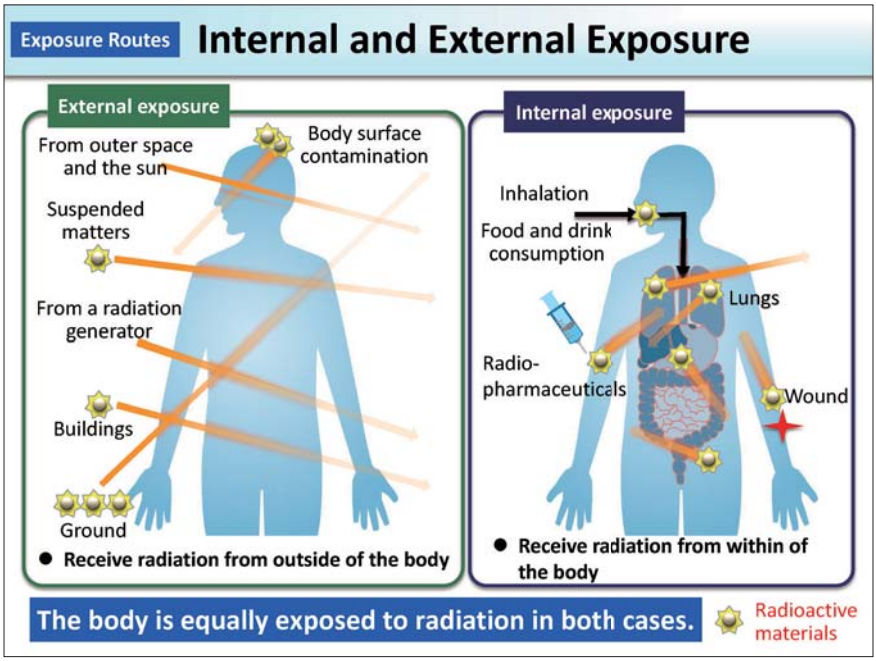

"Radiation exposure" refers to the situation where the body is exposed to radiation. There are two types of radiation exposure, "internal exposure" and "external exposure."

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

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

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

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

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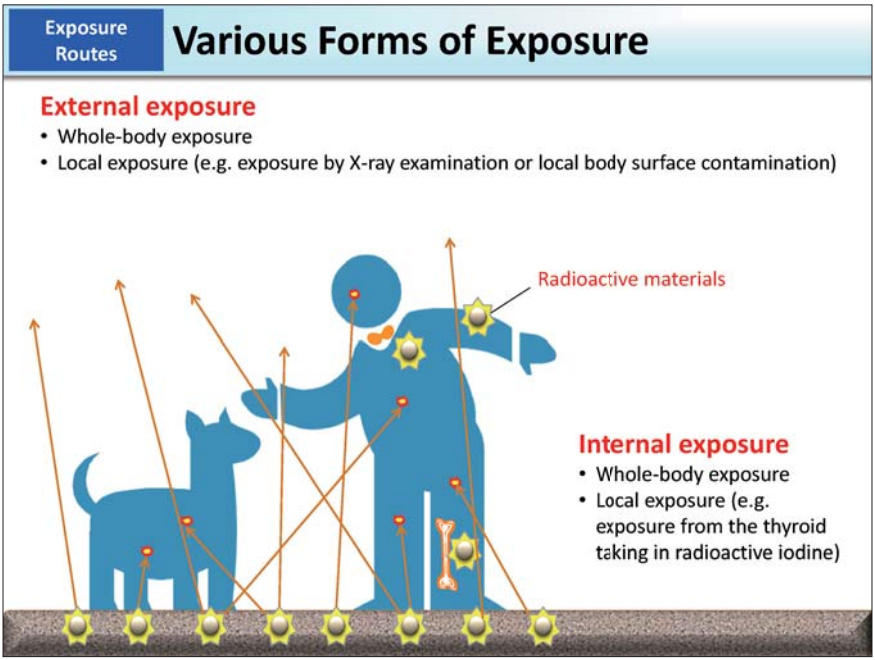

To what extent the body will be affected by radiation exposure depends on the location and the extent of the exposure.

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 NPS Accident, there was an increase in the number of thyroid cancer cases among children. It was due both to the tendency of radioactive iodine to accumulate in the thyroid and children's thyroids having a higher sensitivity to radiation than adults'.

(Related to p.4 of Vol. 1, "Types of Exposure")

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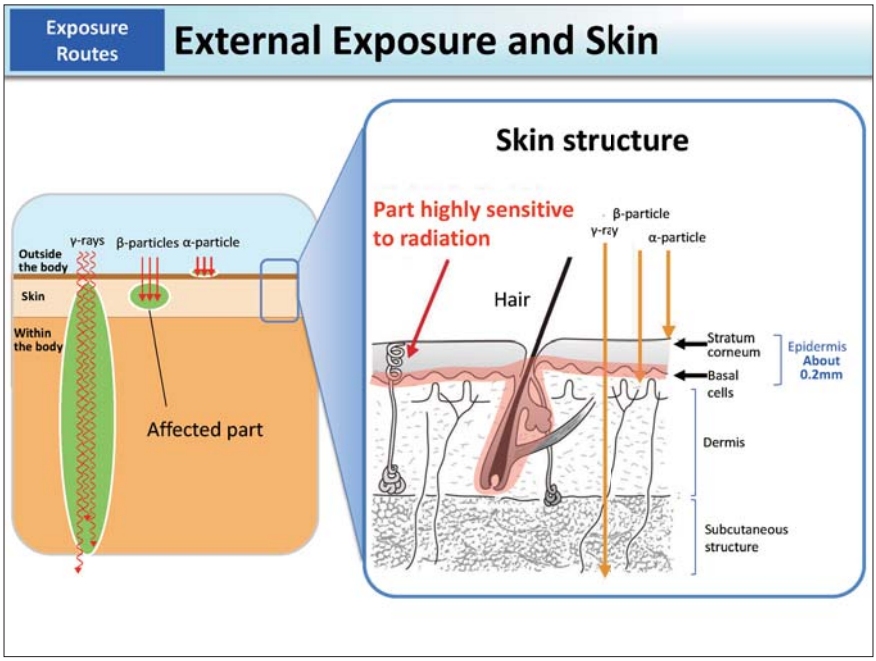
Exposure Routes

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.
(Related to p.21 of Vol. 1, "Penetrating Power of Radiation within the Body," and p.22 of Vol. 1, "Penetrating Power and Range of Effects on the Human Body")

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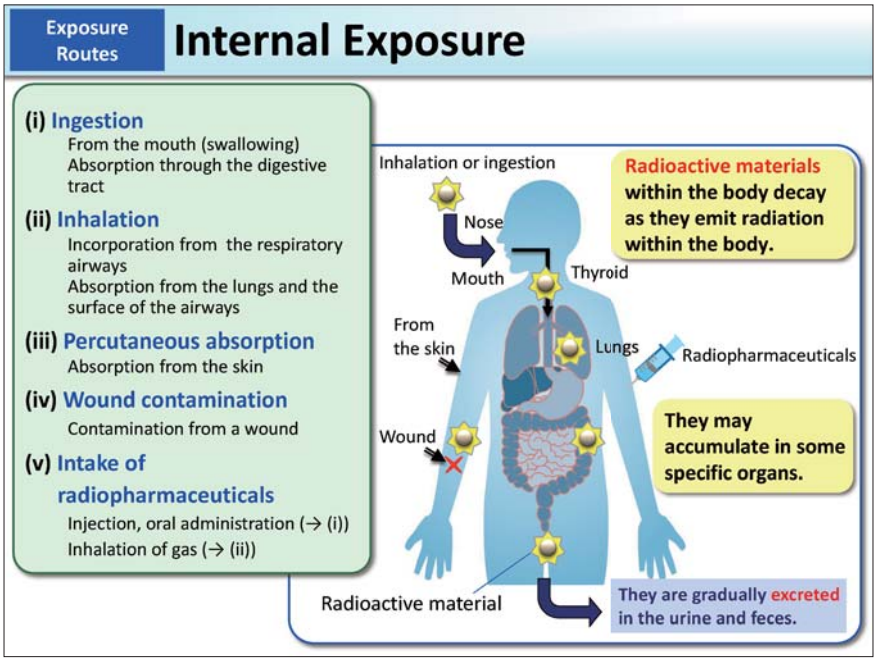

Internal exposure occurs due to radioactive materials being taken in the following routes: ingestion together with food (ingestion); incorporation while breathing (inhalation); absorption from the skin (percutaneous absorption); penetration from a wound (wound contamination), and administration of radiopharmaceuticals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

