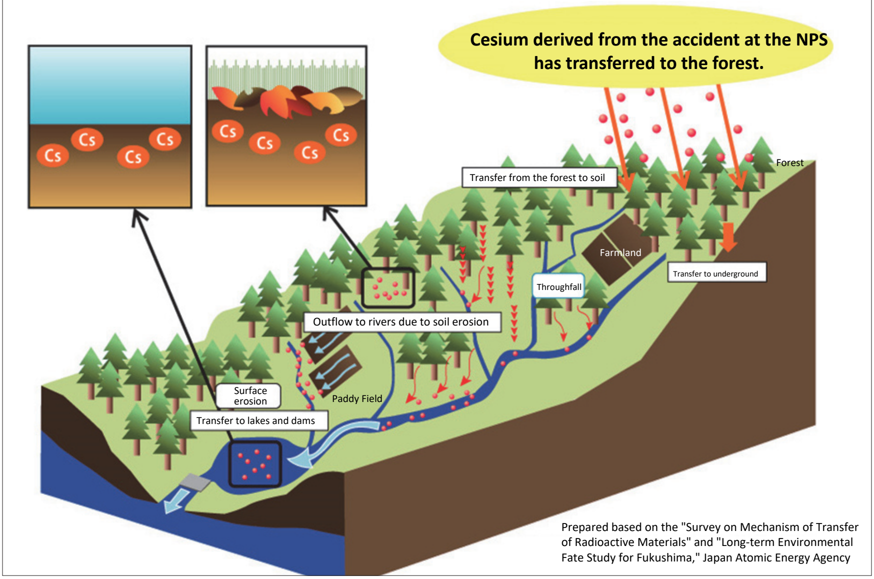
Radioactive cesium in the organic layer gradually transfers into subsoil, and plants that take root deeper than the surface layer will come to absorb such cesium.

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.23 of Vol. 2, "Readings of the Monitoring of Radioactive Cesium in Mountain Streams (2012)").

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

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. 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.

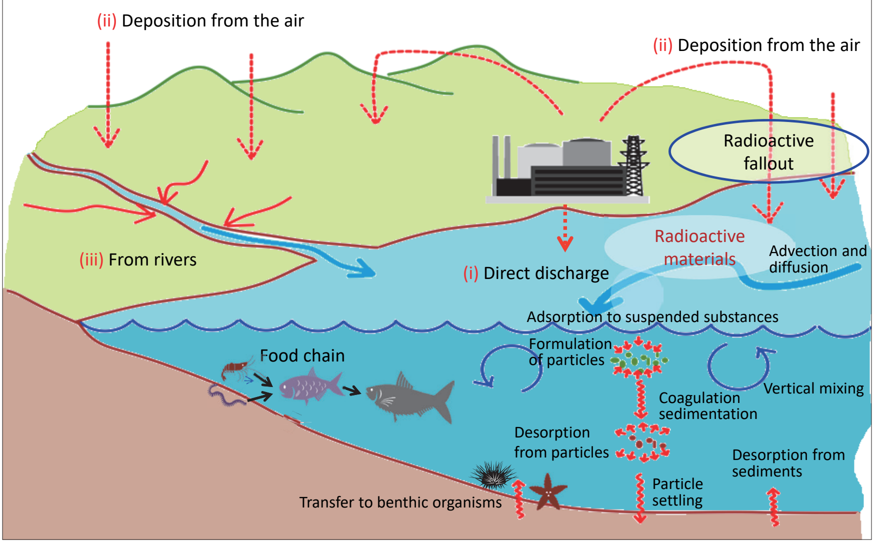
The above figure illustrates the process that fallen and deposited cesium in the forest flows from the upstream to a downstream dam lake. The two enlarged pictures show the forest floor and the sediment at the bottom of the dam lake, both indicating that cesium is deposited in the surface layer of soil.

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 cesium, 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. It has been made clear that radioactive cesium has rarely transferred from sea-bottom soil to marine organisms (Source: "Report on Inspection of Radioactive Materials in Fishery Products" (2015), Fisheries Agency).
(Related to p.78 of Vol. 2, "Trends of Radioactive Cesium Concentrations by Fish Species (2/2)")

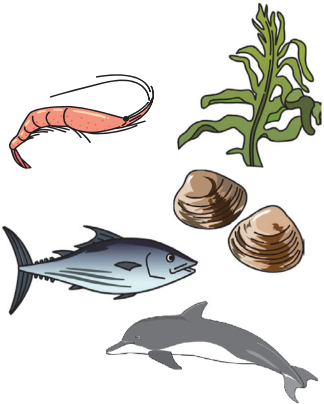
Included in this reference material on March 31, 2013
Updated on March 31, 2017

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.

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

Chapter 5

Assessments by International Organizations

WHO Reports and UNSCEAR 2013 Report (1/3)

Comparison of Assessments (1/2): Overview

	WHO	UNSCEAR
Purpose	To estimate health risks of residents due to radiation exposure for the first one year after the accident (conservative assessment)	・To compile obtained information and make an assessment ・To provide scientific knowledge (realistic assessment)
Content	・Preliminary dose estimation ・Health risk assessment	・Time chart and analyses of the nuclear accident of the nuclear accident ・Release and diffusion of radioactive materials ・Public exposure doses ・Occupational exposure doses ・Health effects ・Exposure doses and risk assessment for non-human biota
Time of assessment	Immediately after the accident (data up to September 2011) Data immediately after the accident contains inaccurate information.	After the elapse of a certain period of time from the accident (data up to September 2012) More recent data, if appropriate, is also taken into consideration.
Time of release	Dose assessment: May 2012 Health risk assessment: February 2013	April 2014
Conclusion	The possibility of increases in diseases due to radiation released as a result of the latest nuclear accident is small, and risk increases are ignorable in Japan except for some areas in Fukushima Prefecture, as well as in neighboring countries.	Lifetime doses that the Japanese people will receive due to the nuclear accident are small and it is hardly likely that any health effects of radiation will be observed among Japanese people in the future.

Reports by the World Health Organization (WHO) on dose estimation and health risk assessment*1 and the 2013 Annual Report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) *2 are compared and their outlines and key points are introduced here.

