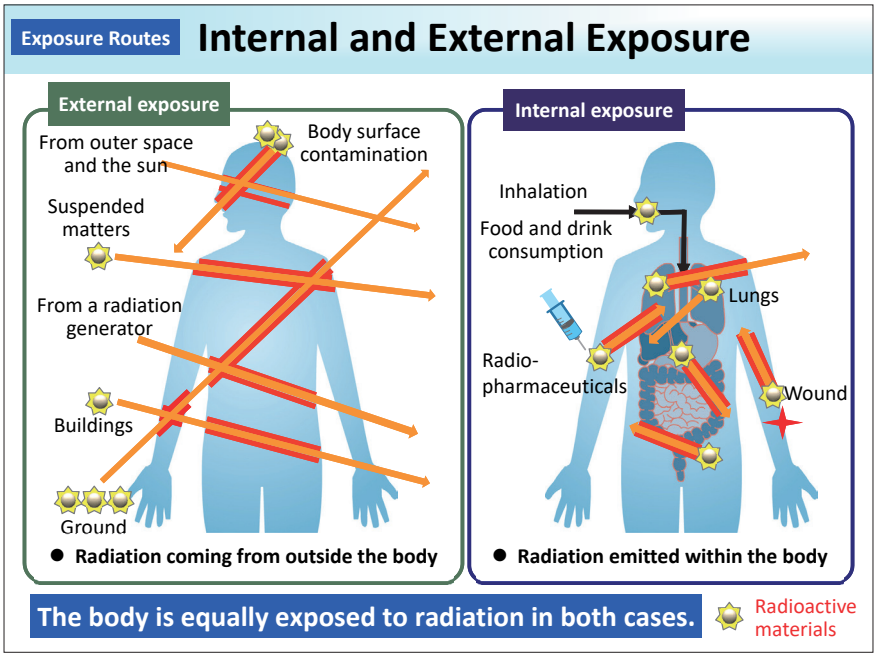


"Radiation exposure" refers to the situation where the body is in the presence of radiation. There are two types of radiation exposure, "internal exposure" and "external exposure."

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").

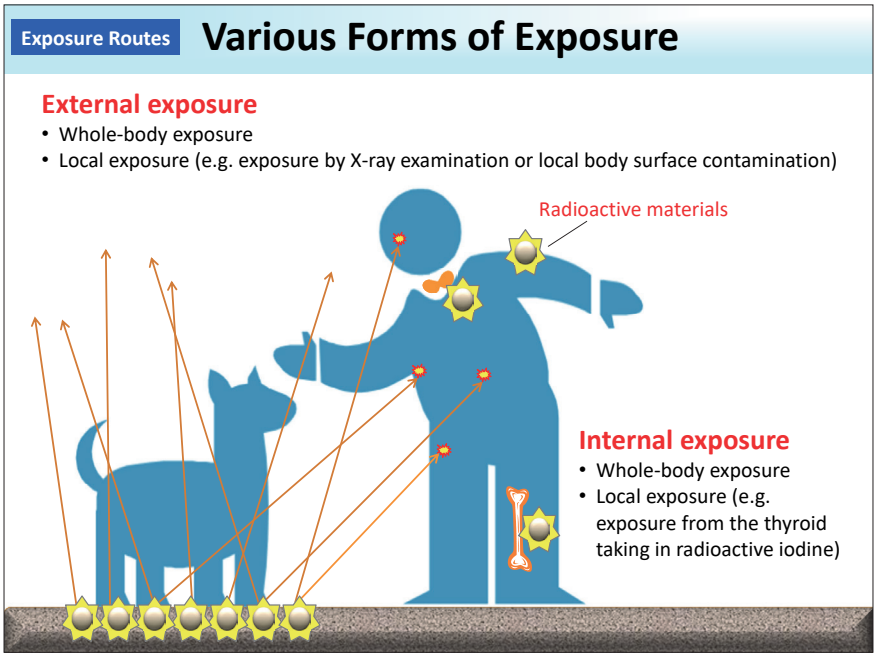
Conversely, internal exposure is caused (i) when a person has a meal and takes in radioactive materials in the food or drink (ingestion); (ii) when a person breathes in radioactive materials in the air (inhalation); (iii) when radioactive materials are absorbed through the skin (percutaneous absorption); (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



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.

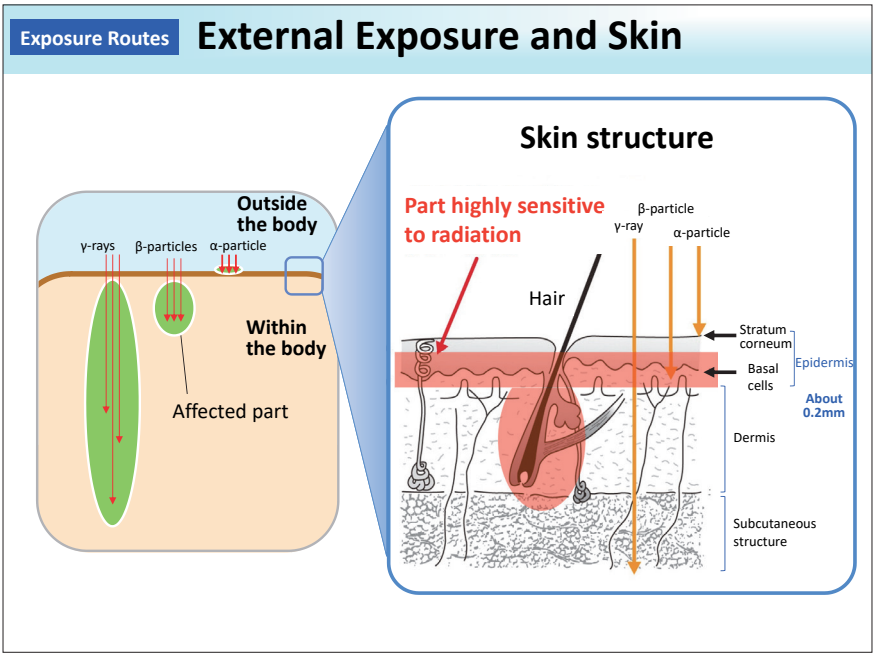
Organs differ in sensitivity to radiation. In local exposure, therefore, the extent of the effects varies greatly depending on whether the exposed part includes organs that are highly sensitive to radiation.

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

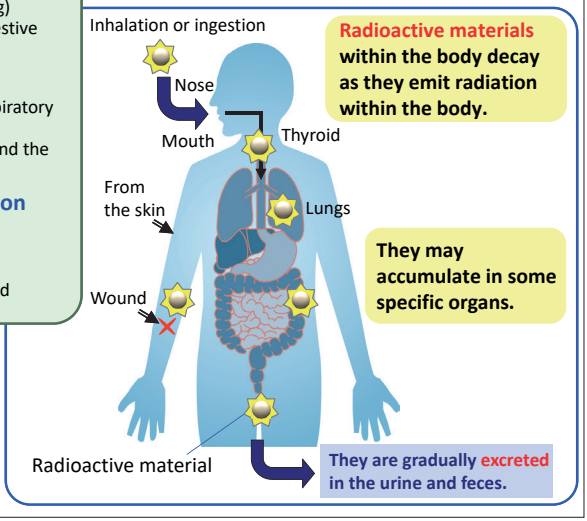
Exposure Routes Internal Exposure

(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



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

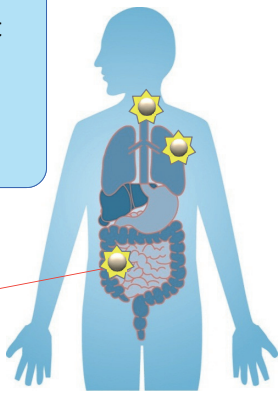
Internal Exposure and Radioactive Materials

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:

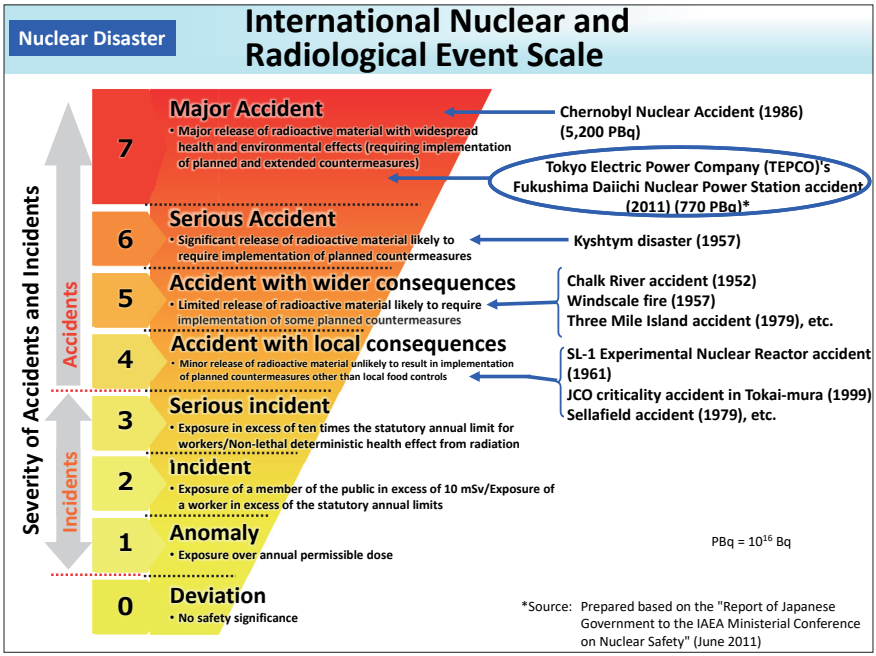
$$1/Te = 1/Tp + 1/Tb$$

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



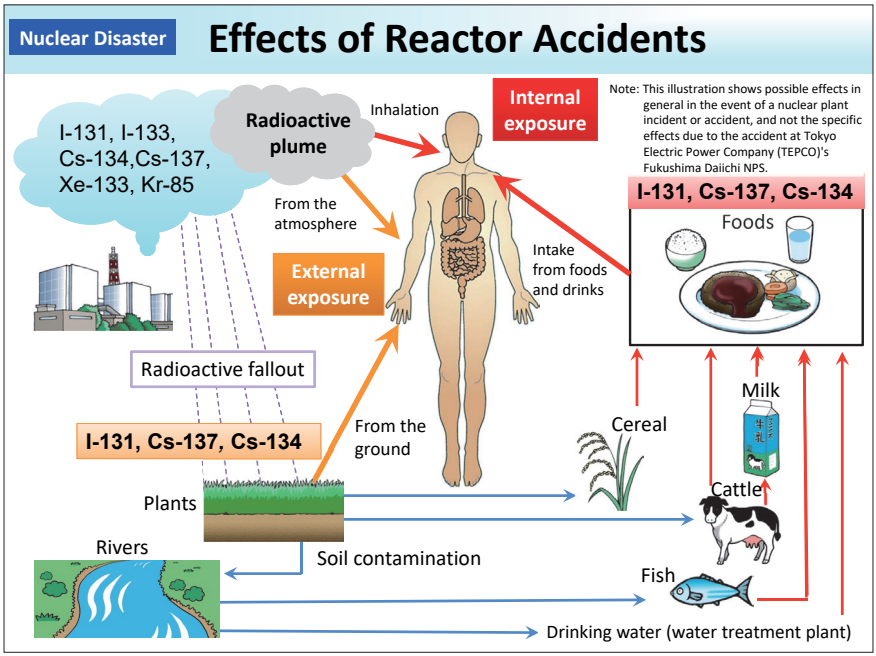
The International Nuclear and Radiological Event Scale (INES) was established by the INES (the International Atomic Energy Agency) and the OECD/NEA (Organization for Economic Co-operation and Development/Nuclear Energy Agency), and in 1992, all countries were recommended to formally adopt it.

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



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.

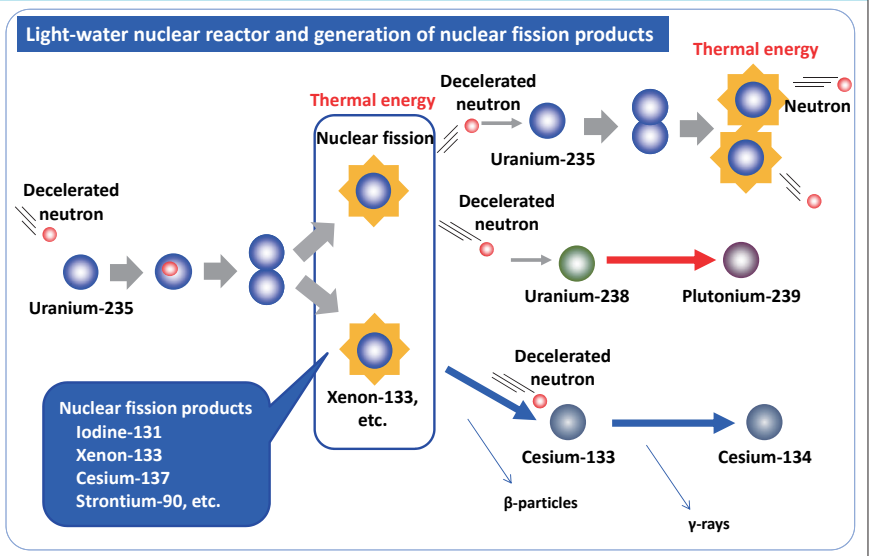
Internal exposure can also occur if one directly inhales radioactive materials while a plume passes or if one consumes drinking water or foods contaminated with deposited radioactive materials.

(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



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.

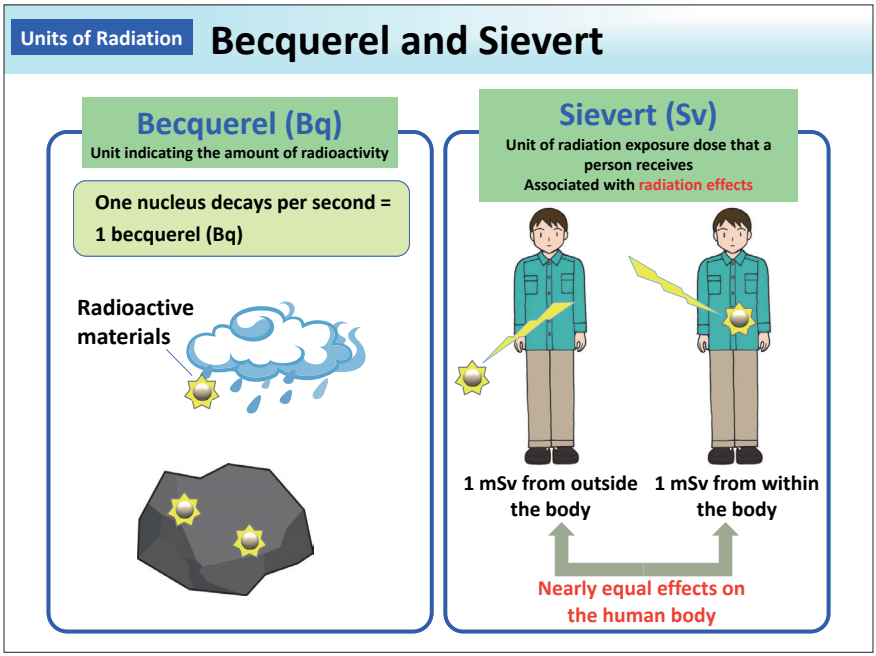
Among them, Cesium-134 and Cesium-137 are the major radionuclides that could pose health threats. The table shows the melting and boiling points of the respective nuclides.

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



"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").