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

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

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

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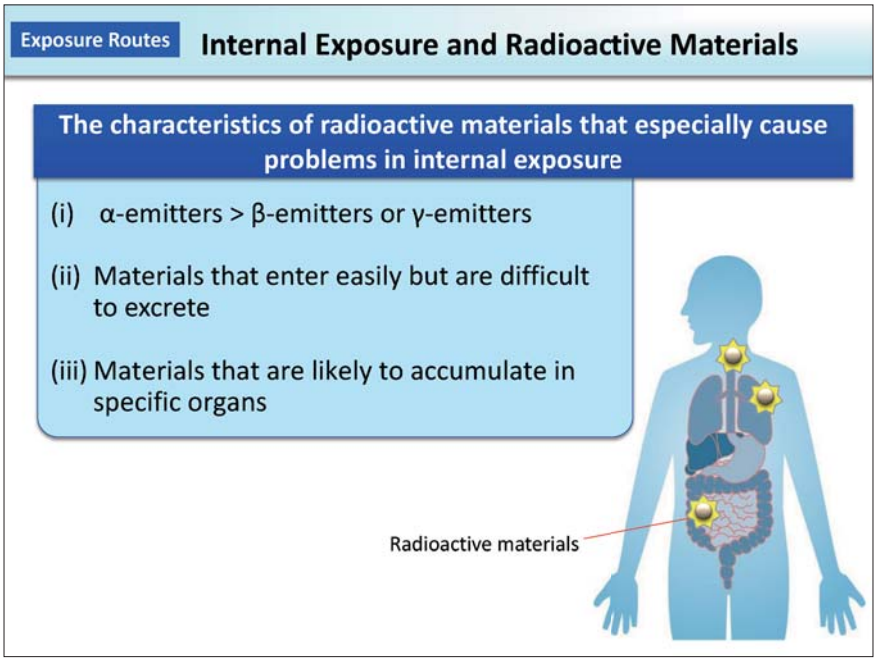

Radioactive materials within the body disintegrate into other elements and are gradually excreted in the urine and feces through metabolism. The time required for radioactive materials to reduce to half by disintegration is called physical half-life (Tp), and the time required for radioactive materials 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-specific biokinetic behavior, radioactive materials that are easily incorporated into the body but are difficult to be excreted, and also those that tend to be accumulated in particular organs/tissues cause problems as they result in increasing internal exposure doses.

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

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

Included in this reference material on March 31, 2013
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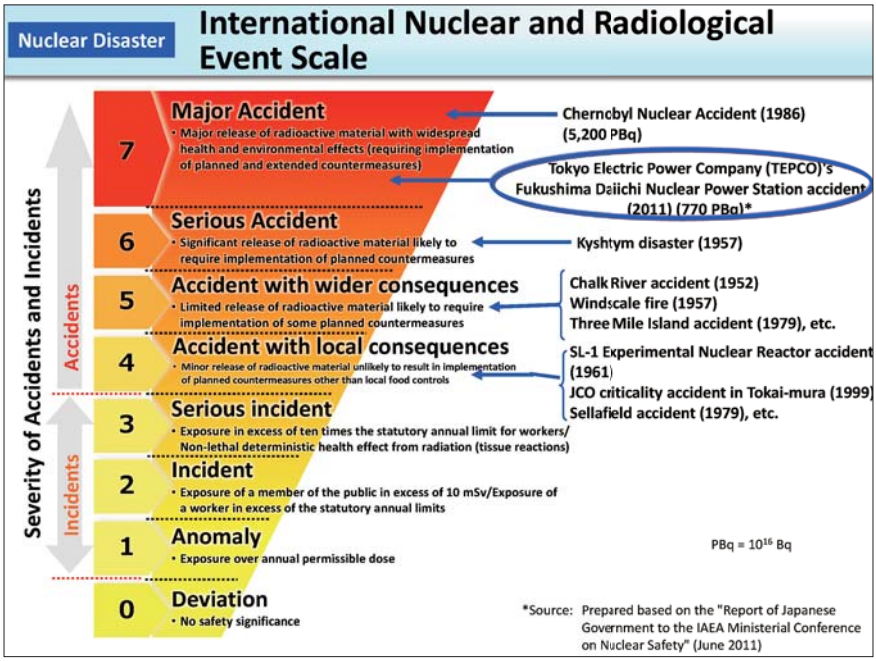

The International Nuclear and Radiological Event Scale (INES) was established by the INES (the International Atomic Energy Agency) and the OECD/NEA (Organization for Economic Co-operation and Development/Nuclear Energy Agency), and in 1992, all countries were recommended to formally adopt it.

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

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

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

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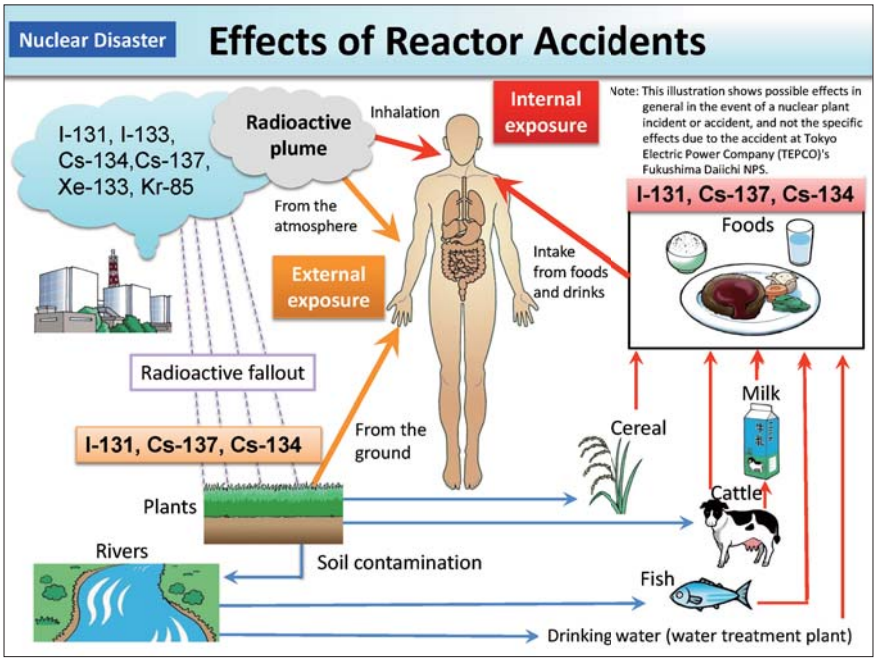

If an emergency happens in a nuclear facility and radioactive gas leaks, it flows into the atmosphere in a state called “plume.” Plumes contain radioactive noble gases and aerosols (micro liquid droplets and particles), such as radioactive iodine and radioactive cesium.

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

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

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

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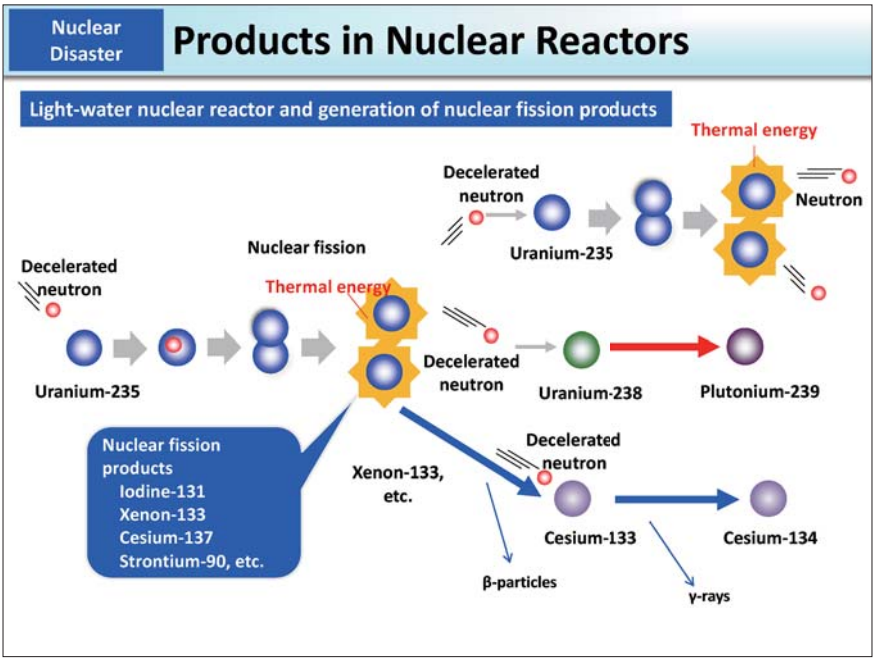
Nuclear Disaster

Products in Nuclear Reactors



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

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

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

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

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Nuclear Disaster

Radioactive Materials Derived from Nuclear Accidents

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

Effective half-life: Related to p.27 of Vol. 1, "Internal Exposure and Radioactive Materials"
Effective half-lives are calculated based on values for organs and tissues where radioactive materials accumulate as indicated in the table of biological half-lives.
*1: Tritium water; *2: ICRP Publication 78; *3: JAEA Technical Manual (November 2011); *4: Assumed to be the same as Cesium-137; *5: ICRP Publication 48

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

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

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

Strontium-90 has a long physical half-life, and once it enters the body, it accumulates in bones because of its chemical properties similar to calcium. Since it does not emit γ-rays, it is not as easy as in the case of Cesium-134 and Cesium-137 to detect where and how much it exists in the body. In a nuclear plant accident, Strontium-90 is also produced as a result of nuclear fission, though smaller in quantity than Cesium-134 and Cesium-137. Plutonium-239 and the like derived from the accident at TEPCO's Fukushima Daiichi NPS have also been detected, but detected amounts are almost equal to the results of the measurement conducted all over Japan before the accident (p.49 of Vol. 2, "Plutonium (Fukushima Prefecture)").
(Related to p.11 of Vol. 1, "Half-lives and Radioactive Decay," and p.30 of Vol. 1, "Products in Nuclear Reactors")

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

Nuclear Disaster **Comparison of Estimated Amounts of Released Radionuclides between the Chernobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accidents**

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

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

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

*PBq equals 10^{15}Bq.