The purpose of the WHO Reports is to estimate people's exposure doses for the first one year after the accident and identify areas requiring emergency measures. Therefore, the WHO provisionally assessed the residents' health risks based on limited information available and released the preliminary dose estimation report in May 2012.

Later, the WHO released preliminary health risk assessment report in February 2013.

In the meantime, the UNSCEAR regularly reports the status of radiation exposure of respective countries all over the world based on its scientific review of information. It has been continuing research and analysis of the effects of the Chernobyl accident for years and it also released the report on the effects of radiation exposure caused by Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS in April 2014.

(Related to p.184 of Vol. 1, "WHO Reports (1/4) Outline of the WHO's Dose Assessment" and p.189 of Vol. 1, "UNSCEAR 2013 Report (2/9) Outline of Assessment of Public Exposure Doses")

*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)

Included in this reference material on March 31, 2015

WHO Reports and UNSCEAR 2013 Report (2/3)
Comparison of Assessments (2/2): Assessment of Public Exposure Doses and Major Uncertainties

	WHO	UNSCEAR
Estimation of effective doses for the first one year after the accident (in millisieverts)	20 years old (adults); 1 year old (infants) (i) Fukushima Prefecture: 1-50 1-50 (ii) Neighboring prefectures: 0.1-10 0.1-10 (iii) Rest of Japan: 0.1-1 0.1-1	20 years old (adults); 1 year old (infants) (i) Precautionary Evacuation Areas: 1.1-5.7 1.6-9.3 (ii) Deliberate Evacuation Areas: 4.8-9.3 7.1-13 (iii) Non-evacuated districts of Fukushima Prefecture: 1.0-4.3 2.0-7.5 (iv) Neighboring prefectures: 0.2-1.4 0.3-2.5 (v) Rest of Japan: 0.1-0.3 0.2-0.5
Uncertainties	Large (prioritized the promptness in assessment)	Uncertainties remain although the report intends to achieve more realistic assessment than that in the WHO Reports.
Major causes of uncertainties in dose assessments	• Estimation of radioactivity concentrations in the air based on measured values of radiation deposited on the ground surface • Information on release of radioactive materials (source terms) and ATDM simulation • Compositions and chemical forms of radionuclides • Shielding effects of buildings • Assumptions for estimation of exposure doses through ingestion of foods • Variation in dose coefficients depending on dietary habits	• Measured values for radionuclides with short half-lives deposited on the ground surface • Changes over time in release rates of radionuclides and knowledge on weather information at the time of their release • Composition of particulate and gaseous I-131 in the air • Biased selection of samples in food monitoring (highly contaminated items are prioritized) • Japanese people's metabolism of iodine (thyroid iodine uptake rate)

Note: The WHO's dose estimation is more conservative (overestimated) than that by the UNSCEAR.
Explanation of terms:
- Source terms collectively refer to data necessary for dose assessment, i.e., types, chemical forms and release amounts of radioactive materials.
- Diffusion simulation means to calculate the tendency of diffusion of radioactive materials by combining the source term data and other data such as weather conditions and wind directions, etc.

For effective dose estimation, the WHO divided Japan into three zones, (i) Fukushima Prefecture, (ii) neighboring prefectures (Chiba, Gunma, Ibaraki, Miyagi and Tochigi Prefectures), and (iii) the rest of Japan, while the UNSCEAR divided Fukushima Prefecture into three zones, and the other prefectures into (iv) neighboring prefectures (Miyagi, Gunma, Tochigi, Ibaraki, Chiba and Iwate Prefectures) and (v) the rest of Japan.

Both the WHO Reports and the UNSCEAR Report state that their assessments of internal and external exposure doses contain certain uncertainties due to uncertainties inherent to basic data. Sources of such uncertainties explained in these Reports are mostly the same despite some differences in expressions. The assessment by the WHO is generally overestimated than that by the UNSCEAR. (Related to p.185 of Vol. 1, "WHO Reports (2/4) Effective Dose Estimation Method"; p.187 of Vol.1, "WHO Reports (4/4) Evaluation of Uncertainties"; p.191 of Vol.1, "UNSCEAR 2013 Report (4/9) Estimation of Public Exposure Doses for Each of the Four Groups"; p.193 of Vol.1, "UNSCEAR 2013 Report (6/9) Assessment of Public Exposure Doses: Results"; and p.195 of Vol.1, "UNSCEAR 2013 Report (8/9) Assessment of Public Exposure Doses: Uncertainties")

[Relevant parts in the reports]
Results of effective dose estimation:
· WHO Report on preliminary dose estimation (prepared based on pages 40 to 45 (3. Results))
· UNSCEAR Report (prepared based on paragraphs 209 to 214 on pages 56 to 57, Annex A (Japanese-language version)) (Original English version: paragraphs 209 to 214 on pages 86 to 87)
Uncertainties in dose assessments:
· WHO Report on preliminary dose estimation (prepared based on sections 4.7.1 to 4.7.7 of 4.7 on pages 60 to 62)
· UNSCEAR Report (prepared based on paragraphs 110 to 115 on pages 35 to 36, Annex A (Japanese-language version)) (Original English version: paragraphs 110 to 115 on pages 60 to 61)

Included in this reference material on March 31, 2015

WHO Reports and UNSCEAR 2013 Report (3/3)

Conservative Assessment and Realistic Assessment

Conservative assessment

- Based on assumptions that would not lead to underestimation of exposure doses based on uncertain information (conservative assumptions), exposure doses and health risks are assessed on the safe side for emergency measures immediately after a nuclear disaster.
- As a result of conservative assessment, calculated values will be larger than the actual exposure doses.
- Risk assessment based on the calculated values will result in overestimation of health effects.

Realistic assessment

In the recovery period after a nuclear hazard, current exposure doses and possible future health effects are to be assessed based on assumptions as close as possible to the reality, using all information and measurement data available at that point in time.

In taking emergency measures immediately after a nuclear disaster, exposure doses and health risks are often overestimated from the perspective of mitigating health effects that may be caused by radiation exposure to the extent possible.