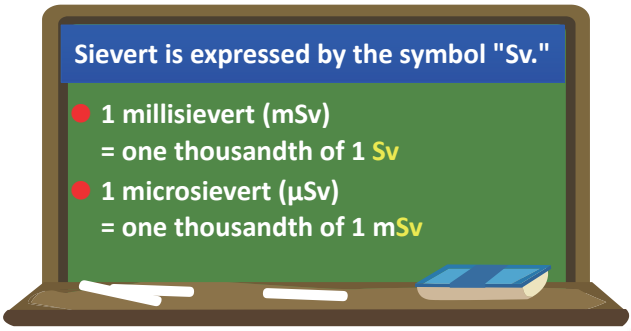
The extent of radiation effects on the human body varies according to the types of exposure, i.e., internal or external exposure, or whole-body or local exposure (p.23-p.27 of Vol. 1, "2.1 Exposure Routes"), and according to the types of radiation (p.13-p.22 of Vol. 1, "1.3 Radiation"). By using sieverts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



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

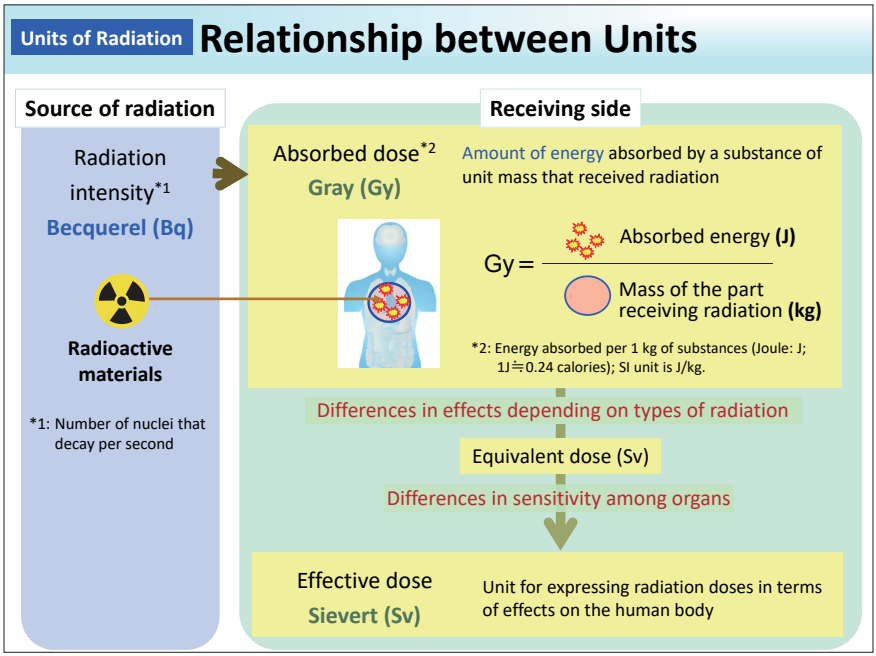
The unit "sievert" is named after Rolf Sievert, a Swedish researcher on radiological protection. He served as the chairman of the International X-ray and Radium Protection Committee (IXRPC), the predecessor of the International Commission on Radiological Protection (ICRP), and participated in founding 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

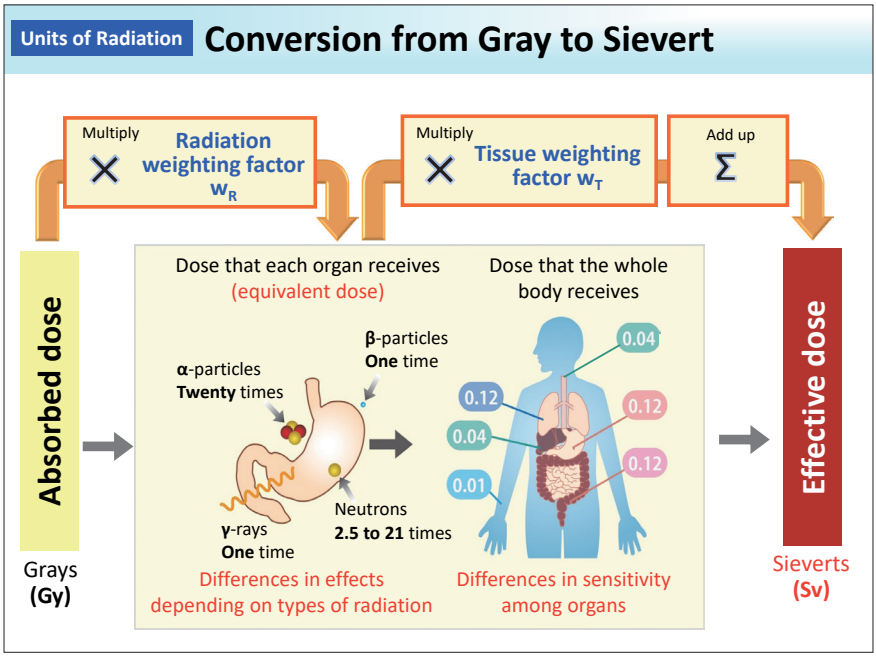


Units of radiation can be broadly divided into units for sources of radiation and units for the receiving side. Becquerel, a unit of radioactivity, is used for sources of radiation. Units for the receiving side are gray and sievert.

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



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

Units of Radiation

Calculation of Equivalent Dose and Effective Dose

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

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

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

= 1 millisievert (mSv)

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

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

= 0.07 millisieverts (mSv)

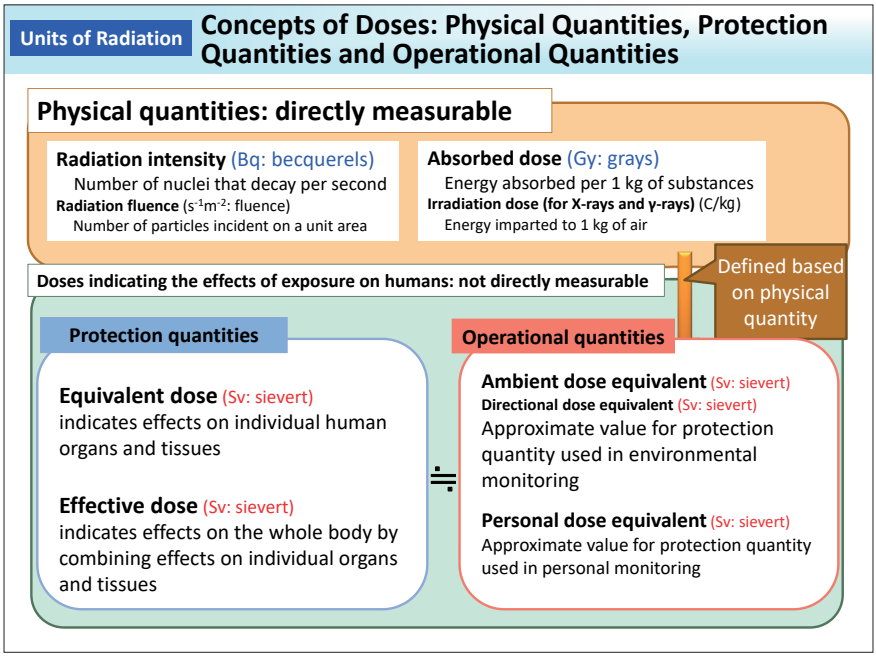
Methods for calculating an effective dose when the whole body is evenly exposed to 1 mGy of γ-ray irradiation and an effective dose when only the head is exposed to 1 mGy of γ-ray irradiation are compared.

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

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

(Related to p.35 of Vol. 1, "Relationship between Units")

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



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

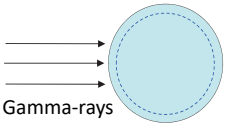
Dose Equivalents:
Measurable Operational Quantities for Deriving Effective Doses

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)

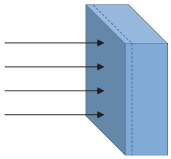
Dose equivalent occurring at a depth of 1cm from the surface of an ICRU sphere, which is 30 cm in diameter and simulates human tissue, placed in a field where radiation is coming from one direction; Ambient dose equivalent is used in measurements of ambient doses using survey meters, etc.



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.

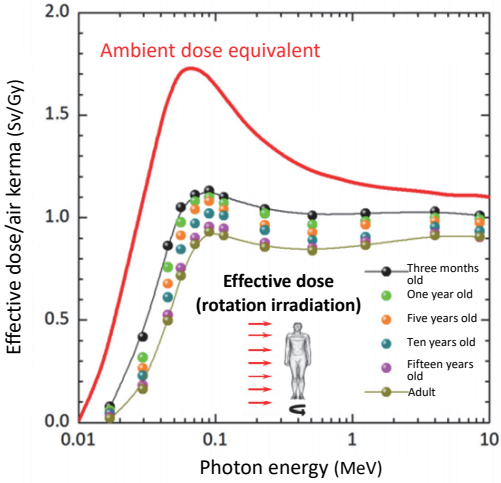
Generally, both the ambient dose equivalent and the personal dose equivalent are also called 1 cm dose equivalents because a depth of 1 cm is used in the case of exposure to γ-rays.