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

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

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

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

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

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

Included in this reference material on March 31, 2017
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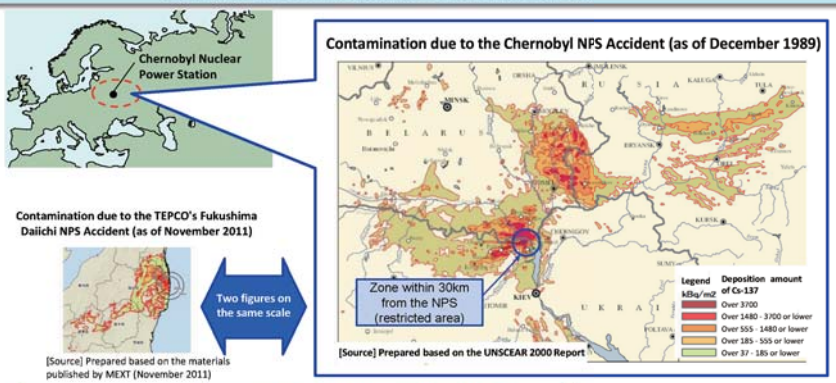
Nuclear Disaster Comparison between the Chernobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident



Contamination concentration (kBq/m²)	Area of the contaminated region (km²)		Size of the TEPCO's Fukushima Daiichi NPS Accident compared with that of the Chernobyl NPS Accident
	Chernobyl NPS Accident	TEPCO's Fukushima Daiichi NPS Accident	
> 1,480	3,100	200	6 %
555 – 1,480	7,200	400	6 %
185 – 555	18,900	1,400	7 %
37 –185	116,900	6,900	6 %
Total area	146,100	8,900	6 %

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

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

The region affected by the Fukushima Daiichi NPS Accident is about 6% of that affected by the Chernobyl NPS Accident in terms of the total area contaminated with Cs-137.

(Related to p.32 of Vol. 1, "Comparison of Estimated Amounts of Released Radionuclides between the Chernobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accidents")

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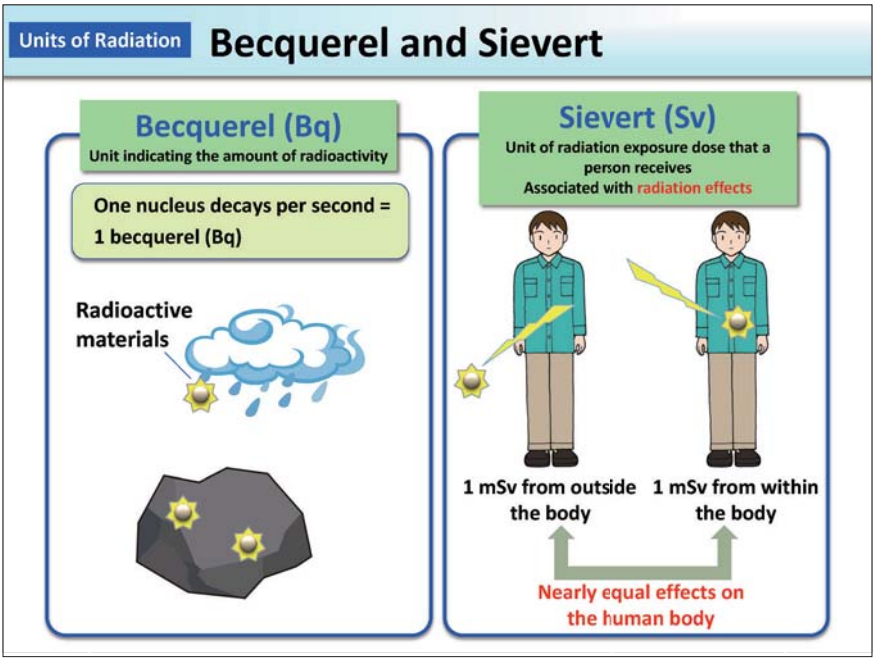

"Becquerel" and "sievert" are the most common units of radiation. Becquerel is a unit of radioactivity and focuses on where radiation comes from. It is used to express the amount of radioactive materials contained in soil, foods, tap water, etc. The higher the value expressed in becquerels, the larger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

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

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

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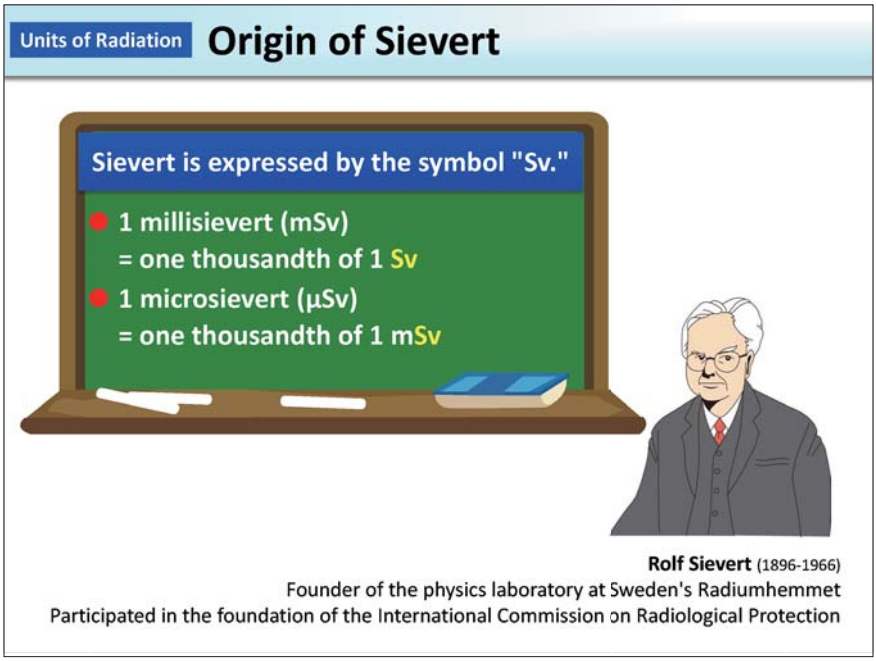

The unit “sievert” is named after Rolf Sievert, a Swedish researcher on radiological protection. He served as the chairman of the International X-ray and Radium Protection Committee (IXRPC), the predecessor of the International Commission on Radiological Protection (ICRP), and participated in founding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

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

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

Included in this reference material on March 31, 2013
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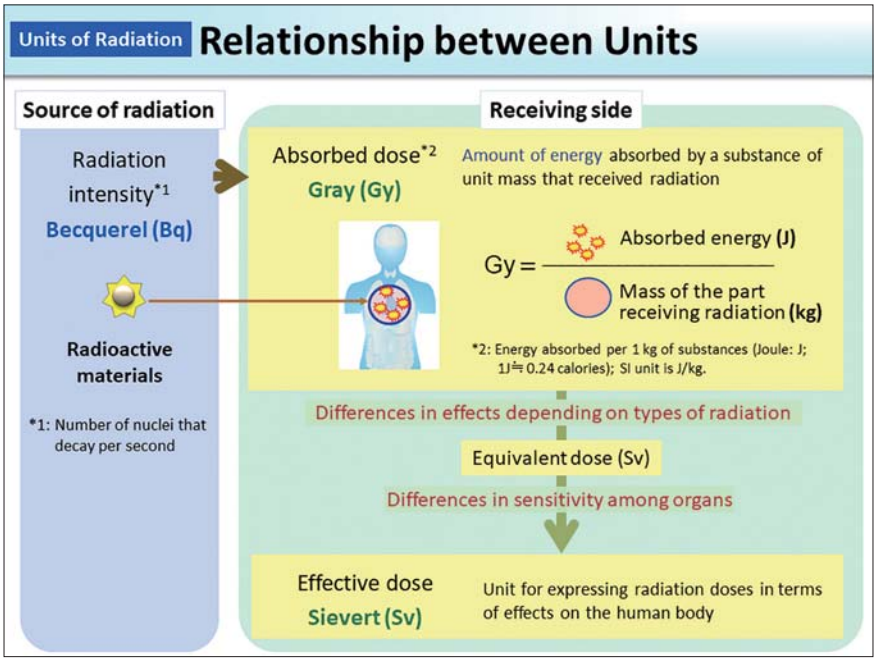

Units of radiation can be broadly divided into units for sources of radiation and units for the receiving side. Becquerel, a unit of radioactivity, is used for sources of radiation. Units for the receiving side are gray and sievert.