In other words, risks are assessed conservatively on the safe side to avoid underestimation. Such conservative assessment is considered to be effective in avoiding the worst situation that may happen. On the other hand, in the recovery period after the completion of emergency measures, exposure situations are to be ascertained more realistically by reflecting on the accident based on fragmentary information and measurement data, and the possibility of health effects into the future are assessed in more detail.

The WHO Report on health risk assessment provisionally calculated health risks based on doses calculated conservatively with limited information and under conservative assumptions. As a result, its risk assessment provided the upper limit but resulted in overestimation as a whole.

The UNSCEAR Report intended to assess exposure levels and radiation risks due to the accident as realistically as possible as of the time when sufficient information was obtained. However, it states that the assessment still contains uncertainties due to the limitations in actual data. For example, there are uncertainties concerning measurement levels of radionuclides deposited on the ground surface and the assumption of radioactivity concentrations in foods. Due to such uncertainties, dose assessment in the UNSCEAR Report is indicated as being likely to be overestimated or underestimated depending on the circumstances.

Included in this reference material on March 31, 2015
Updated on February 28, 2018

WHO Reports (1/4)

Outline of the WHO's Dose Assessment

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 year 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.

Included in this reference material on March 31, 2015

WHO Reports (2/4)
Effective Dose Estimation Method

Key points of effective dose estimation

- Doses due to internal exposure through inhalation and external exposure were calculated based on the measurement data concerning radionuclides deposited on the ground surface.
- Doses due to internal exposure through ingestion were calculated based on the measurement data concerning foods.
- The 20 km-zone from the NPS was excluded.
- For Deliberate Evacuation Areas, people were assumed to have stayed there for four months after the accident.

Exposure pathways

All major exposure pathways were taken into consideration.

- External exposure from groundshine*1
- External exposure from cloudshine*2
- Internal exposure through inhalation
- Internal exposure through ingestion

The key points of the WHO's effective dose estimation method are as follows.
· Doses due to internal exposure through inhalation and external exposure in Japan were calculated based on the data for measured concentrations of radionuclides deposited on the ground surface.
· Doses due to internal exposure through ingestion in Japan were calculated based on the data on measured concentrations of radionuclides in foods.
· For the 20 km-zone from Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS, dose estimation was not conducted as people evacuated therefrom immediately after the accident.
· Regarding Namie Town, Iitate Village and Katsurao Village, which were designated as Deliberate Evacuation Areas, dose estimation was conducted assuming that people stayed in these areas for four months after the accident without taking into account evacuation or other measures actually taken.

The WHO assumed four exposure pathways, namely, external exposure from (i) groundshine*1 and from (ii) cloudshine,*2 and internal exposure through (iii) ingestion of foods and drinking water and through (iv) inhalation.

For external exposure, doses were estimated as 60% of those to be received when being outdoors all day long under the assumption that people stay indoors for 16 hours a day.

*1: Groundshine: External exposure from radionuclides deposited on the ground
*2: Cloudshine: External exposure from radionuclides in radioactive plumes (p.29 of Vol. 1, "Effects of Reactor Accidents")

[Relevant parts in the reports]
· WHO Report on preliminary dose estimation (prepared based on Figure 5 on page 25)
· WHO Report on health risk assessment, FAQ (Q.4)
· WHO Report on preliminary dose estimation, FAQ (latter half of Q.3)
· WHO Report on preliminary dose estimation (pages 38 and 86)

Included in this reference material on March 31, 2015

WHO Reports (3/4)
Summary of Health Risk Assessment

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.
- 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 natural variation is hardly expected.
- Risks of hereditary 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 40 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

WHO Reports (4/4)

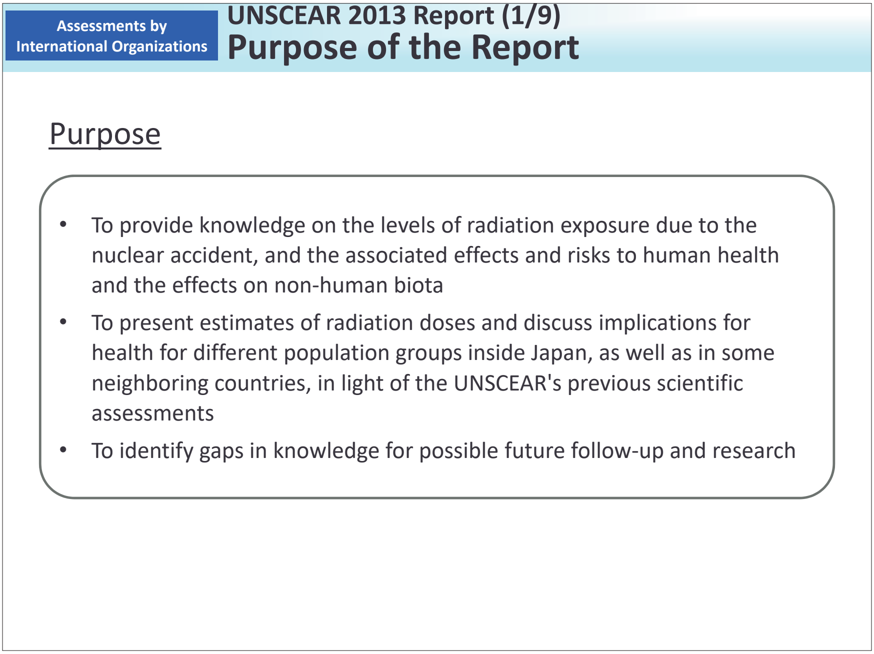
Evaluation of Uncertainties

- Uncertainties concerning the estimation of radioactive concentrations in the air based on measured values of radionuclides deposited on the ground surface
- Uncertainties concerning compositions and chemical forms of radionuclides
- Uncertainties due to a lower assumption of shielding effects of buildings
- Uncertainties in internal dose coefficients due to unique metabolism of radioactive materials in Japanese
- Uncertainties concerning information on release of radioactive materials (source terms) and the Atmospheric Transport and Dispersion Model (ATDM) simulation
- Uncertainties due to assumptions for dose estimation for exposure through ingestion of foods