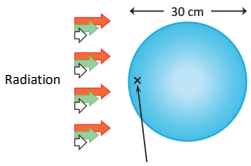
However, while the ambient dose equivalent is measured using measuring instruments that are less affected by directivity, such as a stationary ionization chamber and a survey meter, the personal dose equivalent is measured using a small personal dosimeter worn on the trunk of the body, so incidence from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

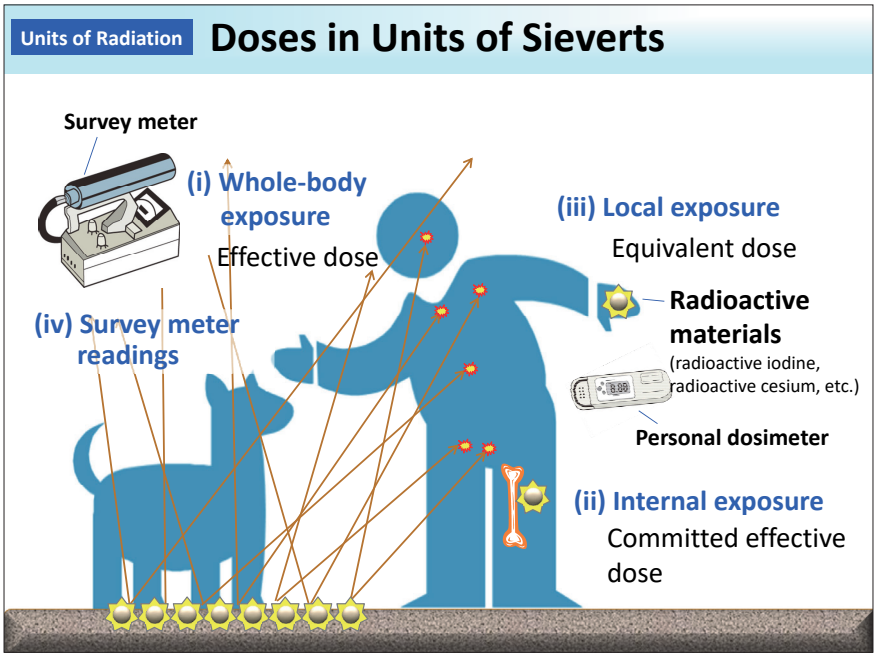
This is also the case for a personal dosimeter when measuring radiation incident only from the front. However, in a setting where a personal dosimeter is worn on the body and radiation sources are evenly distributed, measured value will be close to the value of "effective dose" because of the self-shielding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

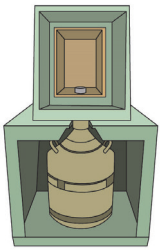


Sievert is used as the unit for (i) radiation dose to the whole body (effective dose) (p.41 of Vol. 1, "Difference between Values of Effective Dose and Dose Equivalent"), (ii) radiation dose due to internal exposure (committed effective dose) (p.53 of Vol. 1, "Committed Effective Doses"), and (iii) dose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

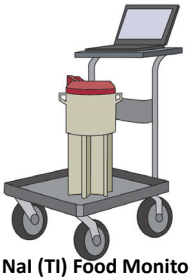
Sievert may also be used for (iv) the readings of survey meters. These values are obtained by multiplying absorbed doses (gray) in the air by a certain factor for conversion to sievert, and are indicated as larger approximations of effective doses received by humans. They may be considered as approximations 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

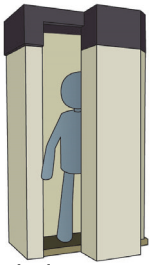
Various Measuring Instruments



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

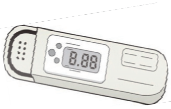


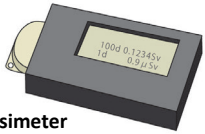
NaI (Tl) Food Monitor
Suitable for efficient radioactivity measurement of foods, etc.



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.

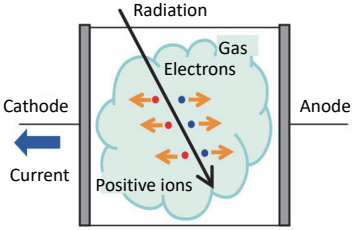
Included in this reference material on March 31, 2013
Updated on March 31, 2017

Dose Measurement and Calculation

Principles of Radiation Measurement

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

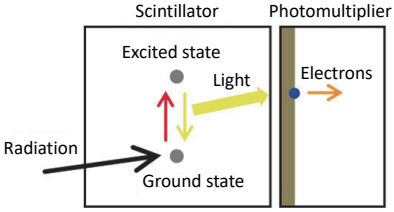
Ionization (with gas atoms)



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

GM counter survey meters, ionization chambers, etc.

Excitation



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

NaI (Tl) scintillation survey meter, etc.

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

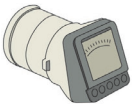
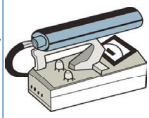
Geiger Muller (GM) counter survey meters and ionization chambers utilize the ionization between radiation and gas atoms. Ionization effect refers to the process in which radiation ejects electrons from nuclei in a substance. Detectors of GM counter survey meters and ionization chambers are filled with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

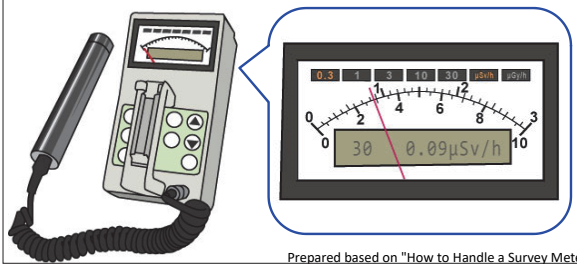
(i) Background measurement

(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.

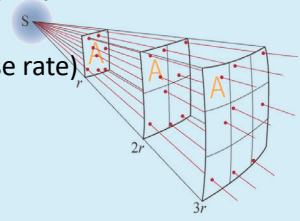
Included in this reference material on March 31, 2017

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.

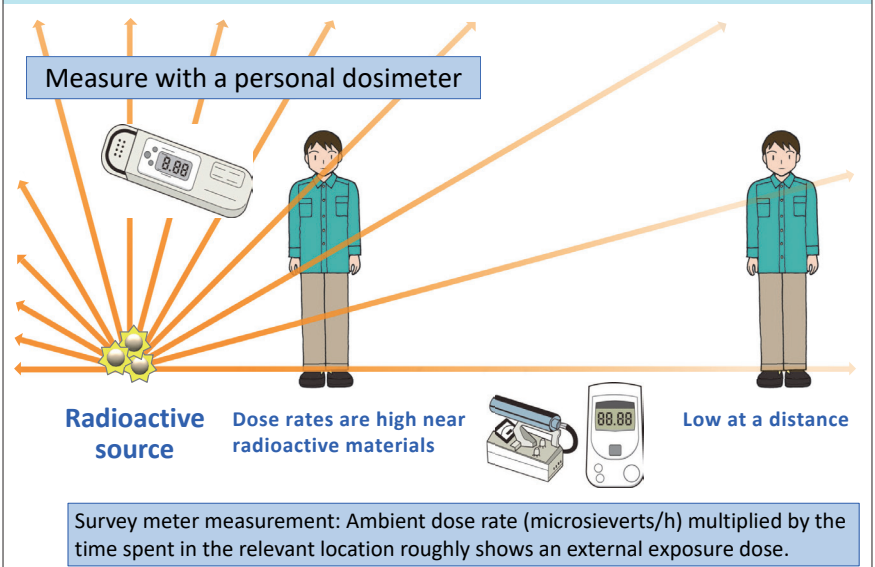
Calculation of external exposure doses is based not on the radioactivity intensity (becquerels) but on the amount of radiation (grays or sieverts) the human body is exposed to.