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

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

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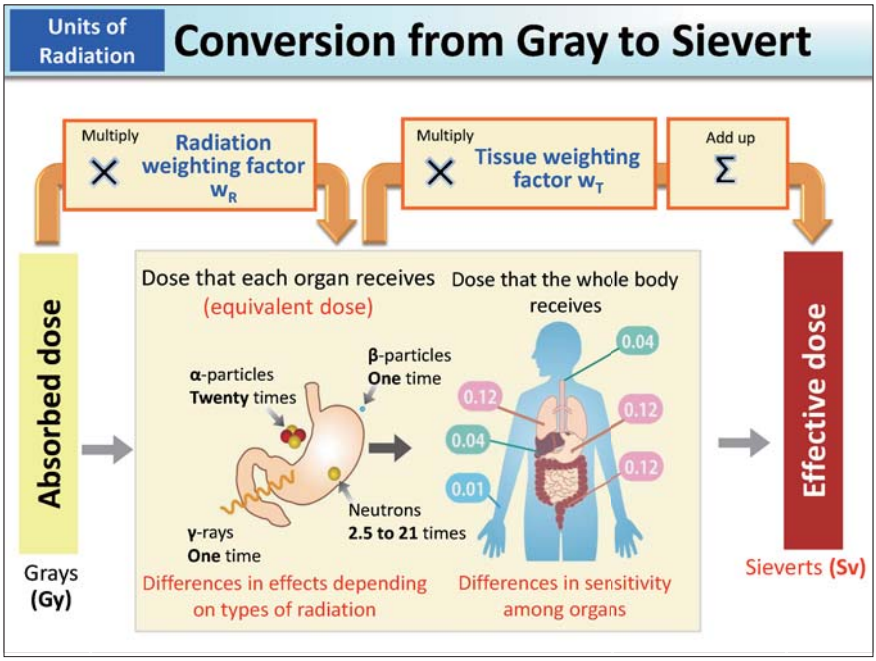

To calculate the effective dose that expresses the effects of radiation exposure on the whole body, it is necessary to first determine the absorbed doses of individual tissues and organs exposed. The equivalent dose (expressed in sieverts) is obtained by multiplying the absorbed doses of individual tissues 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.38 of Vol. 1, “Various Factors”)

Included in this reference material on March 31, 2013
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Units of Radiation Various Factors

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

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

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

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

Sv: sieverts; Gy: grays

Source: 2007 Recommendations of the ICRP

Recommendations issued by the International Commission on Radiological Protection (ICRP) in 2007 presented new radiation weighting factors and tissue weighting factors. It is stated that α-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.37 of Vol. 1, “Conversion from Gray to Sievert”).

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

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

Included in this reference material on March 31, 2013
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Units of Radiation

Calculation of Equivalent Dose and Effective Dose

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

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

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

= 1 millisievert (mSv)

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

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

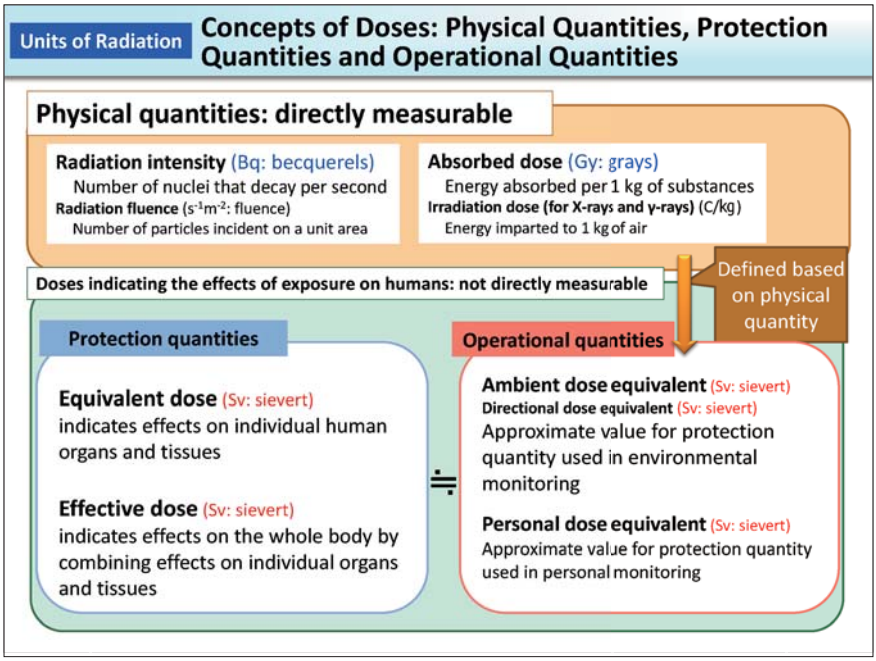
= 0.07 millisieverts (mSv)

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

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

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

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.41 of Vol. 1, “Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses”).

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

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

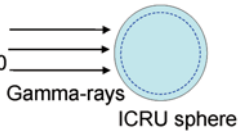
Units of Radiation — Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses

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

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

Ambient dose equivalent (1cm dose equivalent)

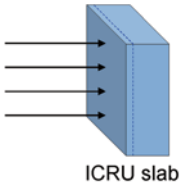
Dose equivalent is a dose that would be produced at a depth of 1 cm from the surface of an ICRU sphere, which is 30 cm in diameter and simulates human tissue, placed in a field where radiation is coming from one direction; Ambient dose equivalent is used in measurements of ambient doses using survey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



Personal dose equivalent (1 cm dose equivalent)

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

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



Operational quantities for approximating effective doses that cannot be actually measured (p.40 of Vol. 1, “Concepts of Doses: Physical Quantities, Protection Quantities and Operational Quantities”) are defined, such as the ambient dose equivalent H*(d) (d is depth) for evaluating ambient doses in a work environment, etc., the personal dose equivalent $H_p(d)$ for evaluating personal exposure, and the directional dose equivalent H’ (d,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.

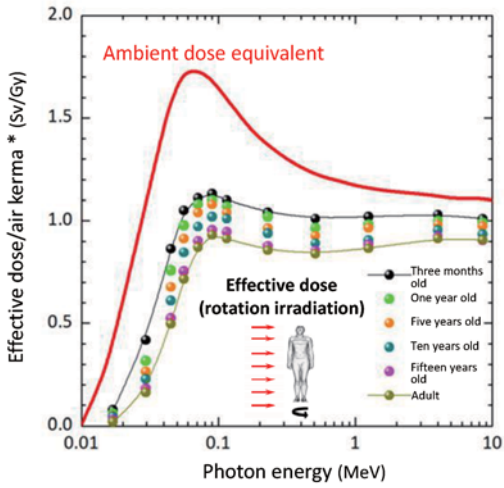
Generally, both the ambient dose equivalent and the personal dose equivalent are also called 1 cm dose equivalents because a depth of 1 cm is used in the case of exposure to γ-rays.

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. In other words, the calculated value will generally be larger than the effective dose.

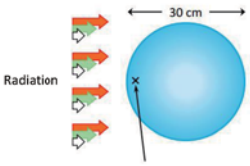
Included in this reference material on March 31, 2017
Updated on March 31, 2021

Units of Radiation

Difference between Values of Effective Dose and Dose Equivalent



* Air kerma is a unit of physical quantity.



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

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

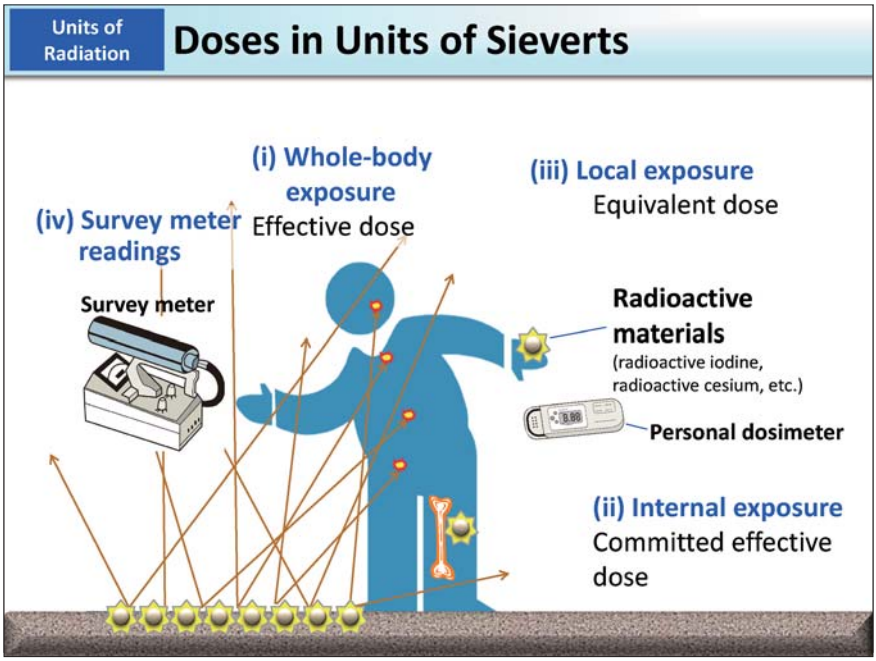
The ambient dose equivalent measured with a survey meter is set to always indicate a larger value than the effective dose.