The WHO mainly explains as follows regarding the uncertainties in the results of effective dose estimation.
・Estimating radioactivity concentrations in the air based on the amounts deposited on the ground surface involves uncertainties. For example, the chemical form of iodine influences the deposition rates, which causes a significant uncertainty in the estimation of exposure doses through inhalation. Additionally, compositions of radionuclides, such as percentages of I-131 and Cs-137, differ by area and this is also a source of uncertainties.
・Dose assessment was conducted assuming wooden houses, whose shielding effects are weaker than those of buildings made of concrete. This is one of the sources of uncertainties that might result in overestimation.
・When estimating internal exposure, dose coefficients (doses due to the intake of 1 Bq in the body) specified by the International Commission on Radiological Protection (ICRP) were used. However, Japanese people take in a lot of marine products and are said to have relatively larger amounts of stable iodine in the body. If this is the case, even if they take in radioactive iodine temporarily, the amount of radioactive iodine entering the thyroid would be smaller. However, such possibility was not taken into consideration and this is also one of the sources of uncertainties.
・Internal exposure through the intake of foods was estimated under assumptions that might lead to overestimation, such as that people had eaten only foods produced in Fukushima Prefecture and neighboring prefectures, which also causes uncertainties.

[Relevant parts in the reports]
・WHO Report on preliminary dose estimation (4.7 "Main sources of uncertainty and limitations" on pages 60 to 62, and 2.6.1 "Ingestion doses inside Japan" on pages 31 to 33)

Included in this reference material on March 31, 2015



Assessments by International Organizations

UNSCEAR 2013 Report (1/9)

Purpose of the Report

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 purposes.
・To evaluate information, mainly from 2011 and 2012, 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, and to a lesser degree in some neighboring countries, using data and information available to UNSCEAR, and against the backdrop of UNSCEAR's previous scientific assessments of effects of radiation on health and the environment from all sources, including accidents
・To identify gaps in knowledge for possible future follow-up and research

On the other hand, the following two are cited as what was not intended by this Report.
・To identify lessons or address policy issues with respect to human rights, public health protection, environmental protection, radiation protection, emergency preparedness and response, accident management, nuclear safety, and related issues
・To provide advice to local governments, the Government of Japan or to national and international bodies

[Relevant parts in the reports]
・UNSCEAR Report (prepared based on paragraph 8 on page 26, Scientific Annex A (Japanese-language version)) (Original English version: paragraph 8 on page 27)

Included in this reference material on March 31, 2015

UNSCEAR 2013 Report (2/9)

Outline of Assessment of Public Exposure Doses

1. The assessment was based on measurement data as far as possible.
2. Doses that the public received for the first one year after the accident were assessed, targeting 20-year-old adults, 10-year-old children and 1-year-old infants.
3. Projections were also made of doses to be received over the first 10 years and up to age 80 years.
4. Models were used, with realistic assumptions, to provide an objective evaluation of the situation.
5. Protective actions taken during the first year were considered and the doses averted by them were estimated.

As indicated in the preface to the Report, at its fifty-eighth session 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 of March 2011. It was decided to mainly utilize 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.

"Chapter IV Assessment of doses to the public" of the UNSCEAR Report comprises the following.

A. Exposure pathways, B. Data for dose assessment, C. Overview of methodology for assessing public exposures, D. Results of dose estimation, E. Uncertainties, and F. Comparison with direct measurements and other assessments

"D. Results of dose estimation" shows the estimation results for effective doses and absorbed doses in specific organs for general public in Japan. The section consists of (i) doses in the first year for members of the public not evacuated, (ii) evacuees' doses, (iii) estimation of doses in Japan for exposure over future years, and (iv) estimation of doses in other countries.

Details of the estimation of public exposure doses will be explained in the following pages.

[Relevant parts in the reports]

・UNSCEAR Report (prepared based on paragraphs 3 to 4 on page 25, and paragraph 12 on page 7, Scientific Annex A (Japanese-language version)) (Original English version: paragraphs 3 to 4 on page 25 and paragraph 12 on page 27)

Included in this reference material on March 31, 2015

UNSCEAR 2013 Report (3/9)
Data Used for Assessment of Public Exposure Doses

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 Report (prepared based on paragraphs 67 to 78 on pages 46 to 48, Scientific Annex A (Japanese-language version) (Original English version: paragraphs 67 to 78 on pages 48 to 50), Appendix A, and "IV. TRANSPORT AND DISPERSION IN THE OCEAN" of Appendix B)

Included in this reference material on March 31, 2015

UNSCEAR 2013 Report (4/9)
Estimation of Public Exposure Doses for Each of the Four Groups

Area classification for dose assessment

Group	Area	Spatial resolution for public dose assessment
1	Settlements in Fukushima Prefecture where people were evacuated in the days to months after the accident	Representative locations were used for each settlement identified in 18 evacuation scenarios
2	Districts of Fukushima Prefecture not evacuated	District level for external and inhalation pathways, based on the estimates for each of the 1-km-grid points, averaged over the district Prefecture level for ingestion pathway
3	Selected prefectures in eastern Japan that were neighboring (prefectures of Miyagi, Tochigi, Gunma and Ibaraki) or nearby (prefectures of Iwate and Chiba) to Fukushima Prefecture	District level for external and inhalation pathways, based on the estimates for each of the 1-km-grid points, averaged over the district Estimated dose due to ingestion for Iwate Prefecture same as for Group 4; for other five prefectures was based on average for the five prefectures
4	All remaining prefectures of Japan	Prefecture level for external and inhalation pathways Average for rest of Japan for ingestion pathway

Public exposure levels differ by location, and evacuees changed their locations as time passed.

Therefore, the UNSCEAR classified areas into four groups for assessing public exposure doses and further narrowed down the targets depending on the exposure pathways. The table above shows the four groups classified by the UNSCEAR.

- Group 1: Settlements in Fukushima Prefecture where people were evacuated in the days to months after the accident
- Group 2: Districts of Fukushima Prefecture not evacuated
- Group 3: Selected prefectures in eastern Japan that were neighboring (prefectures of Miyagi, Tochigi, Gunma and Ibaraki) or nearby (prefectures of Iwate and Chiba) to Fukushima Prefecture
- Group 4: All remaining prefectures of Japan

There are 12 administrative districts classified into Group 1 in Fukushima Prefecture and 18 evacuation scenarios were prepared covering all these 12 districts immediately after the accident, which means that some districts were covered under multiple scenarios at the same time. Therefore, the term "settlement" is used in Group 1 to represent specific zones in a single district that were subject to respective evacuation scenarios.