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)



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

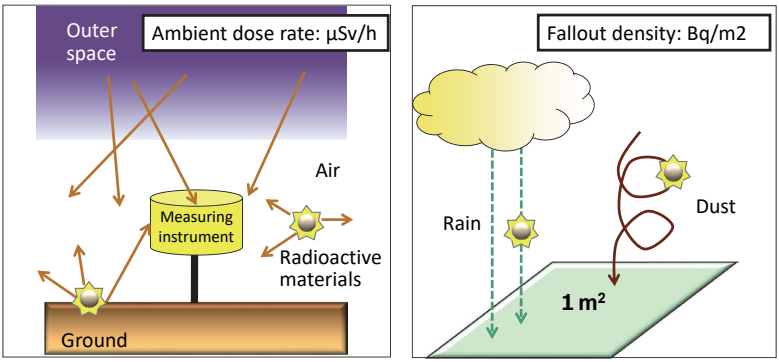
Wearing a personal dosimeter on the body is one of the means to measure doses due to external exposure. Personal dosimeters can measure cumulative amounts of radiation exposure for an extended period of time, and provide hourly readings.

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

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.

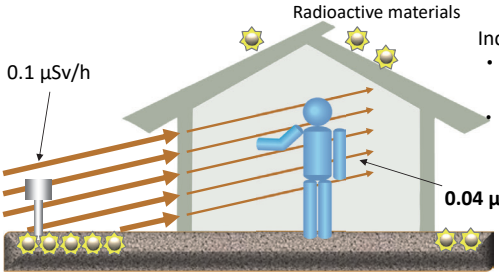
The amount of radioactivity in fallout is expressed as the amount of radioactive materials fallen per unit area.

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

Dose Measurement and Calculation

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

Dose Measurement and Calculation

Additional Exposure Doses after an Accident (Example of Calculation)

It is important to subtract values in normal times.

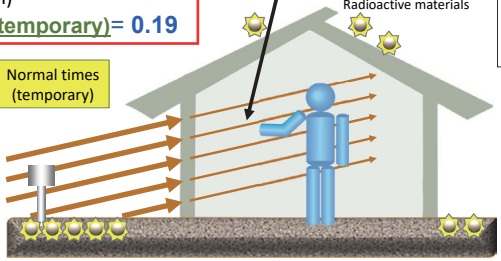
Dose rate (increase due to an accident: μSv/h)
0.23 – 0.04(temporary)= 0.19

Actual measurement (example)

Normal times (temporary)

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).

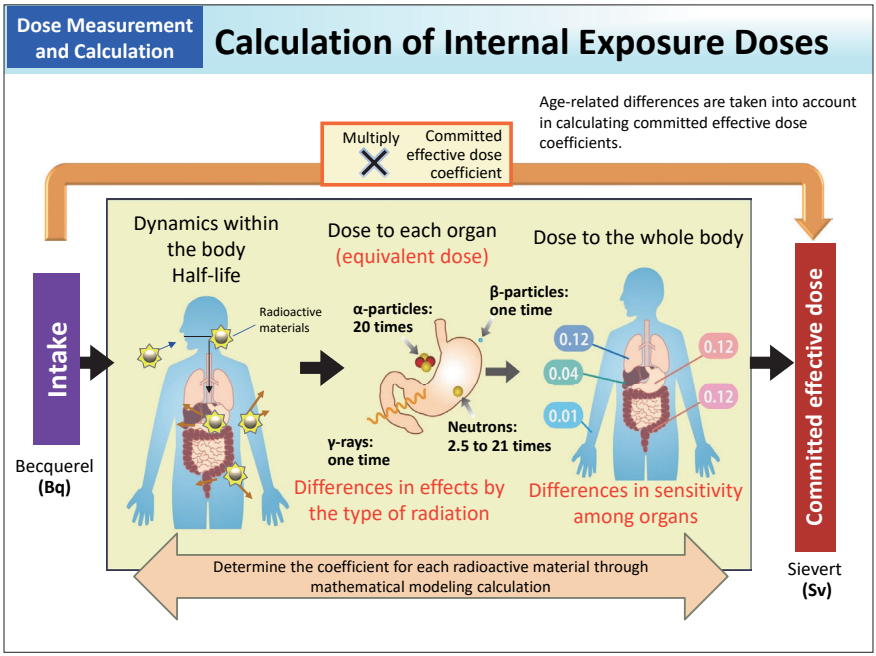
The value obtained by multiplying the increased indoor and outdoor ambient dose rates thus found by the time spent indoors and outdoors is an approximate increase in exposure dose compared with normal times (additional exposure dose).

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



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").

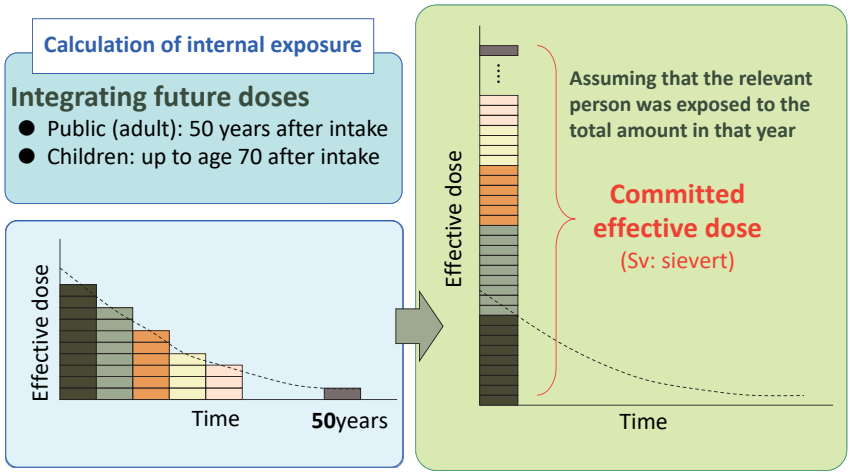
Specifically, internal exposure doses can be obtained by multiplying intake (in becquerels) by a committed effective dose coefficient. Committed effective dose coefficients are defined in detail for each type of radionuclide and age group (p.54 of Vol. 1, "Conversion Factors to Effective Doses").

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

Dose Measurement and Calculation

Committed Effective Doses

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



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

Dose Measurement and Calculation

Conversion Factors to Effective Doses

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

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

μSv/Bq: microsieverts/becquerel

*Tissue free water tritium

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

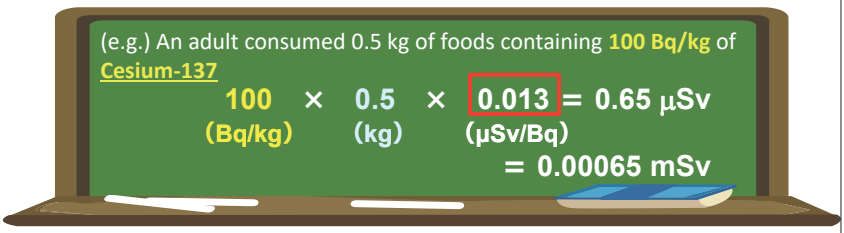
For dose assessment for internal exposure, doses are calculated by estimating an intake for each nuclide and chemical form and multiplying estimated intakes by dose coefficients. Dose coefficients are committed equivalent doses or committed effective doses for an intake of 1 Bq and a specific value has 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

Dose Measurement and Calculation

Exposure Doses from Foods (Example of Calculation)



Committed effective dose coefficients (μSv/Bq)

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

Bq: becquerels; μSv: microsieverts; mSv: millisieverts

Source: 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.