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

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

(Related to p.41 of Vol. 1, "Dose Equivalents: Measurable Operational Quantities for Deriving Effective Doses")

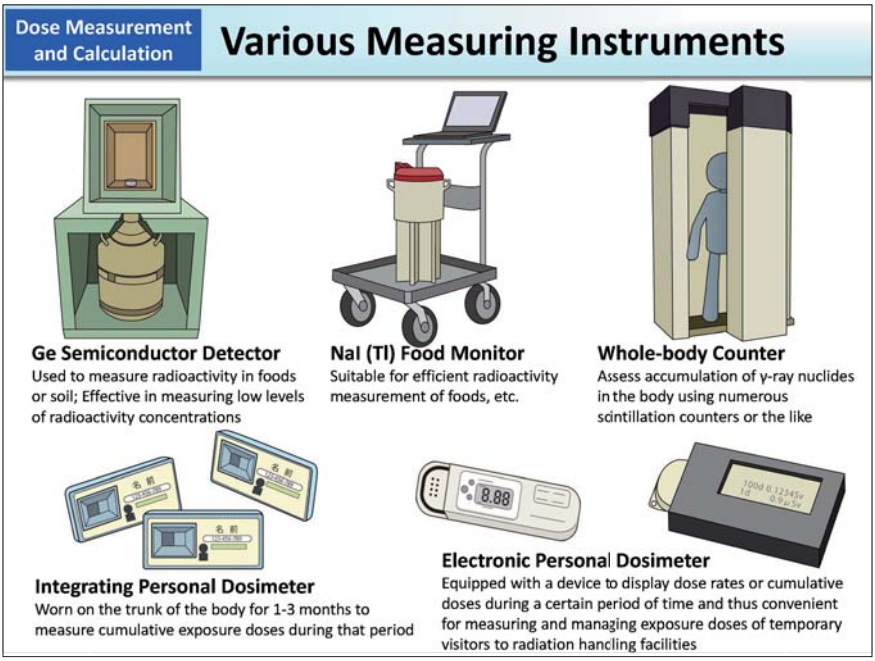
Included in this reference material on March 31, 2017
Updated on March 31, 2019



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

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

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



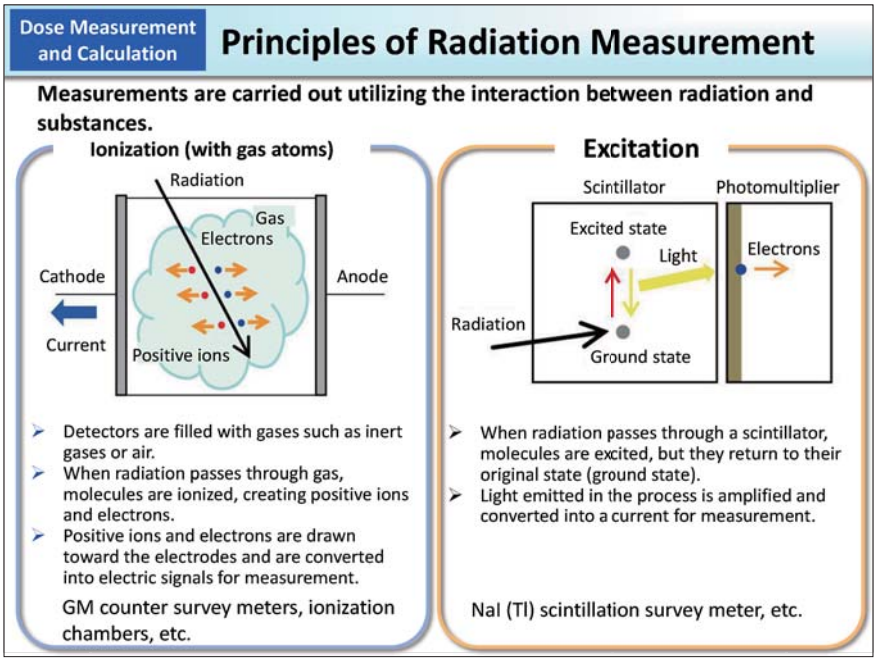
While radiation is not visible to the human eye, it is known to cause ionization and excitation (p.45 of Vol. 1, “Principles of Radiation Measurement”), and a variety of measuring instruments using these effects have been invented for different purposes and applications. The measuring instruments shown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

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

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

(Related to p.60 of Vol. 1, “Instruments for Measuring Internal Exposure”)

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



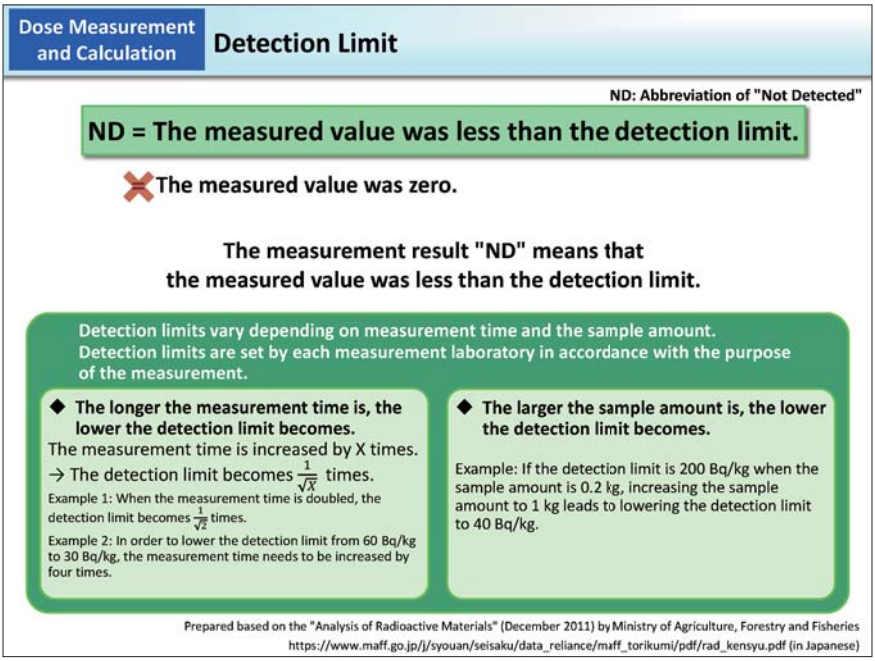
Radiation is known to interact with substances when passing through them. The amount of radiation can be measured utilizing the interaction between radiation and substances.

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



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

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

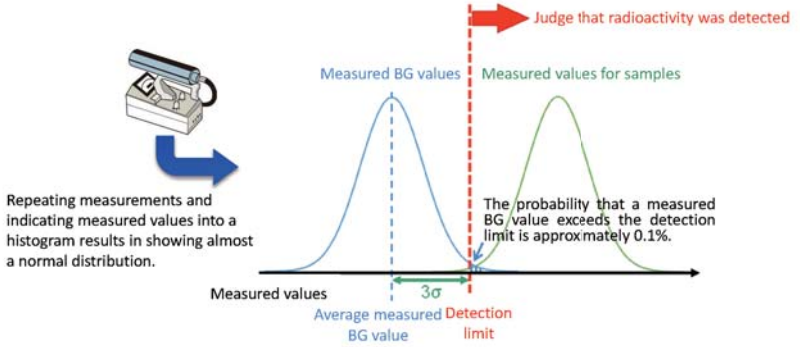
Detection limits vary depending on the measurement time and the sample amount, and in general, the longer the measurement time is and the larger the sample amount is, the lower the detection limit becomes. When setting a detection limit lower, even a small amount of radioactive materials can be detected,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

Included in this reference material on March 31, 2019
Updated on March 31, 2021

Dose Measurement and Calculation

Ideas on Detection Limits (3σ Method)

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



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

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

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

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

Reference:

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

Included in this reference material on March 31, 2019
Updated on March 31, 2022

Dose Measurement and Calculation

Instruments for Measuring External Exposure

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

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

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

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

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

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

Methods of Measuring Doses

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

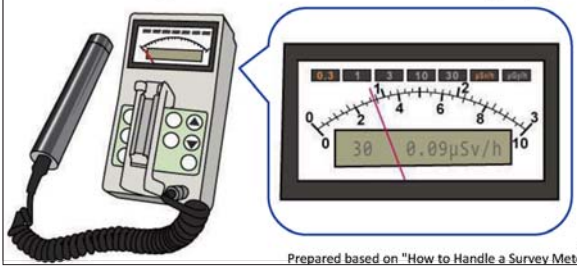
(i) Background measurement

(ii) Field measurement

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

(iii) Dose calculation

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



How to interpret the readings

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

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

The reading at 0.092 μSv/h

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

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

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

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

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

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

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

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

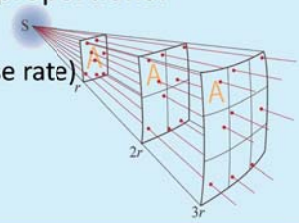
Dose Measurement and Calculation

Characteristics of External Exposure Doses

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

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

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



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

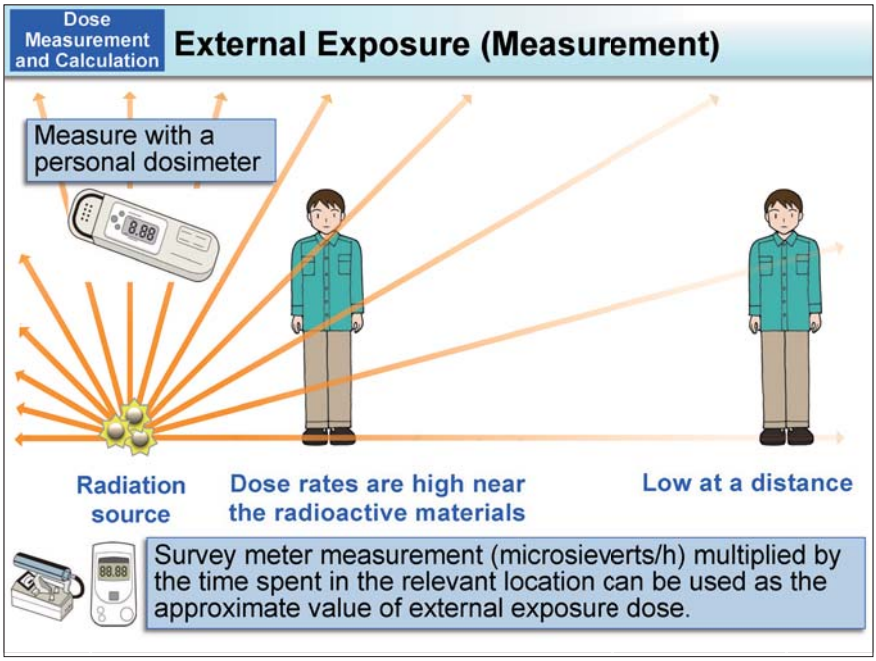
The intensity of radiation (dose rate) is strong (large) when the source of radiation (radiation source) is close, and it gets weaker (smaller) as the distance increases, even if the amount of radioactive materials remains the same. When the radioactive materials are located only in one place (point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