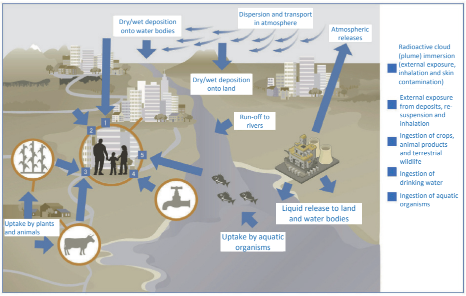
[Relevant parts in the reports]

- UNSCEAR Report (prepared based on paragraphs 79 to 80 on pages 48 to 49, Scientific Annex A (Japanese-language version) (Original English version; paragraphs 79 to 80 on pages 50 to 51), and paragraphs 30 to 32 on pages 155 to 156, Appendix C)

Included in this reference material on March 31, 2015

UNSCEAR 2013 Report (5/9)
Assessment of Public Exposure Doses: Exposure Pathways

Figure V. Exposure pathways from releases of radioactive material to the environment



1. Move of radioactive plumes in the air
   - ✓ External exposure
   - ✓ Internal exposure (inhalation)

2. Deposition on the ground surface
   - ✓ External exposure
   - ✓ Internal exposure (re-suspension, inhalation)

3. Deposition on the ground surface, etc.
   - ✓ Internal exposure (transfer to foods and drinks)

<u>Major exposure pathways to be assessed</u>

(i) External exposure from radioactive materials in plumes and internal exposure through inhalation thereof

(ii) External exposure from radioactive materials deposited on the ground surface and internal exposure through ingestion of radionuclides that have transferred into foods and drinks

(iii) Internal exposure through ingestion of radioactive materials that have transferred into marine products

In order to estimate exposure doses from radioactive materials released into the environment due to the accident, exposure modes are analyzed in the first place.

The figure above roughly shows exposure pathways in which radioactive materials move in the air in the form of a radioactive plume and reach people's residential areas. In this case, exposure occurs in the following two pathways: external exposure directly from a radioactive plume passing by and internal exposure through inhalation of radioactive materials in a plume.

Furthermore, when radioactive materials in a plume were deposited on the ground surface due to rain, etc., exposure occurs in the following two pathways. The first is external exposure due to radiation from radioactive materials deposited on the ground surface. The second is internal exposure through ingestion of agricultural products with deposited radioactive materials or ingestion of meat of livestock that ate such contaminated agricultural products. As exposure through ingestion of foods and drinks, the following two pathways are considered: internal exposure through ingestion of tap water or other drinking water containing radioactive materials and internal exposure through ingestion of fish into which radioactive materials that had moved into the ocean transferred.

There is also the possibility that radioactive materials deposited on the ground surface become re-suspended in the air and cause internal exposure through inhalation, but radiation effects through this exposure pathway are considered to be minor.

Given these, the major exposure pathways due to radioactive materials released into the air are as follows.

(i) External exposure from radionuclides in the radioactive plumes
(ii) Internal exposure from inhalation of radionuclides in the radioactive plumes
(iii) External exposure from radionuclides deposited on the ground
(iv) Internal exposure from ingestion of radionuclides in foods and water

[Relevant parts in the reports]

・UNSCEAR Report (prepared from paragraphs 65 to 66 on pages 45 to 46, Scientific Annex A (Japanese-language version) (Original English version: paragraphs 65 to 66 on pages 47 to 48), and paragraphs C3 to C7 on pages 148 to 149, Appendix C)

Included in this reference material on March 31, 2015

Assessment of Public Exposure Doses: Results

Table 1. Estimated average effective doses and absorbed doses to the thyroid by area for the first one year after the accident[*1]

Evacuated settlements					
Group		Effective dose (mSv)		Absorbed dose to the thyroid (mGv)	
		20-year-old (Adults)[*2]	1-year old (Infants)	20-year-old (Adults)[*2]	1-year old (Infants)
1[a]	Precautionary Evacuation Areas[b]	1.1-5.7	1.6-9.3	7.2-34	15-82
	Deliberate Evacuation Areas[c]	4.8-9.3	7.1-13	16-35	47-83
Non-evacuated areas					
2	Fukushima Prefecture (other than evacuated settlements)	1.0-4.3	2.0-7.5	7.8-17	33-52
3	Neighboring prefectures[d]	0.2-1.4	0.3-2.5	0.6-5.1	2.7-15
4	Rest of Japan	0.1-0.3	0.2-0.5	0.5-0.9	2.6-3.3

[a] Estimate evacuees' doses using 18 evacuation scenarios

[b] Settlements where evacuation was ordered from March 12 to 15, 2011, as emergency protective measures to prevent high-level exposure

[c] Settlements where evacuation was ordered from the end of March to June 2011

[d] Iwate, Miyagi, Ibaraki, Tochigi, Gunma and Chiba Prefectures

*1: Estimation of doses for typical residents of evacuated settlements and other areas in Japan

mSv: millisieverts mGy: milligrays

*2: Estimated doses for 10-year-old children are omitted here.

Reference: Estimation of the public doses in neighboring countries and the rest of the world: The UNSCEAR concluded that the average effective dose for people residing outside Japan for the first one year after the accident was lower than 0.01 mSv.

This table shows estimated effective doses and absorbed doses to the thyroid for the first one year after the accident for typical residents in evacuated settlements and residents in administrative districts other than evacuated settlements in Fukushima Prefecture and in other prefectures in Japan.

Doses in the table show doses added to background doses due to natural 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 representative values for each municipality in areas or for each evacuation scenario among targeted groups.

[Relevant parts in the reports]

・UNSCEAR Report (prepared based on paragraphs 209 to 214 on pages 80 to 81, Scientific Annex A (Japanese-language version)) (Original English version: paragraphs 209 to 214 on pages 86 to 87)

Included in this reference material on March 31, 2015

Assessments by International Organizations

UNSCEAR 2013 Report (7/9)

Assessment of Health Effects on General Public

- 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 hereditary effects are not detected.