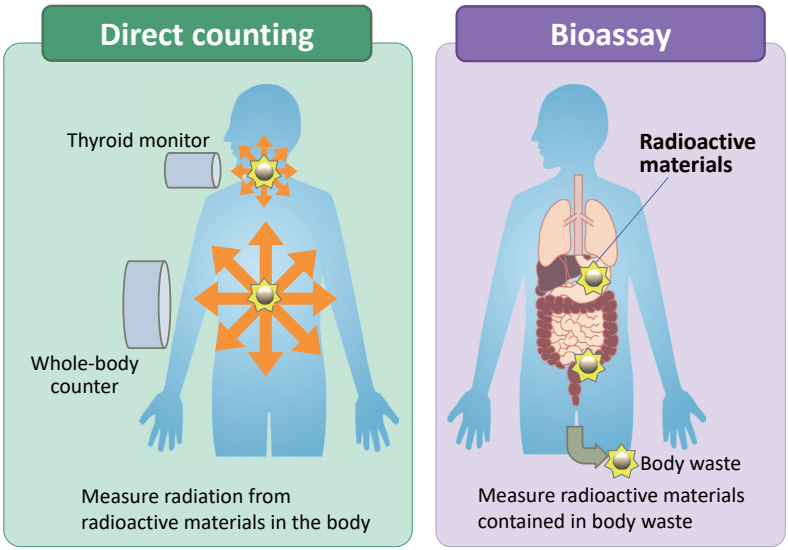
The amount of Cesium-137 actually consumed is 50 Bq. This value is multiplied by an effective dose coefficient to calculate committed effective dose (p.53 of Vol.1, "Committed Effective Doses").

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

Dose Measurement and Calculation

Methods of Measuring Radioactivity for Estimation of Intake



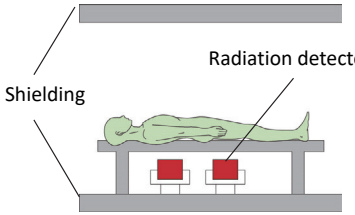
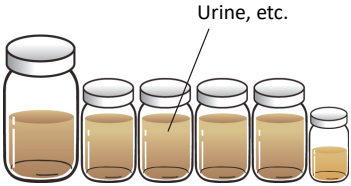
Direct counting methods that directly measure γ-rays coming from within the body or bioassay methods that measure the amount of radioactive materials in urine or feces are used to estimate the intake, which is required for calculating internal exposure doses.

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

Dose Measurement and Calculation

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

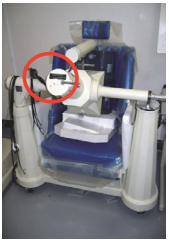
Dose Measurement and Calculation

Instruments for Measuring Internal Exposure

Stand-up whole-body counter

Scanning bed whole-body counter

Chair whole-body counter



Thyroid monitor

○ Detector

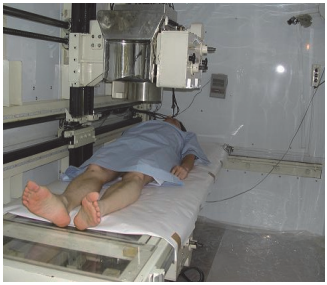
An instrument for measuring γ-rays emitted from the whole body, called a whole-body counter, is used to directly measure internal radioactivity. Whole-body counters have several types, including a stand-up type, bed type, and chair type.

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

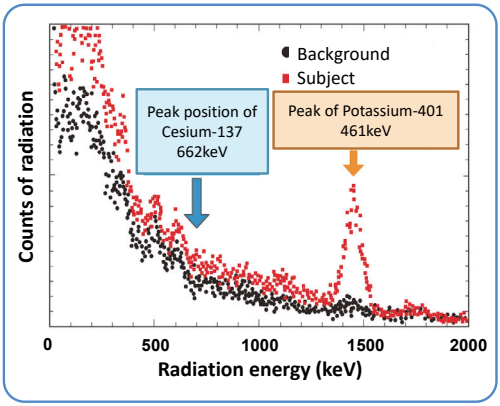
The time required for measurement is 1 to 5 minutes for simplified whole-body counters, 10 to 30 minutes for precision whole-body counters, and 2 to 5 minutes for thyroid monitors.

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.

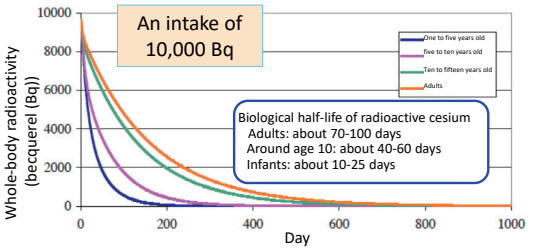
The black round dots in the graph represent values measured while no one is on the bed (background state). When the subject is on the bed, radiation peaks appear, as indicated by the red square dots. The energy of γ-rays is unique for each radioisotope. For example, radioactive potassium, K-40, emits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

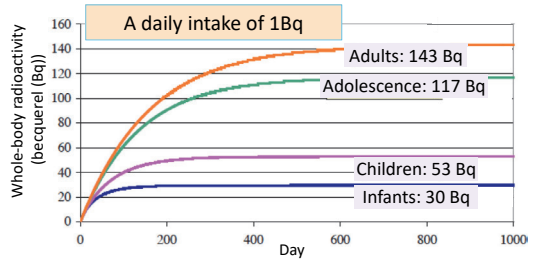


The younger a person is, the faster the metabolism.

↓

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").

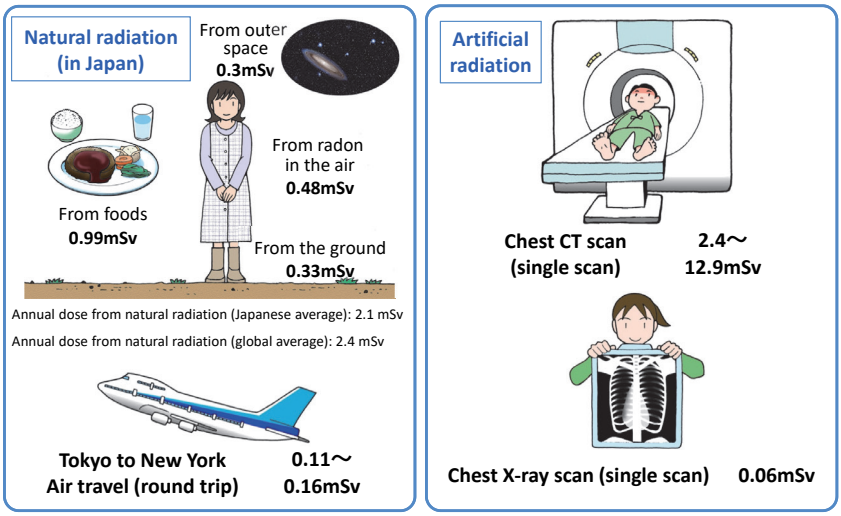
In contrast, children have high metabolism, so estimation of their initial exposure from an intake of a trace amount of radioactive materials would be only effective for around half a year after an accident, and estimation of their chronic internal exposure would often provide values below detection 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.

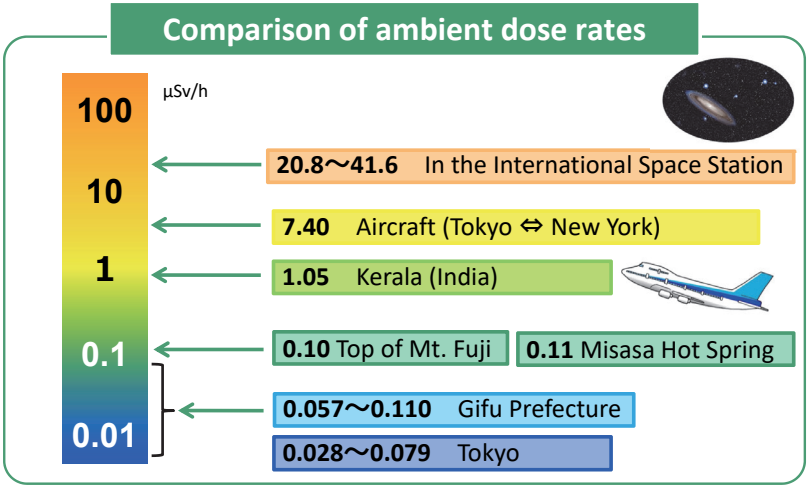
External exposure to natural radiation from outer space and the ground, and internal exposure to naturally occurring radioactive materials, such as those in foods and radon in the air, amount to a global average of 2.4 mSv and a Japanese average of 2.1 mSv annually (p.63 of Vol. 1, "Comparison of Exposure 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



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)