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

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

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

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



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

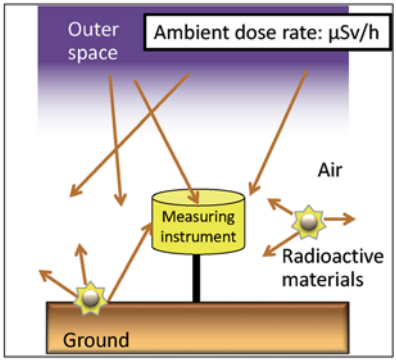
Another means is to measure radiation dose rates in a workplace with a survey meter to estimate the level of exposure supposing that a person stays in that place. Since α-particles and β-particles from outside the body do not reach into the body (p.22 of Vol. 1, “Penetrating Power and Range of Effects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

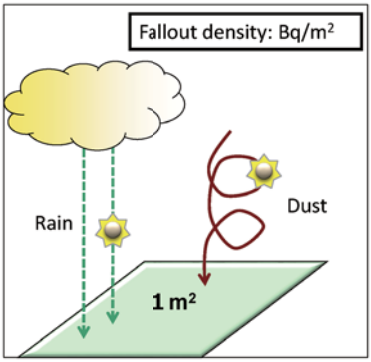
Included in this reference material on March 31, 2013
Updated on March 31, 2021

Dose Measurement and Calculation

Measurement of Environmental Radiation and Radioactivity

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





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

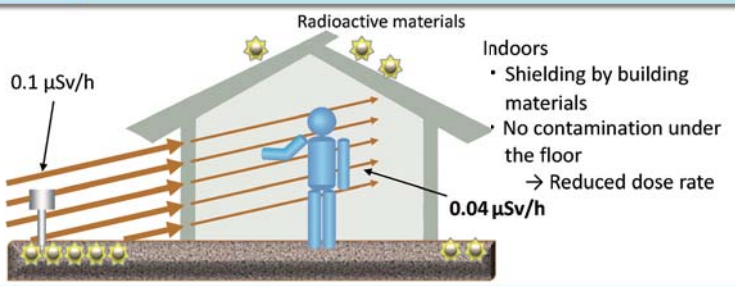
Normally, a measuring instrument is placed at a height of about 1 m from the ground, because most important internal organs are located at this height in the case of an adult. There are cases where a measurement instrument is placed at a height of 50 cm from the ground in places where mainly children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

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

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

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

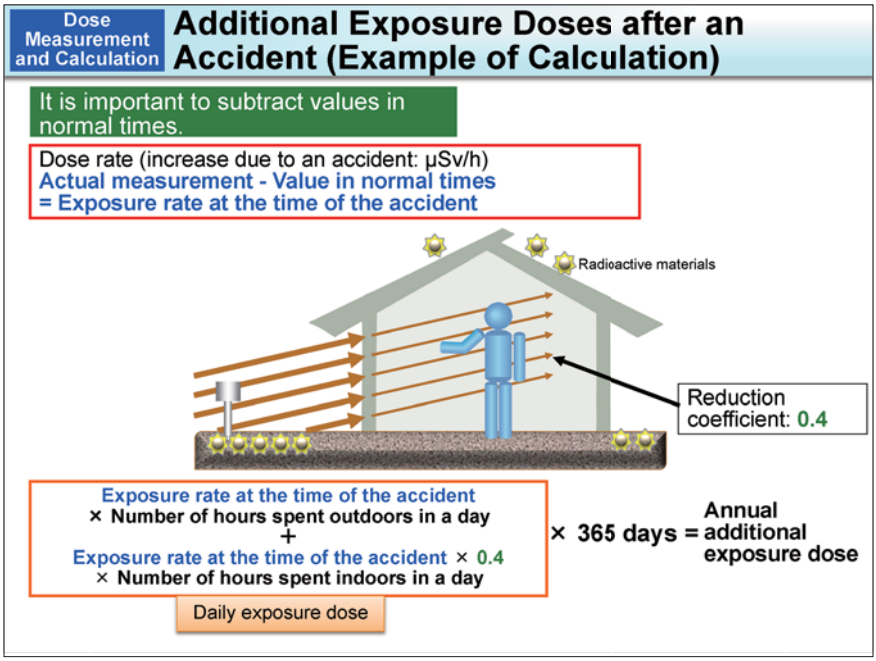
* The ratio of doses in a building when assuming that a dose outdoors at a sufficient distance from the building is 1

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

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

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

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



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

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

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

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

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

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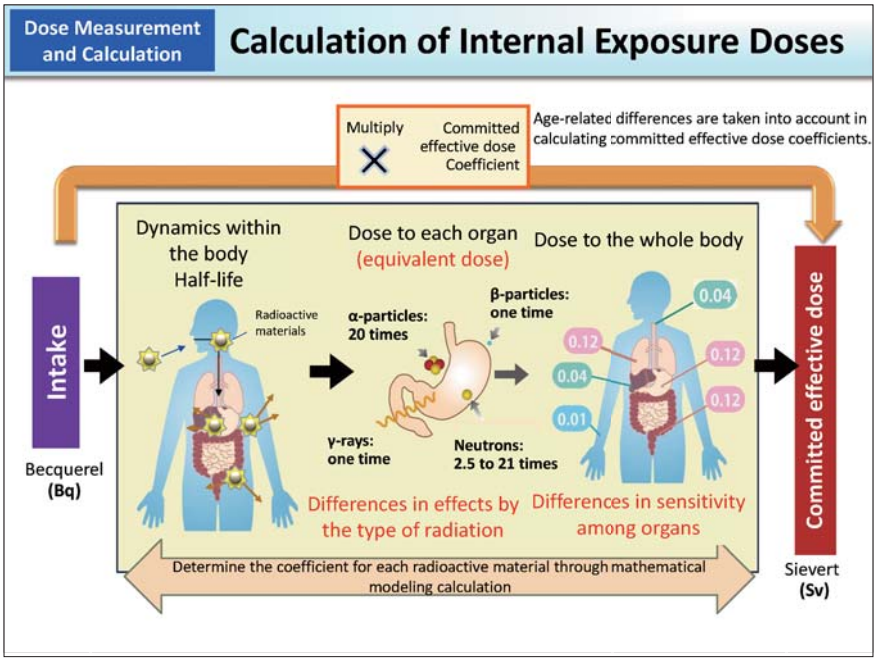

Methods of obtaining effective doses due to internal exposure are essentially the same as for external exposure. However, how to calculate absorbed doses for respective organs and tissues is different.

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

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

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

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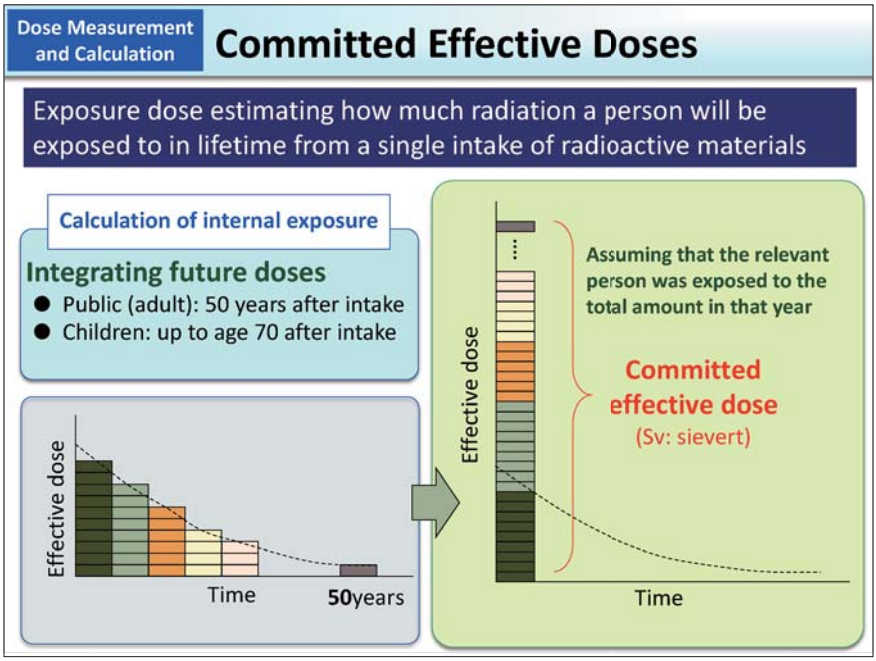

Radioactive materials remain in the body for a certain period of time after being taken into the body. In the meantime, the body will be continuously exposed to radiation. Thus, the total amount of radiation that a person will be exposed to into the future is calculated as dose due to internal exposure 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: Prepared based on the ICRP Publication 119, Compendium of Dose Coefficients based on ICRP Publication 60, 2012, International Commission on Radiological Protection (ICRP)

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

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

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)

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

100 (Bq/kg) × 0.5 (kg) × 0.013 (μSv/Bq) = 0.65 μSv

= 0.00065 mSv

Committed effective dose coefficients (μSv/Bq)