Source: Prepared based on the UN document, "UNSCEAR: Fukushima-Daiichi NPS Accident (Evaluating Radiation Science for Informed Decision-Making)"

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 Chernobyl 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 Chernobyl accident.

・Leukemia: The UNSCEAR considered the risk to those exposed as foetuses 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.

[Relevant parts in the reports]

・UNSCEAR Report (prepared based on paragraphs 220 and 222 to 224 on pages 82 to 83, Scientific Annex A (Japanese-language version)) (Original English version: paragraphs 220 and 222 to 224 on page 89)

Included in this reference material on March 31, 2015

UNSCEAR 2013 Report (8/9)
Assessment of Public Exposure Doses: Uncertainties

1. Measurement levels of short-half-life radionuclides deposited on the ground surface and their spatial distribution by area
2. Changes in release rates of radionuclides over time and weather information at the time of their release
3. Particle sizes and chemical forms of radioactive iodine
4. Assumption of radioactivity concentrations in foods
5. Japanese people's thyroid iodine uptake rate

The UNSCEAR estimated public exposure doses from radioactive materials released due to the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS under certain assumptions based on insufficient knowledge and information, and therefore, it considers that the results contain certain uncertainties.

1. Uncertainties concerning measurements of radionuclides deposited on the ground surface
 ・Uncertainties in measurement values of Cs-134 and Cs-137 are relatively small.
 ・Regarding I-131, whose half-life is approx. 8 days, uncertainties are significant due to the fact that its radioactive decay had progressed before the measurement.

2. Uncertainties concerning changes in release rates of radionuclides over time and weather information at the time of their release
 ・Estimation of doses for people who evacuated in March 2011 is based on the results of the Atmospheric Transport and Dispersion Model (ATDM) simulations.
 ・As a result, the estimation results may be overestimated or underestimated by a factor of up to typically four to five.

3. Uncertainties affecting assessment of absorbed doses to the thyroid
 ・There was no data on relative amounts of particulate and gaseous forms of I-131 in the air and the estimation was made under the assumption that equal amounts of iodine were released in particulate and gaseous forms. This resulted in an uncertainty of up to about a factor of two over the periods of the principal exposures.

4. Uncertainties concerning the assumption of radioactivity concentrations in foods
 ・Foodstuffs were not sampled randomly, because the authorities gave priority to identifying foods with the highest concentrations. It was therefore likely that the values of average concentrations used for the assessment led to overestimation.
 ・Assumptions concerning the pattern of food distribution and consumption (overestimation of the intake of foods produced in Fukushima Prefecture) were another source of uncertainty.
 ・Measured radioactivity concentrations in foods below the detection limits were all assumed as 10 Bq/kg, and this led to overestimation of internal exposure through ingestion of foods for the first one year.

5. Uncertainties concerning Japanese people's thyroid iodine uptake rate
 ・Japanese people's thyroid iodine uptake rate may be different from the standard model adopted by the ICRP (the level of uncertainties is smaller than those concerning the aforementioned four items and a possible reduction in exposure doses due to this factor is less than 30%).

[Relevant parts in the reports]
・UNSCEAR Report (prepared based on paragraphs 110 to 115 on pages 57 to 58, Scientific Annex A (Japanese-language version) (Original English version: paragraphs 110 to 115 on pages 60 to 61), and C113 to C131 of "IV. Uncertainties" on pages 188 to 192, Appendix C)

Included in this reference material on March 31, 2015

Assessments by International Organizations

UNSCEAR 2013 Report (9/9)

Comparison with Direct Measurements

Two sets of measurement information of radionuclides served as information sources for assessing public exposure doses.

(i) Measured values of I-131 in the thyroid, especially in the thyroid of children

(ii) Results of the whole-body monitoring of Cs-134 and Cs-137

1. The UNSCEAR's estimates of settlement-average absorbed doses to the thyroid from internal exposure were up to about five times higher than the corresponding values derived from direct monitoring of this group.
2. The results of the whole-body counting of more than 106,000 residents of Fukushima Prefecture were substantially lower than the UNSCEAR's estimates of average effective doses through inhalation and ingestion of Cs-134 and Cs-137.

The UNSCEAR Report suggests the possibility of certain overestimation in assumptions on protective measures and factors concerning dose measurements due to lack of information when estimating public exposure doses. This possibility was also confirmed in the comparison with the results of the measurement of absorbed I-131 to the thyroid conducted in Fukushima Prefecture after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS and the whole-body counting of Cs-134 and Cs-137.

Data used for the comparison was as follows.

(i) Absorbed doses to the thyroid due to internal exposure: Data for the thyroid monitoring carried out targeting 1,080 children aged between 1 and 15 years in Iwaki City, Kawamata Town and Iitate Village over the period from March 26 to 30, 2011, using hand-held dose-rate instruments

(ii) Effective doses through internal exposure: Data for the whole-body counting targeting more than 106,000 residents of Fukushima Prefecture conducted as part of the Fukushima Health Management Survey, and data for the whole-body counting targeting 33,000 residents of Fukushima Prefecture and neighboring prefectures conducted by researchers from October 2011 to February 2012

As shown in the slide above, the UNSCEAR Report concludes as follows with regard to the comparison between its estimation and these direct measurements.

・Regarding (i) above, the UNSCEAR's estimates were up to about five times higher than the settlement-average absorbed doses obtained through direct measurements.

・Regarding (ii) above, the UNSCEAR's estimates were substantially higher than the results of direct measurements (direct measurement data is substantially lower than the UNSCEAR's estimates).

[Relevant parts in the reports]

・UNSCEAR Report (prepared based on paragraphs 116 to 118 on page59, Scientific Annex A (Japanese-language version)) (Original English version: paragraphs 116 to 118 on page 62)

Included in this reference material on March 31, 2015

Follow up of the UNSCEAR Report
Developments and Outline

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 are publicized every year. The one publicized in 2017 is the third White Paper.

* "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 that have been 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 conducts ongoing follow-up activities to collect and evaluate such pieces of information systematically. The results of the follow-up activities are compiled as a white paper and are publicized every year. The UNSCEAR has publicized three White Papers by the end of 2017.