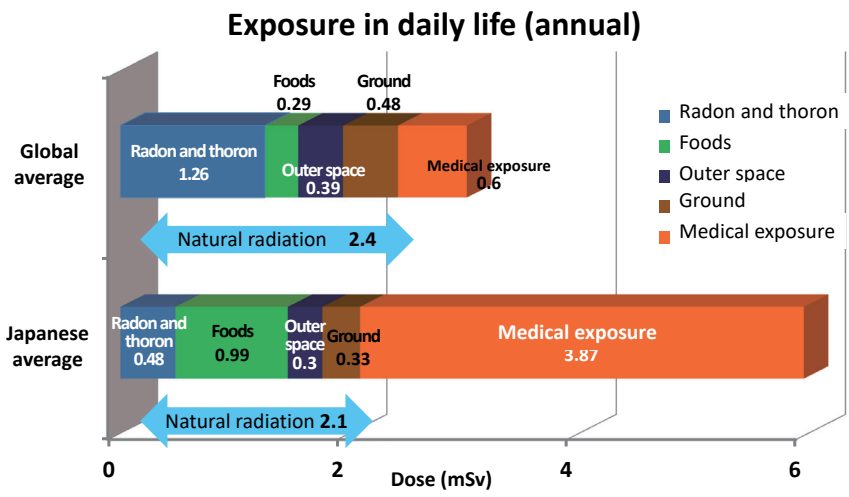
In outer space and aircraft, ambient dose rates are higher because of cosmic rays from galaxies and the Sun. Ambient dose rates are also high at high altitudes such as the top of Mt. Fuji, compared to low altitudes, because the influence of cosmic rays is stronger. At low altitudes, cosmic rays (radiation) 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

Radiation around Us

Breakdown of Natural Exposure Doses (Japanese)

Type of exposure	Breakdown of radiation sources	Effective dose (mSv/year)
External exposure	Cosmic rays	**0.3**
	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.

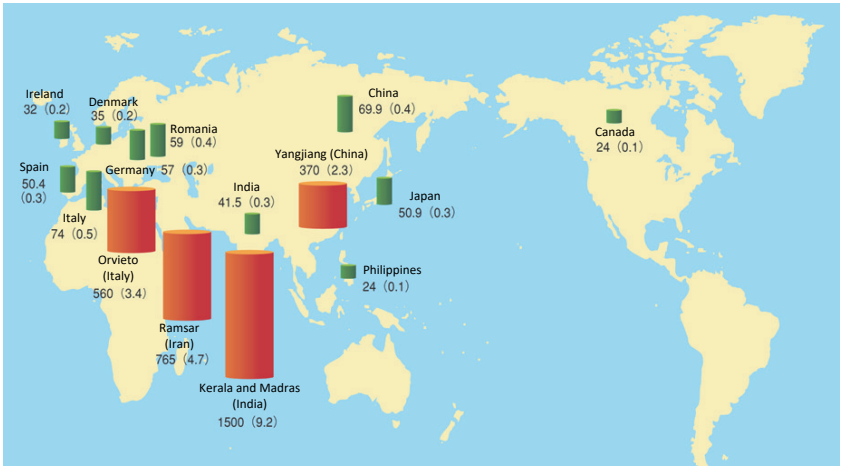
Tritium has smaller effects on the human body compared with other nuclides and exposure doses due to natural tritium are relatively small.

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

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.

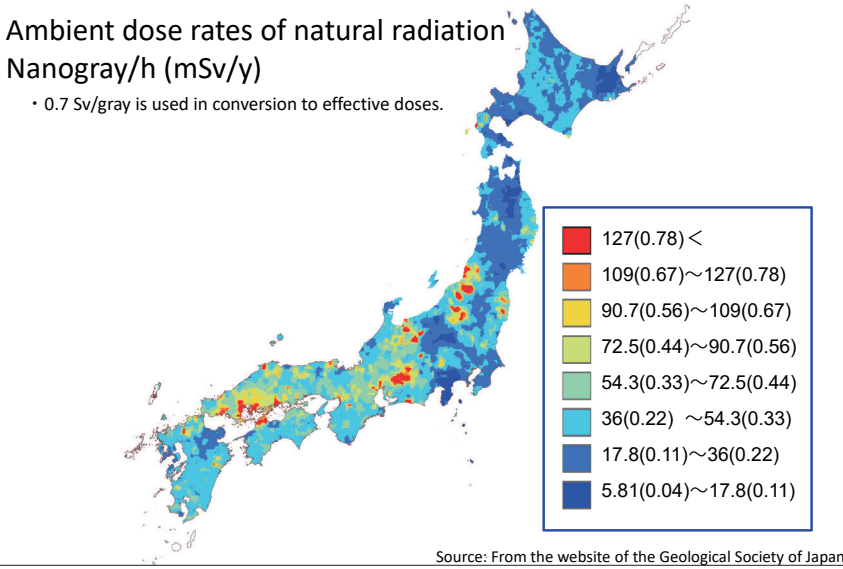
It has been reported that in Guarapari in Brazil, which was previously well-known as a high natural radiation area, ambient dose rates have reduced as a result of asphalt paving for urbanization.

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)



Source: From the website of the Geological Society of Japan

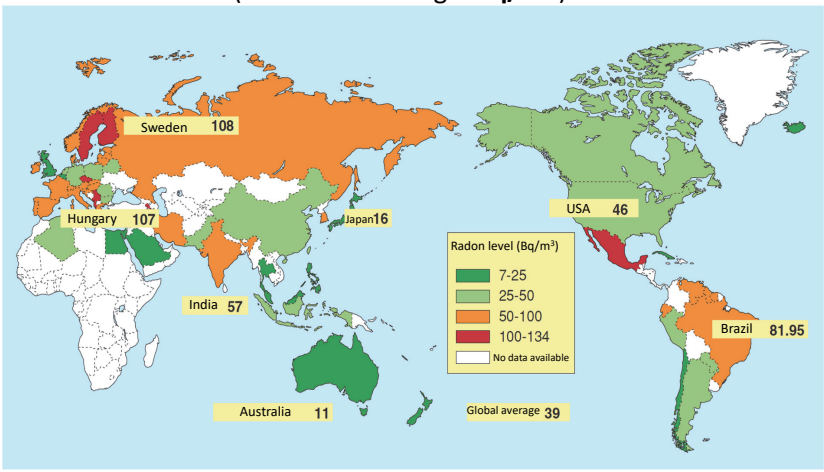
In Japan, like everywhere else, the amount of ground radiation varies from area to area. Comparison of ambient dose rates among different prefectures shows that there is a difference of 0.4 mSv per year between Gifu, where the ambient dose rates are highest, and Kanagawa, where the values are lowest.

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

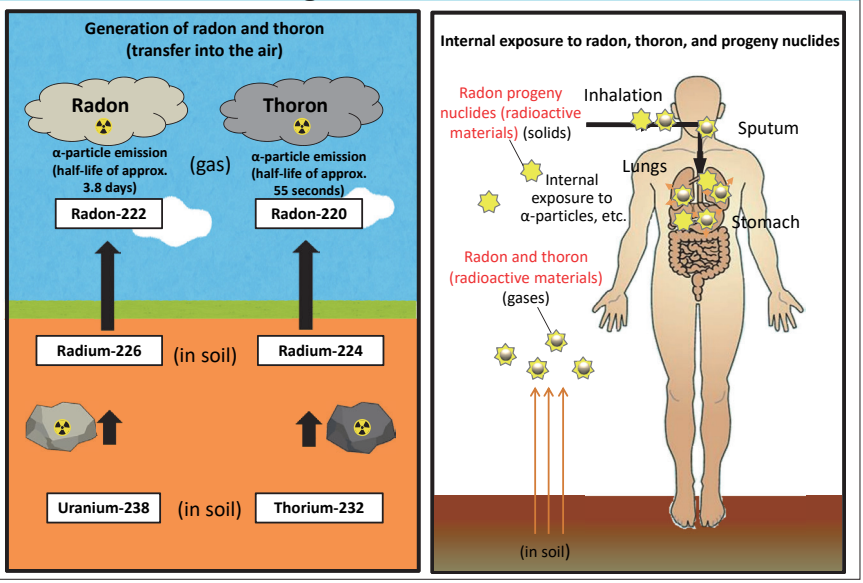
Radon is a radioactive noble gas produced by the alpha-decay of radium, which is universally present under the ground. Since radon is a gas, it is emitted from the ground and seeps into houses (p.68 of Vol. 1, "Internal Exposure to Radon and Thoron through Inhalation").