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

Bq: becquerels; μSv: microsieverts; mSv: millisieverts

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

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

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

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

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

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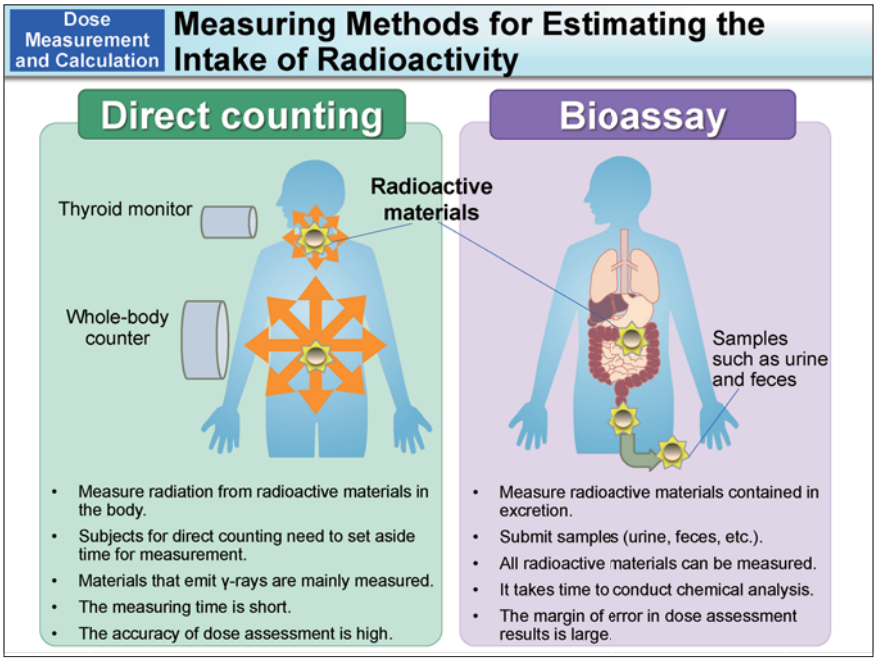

Direct counting methods that directly measure γ-rays coming from within the body or bioassay methods that measure the amount of radioactive materials in samples such as urine and feces are used to estimate the intake of radioactive materials, which is required for calculating internal exposure doses.

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

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

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

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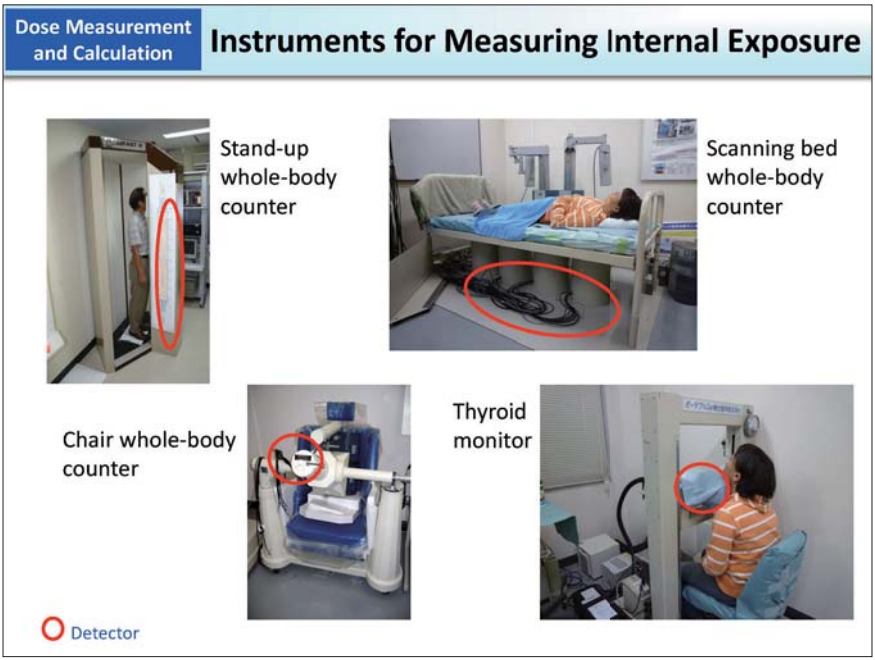
Updated on March 31, 2021



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

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

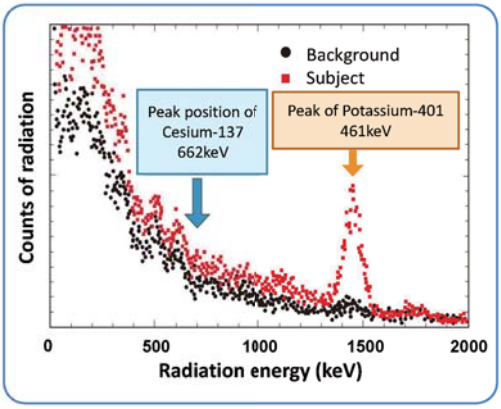
The time required for measurement is 1 to 5 minutes for simplified whole-body counters, 10 to 30 minutes for precision whole-body counters, and 2 to 5 minutes for thyroid monitors. (Related to p.164 of Vol. 2, "Internal Exposure Measurement Using a Whole-body Counter")

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

Dose Measurement and Calculation

Data on Internal Exposure Measured by Direct Counting

Whole-body counter



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

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

keV: kilo electron volts

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

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

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

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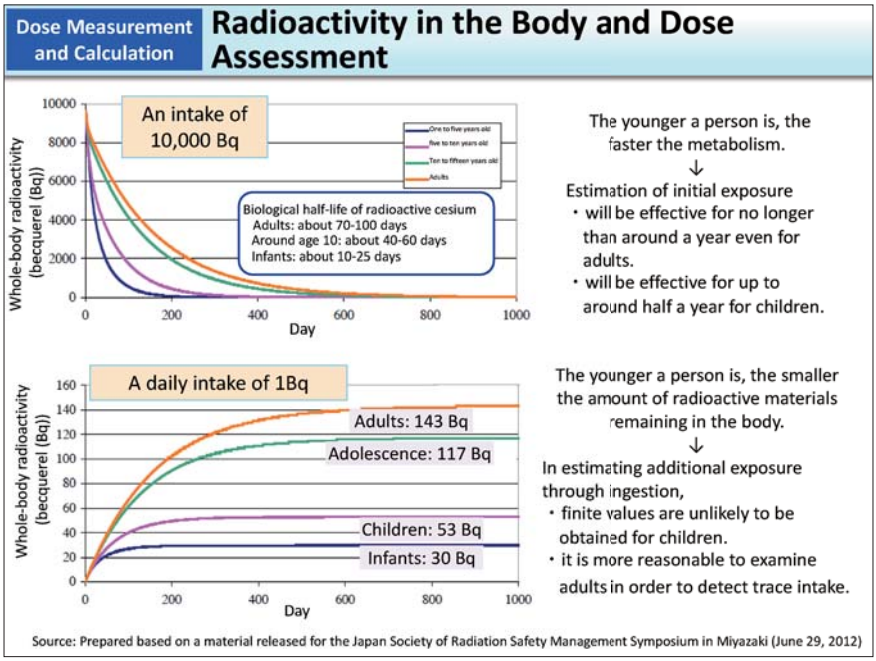

Whole-body counters (WBCs) can measure the content of radioactivity in a body on the day of measurement. Like other radiation measuring instruments, WBCs have a detection limit depending on their performance and counting time.

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

In contrast, whole-body counting for children is likely to result in values lower than the detection limit because a trace amount of the initial intake can be observed for only around half a year and the residual radioactivity in the body accumulated by chronic intake is also small due to the rapid metabolism of children. In such cases, it would rather be reasonable to examine adults and estimate their internal doses in terms of understanding the internal exposure situation in details, taking into account the fact that the committed effective dose coefficients are similar for both children and adults even though their metabolism rates are quite different.

In order to estimate the committed effective dose from the measurement result for the radioactivity in the body (p.56 of Vol. 1, “Committed Effective Doses”), it is necessary to use an appropriate intake scenario and an appropriate model based on the exposure situation, such as acute or chronic intake, inhalation or ingestion as a dominant route of intake, the time when the intake started, and so on.

Radionuclides with short effective half-lives, such as I-131, cannot be detected by a whole-body counter (WBC) or other radiation measurement equipment after their decay out. Pure beta-emitters that do not emit γ-rays, such as Sr-90, also cannot be detected by a WBC.

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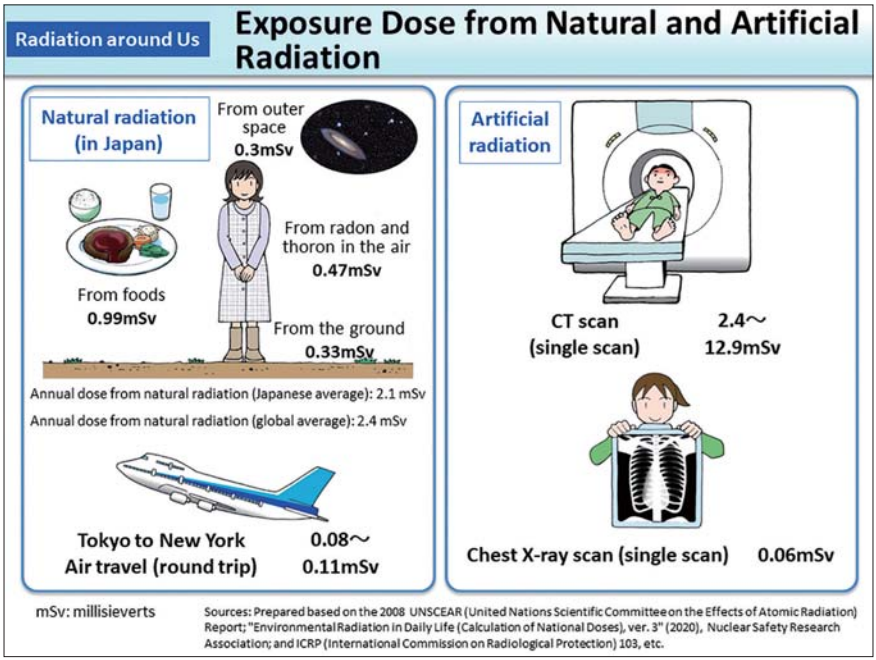

Radiation exists around us and we are exposed to it in our daily lives without realizing. It is impossible to completely avoid radiation exposure in our daily lives.