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
http://www.unscear.org/unscear/en/publications/Fukushima_WP2015.html
- "Fukushima 2016 White Paper," UNSCEAR
http://www.unscear.org/unscear/en/publications/Fukushima_WP2016.html
- "Fukushima 2017 White Paper," UNSCEAR
http://www.unscear.org/unscear/en/publications/Fukushima_WP2017.html

Included in this reference material on March 31, 2017
Updated on February 28, 2018

Follow up of the UNSCEAR Report
Major Conclusions

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 latest 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 33 to 37 of the Japanese-language version) (Original English version: paragraphs 137 to 143 on pages 34 to 38)

Included in this reference material on March 31, 2017
Updated on February 28, 2018

Abbreviations

Act on Special Measures Concerning Nu-clear Emergency	Act on Special Measures Concerning Nuclear Emergency Prepar-edness
Act on Special Measures (Concerning the Handling of Environment Pollution by Ra-dioactive Materials)	Act on Special Measures Concerning the Handling of Environmen-tal Pollution by Radioactive Materials Discharged by the Nuclear Power Plant Accident Accompanying the Earthquake that Occurred off the Pacific Coast of the Tohoku Region 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 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)

Index

Glossary

A

Act on Special Measures Concerning the Handling of Environment Pollution by Radioactive Materials

The radioactive materials released due to the accident at TEPCO's Fukushima Daiichi 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).

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 Areas where Returning is Difficult.

Areas where Returning is Difficult

Areas where annual accumulated doses are currently over 50mSv and are highly likely to be over 20mSv even after five years from 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. (Based on the website of Fukushima Prefecture [d])

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 the Research Organization for Information Science and Technology)

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 (137Cs) and Cesium-134 (134Cs) are radioisotopes of cesium and their physical half-lives are about 30 and two years, respectively. 137Cs decomposes to 137Ba through beta decay associated with gamma radiation (0.662 MeV), and then to nonradioactive barium. 137Cs is generated as one of the fission products, whereas 134Cs 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. 137Cs and 134Cs were released into the environment due to the Fukushima Daiichi nuclear power plant 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.

Chernobyl Nuclear Accident

A nuclear reactor accident that occurred at Unit 4 of the Chernobyl Nuclear Power Plant 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 (wT). The commitment period is taken to be 50 years for adults, and to age 70 years for children. (Cited from ICRP, 2007) (See p.53 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.

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 from unstable to more stable states. Radiation of alpha-ray, beta-ray, gamma-ray etc. occurs in the process. (Cited from the website of Public Health England, 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) 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 20mSv 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 8,000Bq/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 8,000Bq/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)

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 Public Health England, 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 the Research Organization for Information Science and Technology)

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 the Research Organization for Information Science and Technology)

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 clad

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 the Research Organization for Information Science and Technology)

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 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 2,000mGy (2Gy) 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 the Research Organization for Information Science and Technology)

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, 92 municipalities in eight prefectures are designated as Intensive Contamination Survey Areas (as of the end of December 2017).

Interim storage facility

A facility to manage and store the soil and waste. containing radioactive materials safely and intensively until their final disposal.

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, OECS/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 Chernobyl 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 Public Health England, 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 2.1mSv on average from naturally occurring radiation and 3.87mSv 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 the Research Organization for Information Science and Technology)

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 Public Health England, 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 the Research Organization for Information Science and Technology)

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 used for electricity generation. Nuclear fission can be sustained in a self-supporting chain reaction involving neutrons. In thermal reactors, fission is brought about by thermal neutrons. Nuclear energy is released by fission reactions of nuclear material. This energy is used for the electricity generation. (Cited from the website of Public Health England, 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 the Research Organization for Information Science and Technology)

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 Public Health England, 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. Plutonium-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 the Ministry of Health, Labour and Welfare [c])

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 20mSv 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 the Research Organization for Information Science and Technology)

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 the Research Organization for Information Science and Technology)

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 the Research Organization for Information Science and Technology)

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 the Research Organization for Information Science and Technology)

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 the Research Organization for Information Science and Technology)

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 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 restricted areas. (Based on the website of Fukushima Prefecture [d])

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 used for radiation measurement. It contains material that emits light flashes when exposed to ionizing radiation. The flashes are converted to electric pulses and counted. The number of pulses is related to dose. (Cited from the website of Public Health England, 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 Restricted Area or a Deliberately-Evacuated Settlement are designated.

Specific Spots Recommended for Evacuation

Areas that do not fall under Restricted Areas or Deliberately-Evacuated Settlements but where accumulated doses are highly likely to be over 20mSv 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

Zones among Areas where Returning is Difficult 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 the Research Organization for Information Science and Technology)

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 Public Health England, 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])

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 Fukushima Daiichi Nuclear Power Station 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 emits 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 Examination

Thyroid examination covers roughly 380,000 residents aged 0 to 18 years at the time of the nuclear accident. The Preliminary Baseline Screening 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.

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 the Research Organization for Information Science and Technology)

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 the Research Organization for Information Science and Technology)

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.

Bibliography for the Glossary

[1] Fukushima Prefecture [a]. Explanation - Changes in Evacuation Areas (in Japanese). Retrieved October 12, 2018 from http://www.pref.fukushima.lg.jp/site/portal/cat01-more.html.

[2] Fukushima Prefecture [b]. Food Inspection System in Fukushima Prefecture. Retrieved October 12, 2018 from http://www.pref.fukushima.lg.jp/site/portal-english/en01-02.html.

[3] Fukushima Prefecture [c]. Fukushima Health Management File (in Japanese). Retrieved October 12, 2018 from http://www.pref.fukushima.lg.jp/site/portal/ps-kenkocyosa-file.html.

[4] Fukushima Prefecture [d]. Glossary of Nuclear Science Terms (in Japanese). Retrieved October 12, 2018 from https://www.pref.fukushima.lg.jp/sec/16025c/genan183.html.

[5] Health Physics Society. Radiation Terms and Definitions. Retrieved on October 12, 2018 from http://hps.org/publicinformation/radterms/Sourceterm.html. Reprinted with Permission.

[6] Henriksen, T., & Maillie, D. H., 2002. [Advanced Reading] What is ionizing radiation? *Radiation and Health (1st ed.)*. London and New York: Taylor & Francis.