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.

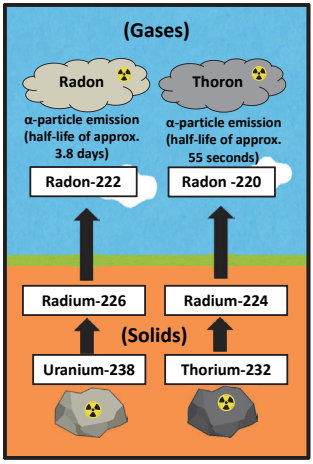
Because radon and thoron diffuse into the air from the ground, building materials, etc., people inhale radon and thoron in their lives on a daily basis. Inhaled radon reaches the lungs and emits α-particles, causing internal exposure of the lungs. Radon inhaled into the body further decays into progeny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

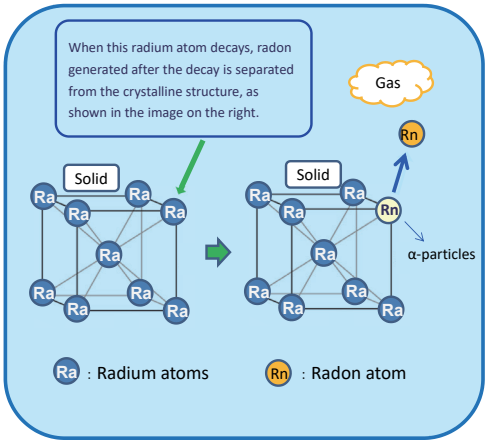
Radon contributes less to internal exposure than its progeny nuclides. This is because radon, being a gas, is easily exhaled, while radon progeny nuclides, i.e., radioactive Polonium-218 and Lead-214 that is created through decay of the former, are solids and therefore not easily expelled out of the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

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.





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

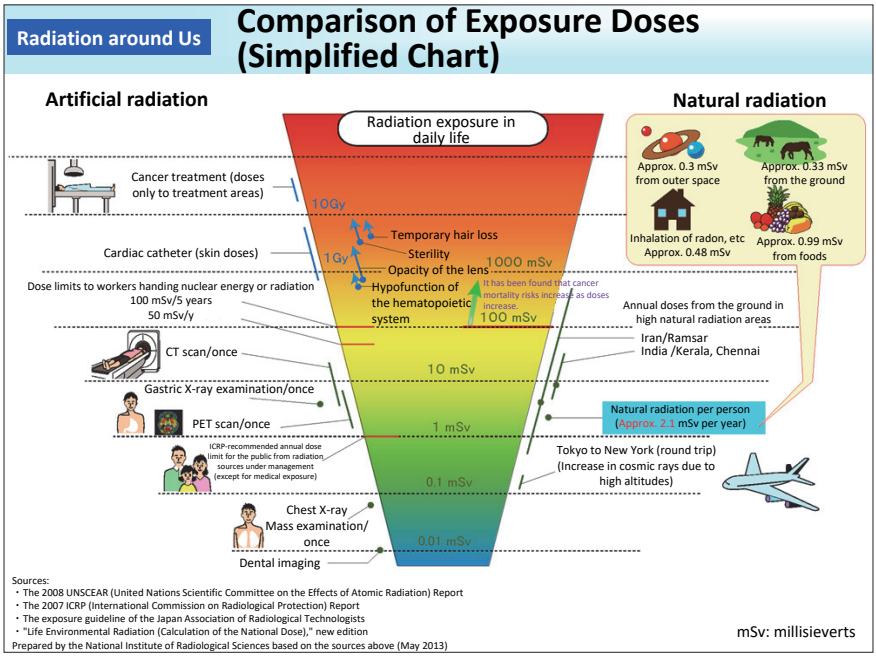
*1 : "Diagnostic Reference Levels based on the Latest Survey within Japan," J-RIME, etc., June 7, 2015 (partially updated on August 11, 2015) (http://www.radher.jp/J-RIME/)
*2 : "Q&A on Medical Exposure Risks and Protection Regarding Medical Exposure from CT Scans, etc.," National Institutes for Quantum 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



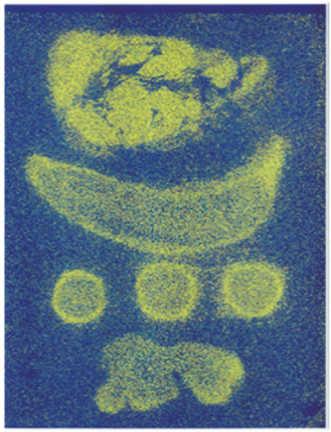
Comparison of radiation doses in daily life shows that doses from one single event and annual doses are mostly on the order of millisieverts, except for special cases such as radiation therapy (p.71 of Vol. 1, "Radiation Doses from Medical Diagnosis").

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

Radiation around Us

Visualized Radiation



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

Radiation from foods

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

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

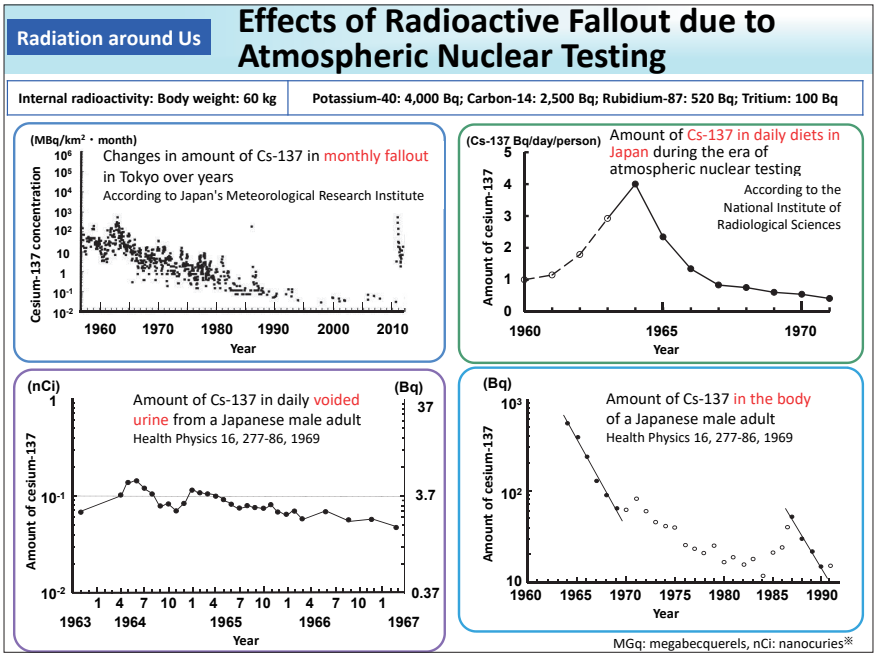
Source: Applied Physics Vol.67, No.6, 1998

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



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.

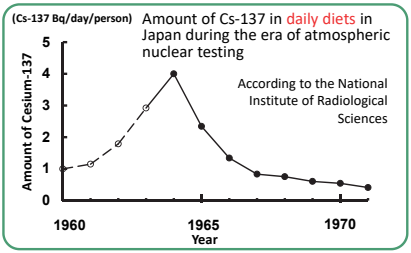
Like the amount of cesium in daily diets, the amounts of Cesium-137 in urine and the body were also highest in 1964. An increase in the amount of cesium in the body was also found among Japanese people as a result of the influence of the Chernobyl nuclear disaster.

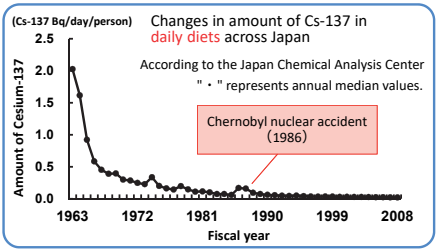
*Curie (Ci): Unit of radioactivity; 1 nanocurie (1 nCi) is 10-9 of one curie (1 Ci), i.e., a billionth of one curie.

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

Radiation around Us

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





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