[7] IAEA (International Atomic Energy Agency), International Labour Office, 1999. *Occupational Radiation Protection, Safety Standards Series* No. Rs-G-1.1. p.6. Vienna: IAEA.

[8] ICRP (International Commission on Radiological Protection), 2007. Glossary. *The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103*. Volume 37, pp.17-34. Stockholm: Elsevier Ltd.

[9] National Research Council, 1989. *Improving Risk Communication.* Washington, DC: The National Academies Press. DOI: https://doi.org/10.17226/1189. Republished with permission of Taylor and Francis Group LLC Books, from the above publication; permission conveyed through Copyright Clearance Center, Inc.

[10] NSRA (Nuclear Safety Research Association), 2011. *Revised Version: Radiation in Living Environment (in Japanese).* Tokyo: NSRA.

[11] Public Health England, Radiation Protection Services. Glossary. Retrieved on October 12, 2018 from https://www.phe-protectionservices.org.uk/glossary.

[12] The EIC Network. Glossary of Environmental Terms (in Japanese). Retrieved October 12, 2018 from http://www.eic.or.jp/ecoterm/.

[13] The Food Safety Commission of Japan. Food Safety Glossary (ver.5.1) (in Japanese). Retrieved October 12, 2018 from http://www.fsc.go.jp/yougoshu.data/yougoshu_fsc_5.1_201604.pdf.

[14] The Ministry of Health, Labour and Welfare [a]. Chapter 5. Applicable laws and regulations. *The Textbook for Special Education on Accident-derived Waste Disposal Work*. Retrieved October 12, 2018 from https://www.mhlw.go.jp/new-info/kobetu/roudou/gyousei/anzen/dl/130417-5.pdf

[15] The Ministry of Health, Labour and Welfare [b]. Outline of the Food Sanitation Act (in Japanese). Retrieved (in Japanese). October 12, 2018 from https://www.mhlw.go.jp/bunya/kenkou/seikatsu-eisei04/08.html.

[16] The Ministry of Health, Labour and Welfare [c]. Start with Obtaining Knowledge - Everybody's Mental Health (in Japanese). Retrieved October 12, 2018 from https://www.mhlw.go.jp/kokoro/know/disease_ptsd.html.

[17] The Ministry of the Environment. Outline of the Act on Special Measures Concerning the Handling of Environment Pollution by Radioactive Materials (in Japanese). Retrieved October 12, 2018 from http://josen.env.go.jp/about/tokusohou/summary.html.

[18] The National Cancer Center Japan. Glossary of Cancer-related Terms (in Japanese). Retrieved October 12, 2018 from https://ganjoho.jp/words.html.

[19] The National Institute of Radiological Sciences. Glossary - Naturally Occurring Radioactive Materials Database (in Japanese). Retrieved October 12, 2018 from http://www.nirs.qst.go.jp/db/anzendb/NORMDB/index.php.

[20] The Nuclear Fuel Cycle Engineering Laboratories, JAEA. Glossary of Nuclear Science Terms (in Japanese). Retrieved October 12, 2018 from https://www.jaea.go.jp/04/ztokai/local/kiso/words/index.html.

[21] The Radiation Medical Science Center, Fukushima Medical University Retrieved October 12, 2018 from http://fmu-global.jp/.

[22] The Reconstruction Agency [a]. Plan for Reconstruction and Revitalization for the Specified Reconstruction and Revitalization Base (in Japanese). Retrieved October 12, 2018 from http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/saiseikyoten/20170913162153.html.

[23] The Reconstruction Agency [b]. Roles of the Reconstruction Agency (in Japanese). Retrieved October 12, 2018 from http://www.reconstruction.go.jp/topics/main-cat12/yakuwari.html.

[24] The Research Organization for Information Science and Technology (in Japanese). ATOMICA. Retrieved October 12, 2018 from http://www.rist.or.jp/atomica/.

[25] United States Environmental Protection Agency, Office of Air and Radiation/ Office of Radiation and Indoor Air. Radiation Glossary. Retrieved October 12, 2018 from https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&vocabName=Radiation%20Glossary&uid=1869530&taxonomyName=Radiation%20Glossary.

[26] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic

Radiation), 2017. Glossary. *UNSCEAR 2017 Report. Sources, Effects and Risks of Ionizing Radiation. Report to the General Assembly and Scientific Annexes A and B.* p.178. New York: United Nations.

[27] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), 2013. Glossary. *UNSCEAR 2013 Report. Sources, Effects and Risks of Ionizing Radiation. Volume I. Report to the General Assembly and Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami.* p.285. New York: United Nations.

[28] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), 1993. *Annex F: Influence of dose and dose rate stochastic effects of radiation. UNSCEAR Report 1993. Sources, Effects and Risks of Ionizing Radiation. Report to the General Assembly, with Scientific Annexes.* p.624. New York: United Nations.

[29] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), 2013. Table 6. Estimated settlement-average effective doses and absorbed doses to the thyroid for evacuees for the first year following the accident. *UNSCEAR 2013 Report. Sources, Effects and Risks of Ionizing Radiation. Volume I. Report to the General Assembly and Scientific Annexes A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami.* p.57. New York: United Nations.

[30] WHO (World Health Organization), 2012. Glossary. *Preliminary dose estimation from the nuclear accident after the 2011 Great East Japan earthquake and tsunami.* pp.72-76. Geneva: World Health Organization.

[31] WHO (World Health Organization), 2013. Glossary. *Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation.* pp.108-113. Geneva: World Health Organization.

BOOKLET to Provide Basic Information Regarding Health Effects of Radiation
Vol. 1 Basic Knowledge and Health Effects of Radiation

1st Edition : Published in January 2019

This English Version is based on the 5th edition of the BOOKLET in Japanese
(published on February 28, 2018).

Publishers:
Radiation Health Management Division, Environmental Health Department, Minister's Secretariat, Ministry of the Environment, Government of Japan
1-2-2, Kasumigaseki, Chiyoda-ku, Tokyo, Japan

National Institutes for Quantum and Radiological Science and Technology
4-9-1, Anagawa, Inage-ku, Chiba-shi, Chiba, Japan