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

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

Included in this reference material on March 31, 2013
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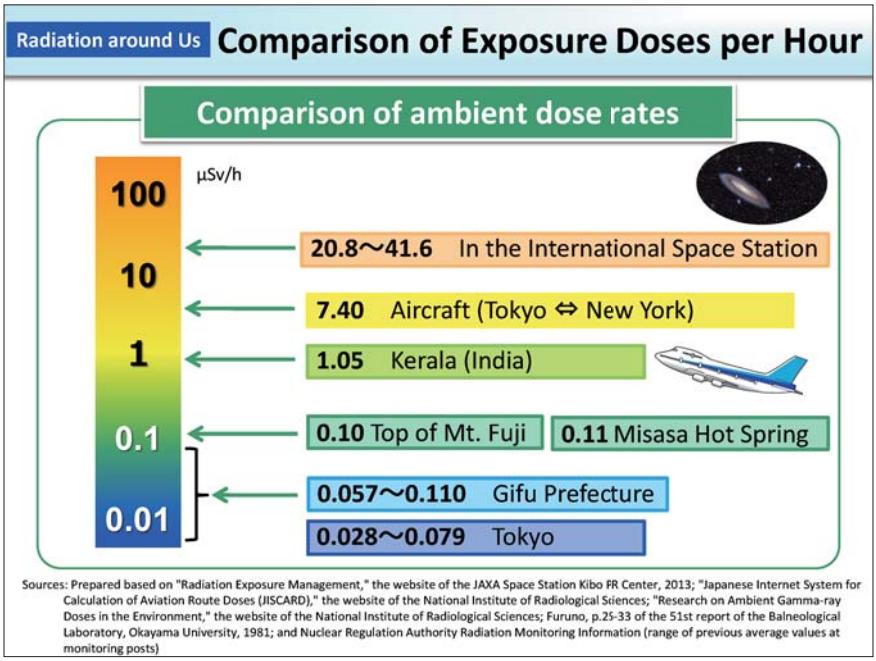

In outer space and aircraft, ambient dose rates are higher because of cosmic rays from galaxies and the Sun. Ambient dose rates are also high at high altitudes such as the top of Mt. Fuji, compared to low altitudes, because the influence of cosmic rays is stronger. At low altitudes, cosmic rays (radiation)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

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

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

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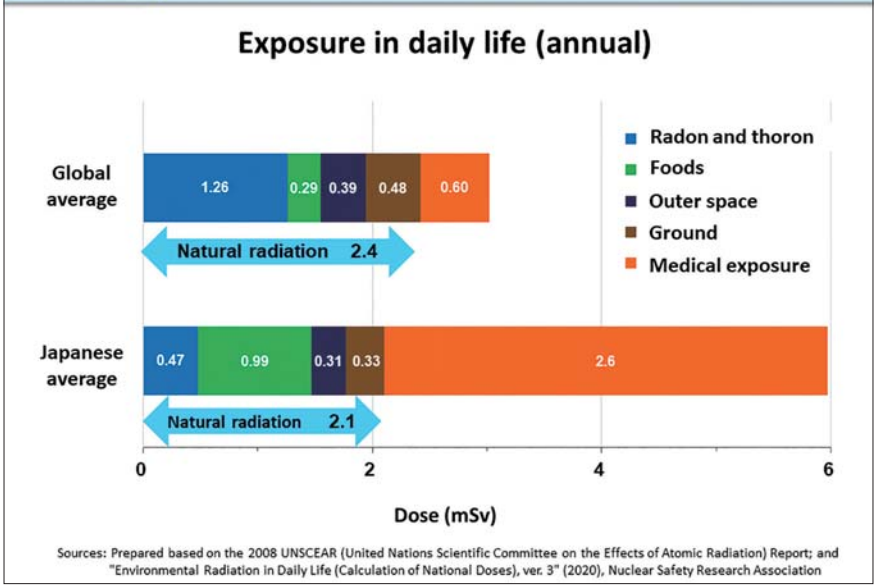
Comparison of Exposure Doses per Year



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

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

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

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

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

Radiation around Us

Breakdown of Natural Exposure Doses (Japanese)

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

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

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

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

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

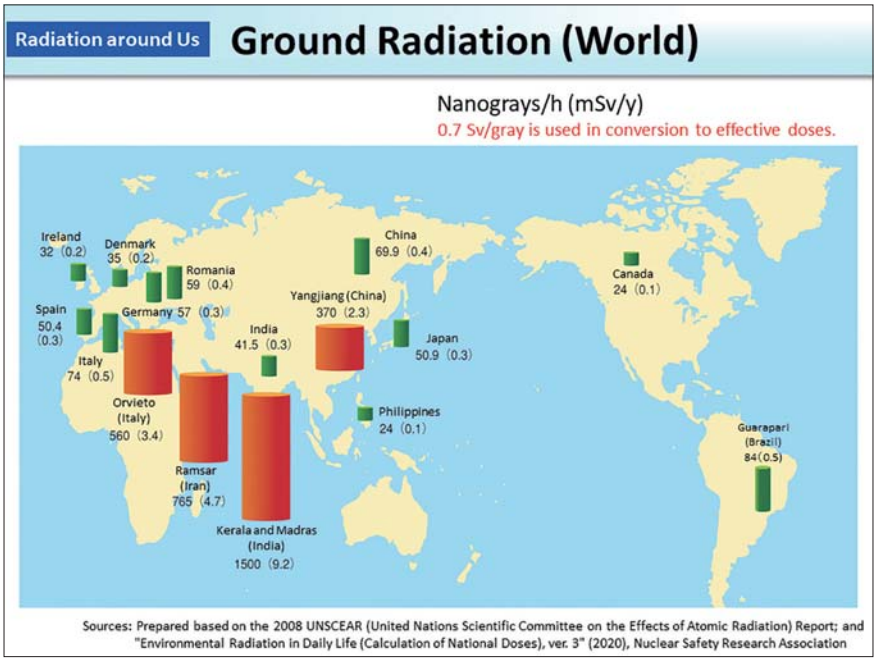
One reason why Japanese people's exposure doses from foods are higher compared to the rest of the world is that their diets contain lots of fish, which is rich in Polonium-210. This accounts for Japanese people's large effective doses. Incidentally, analyses of Lead-210 and Polonium-210 in foods have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

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.71 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 (p.57 of Vol. 1, "Conversion Factors to Effective Doses").

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

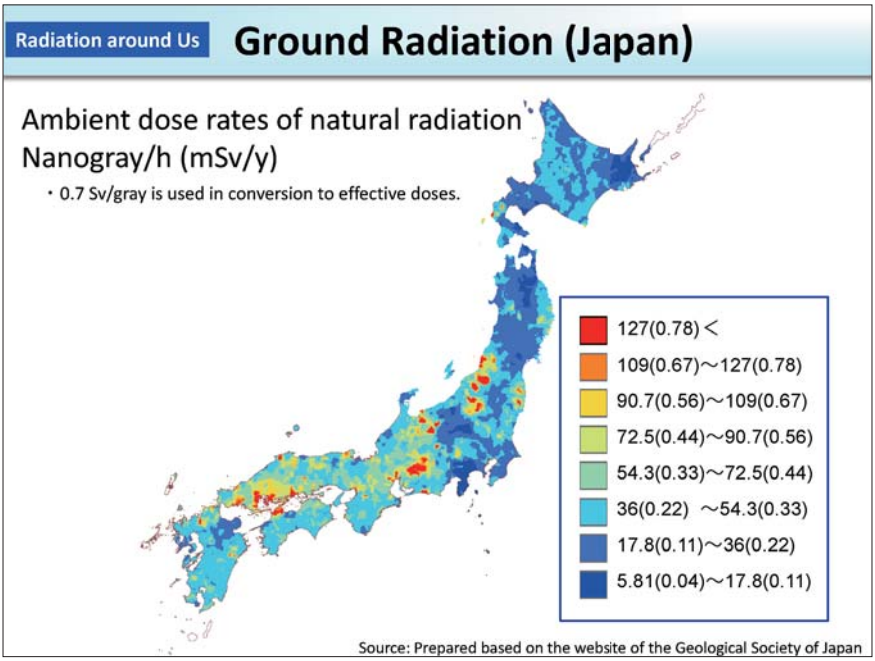


There are regions around the world where natural radiation is 7 to 30 times higher than in Japan, such as Yangjiang in China, Kerala in India, and Ramsar in Iran. The high levels of natural radiation in these regions are due to the fact that soil there is rich in radioactive materials such as radium,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

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

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

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



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

In the Kanto Plain, where a fewer types of radionuclides are contained in the ground, the amount of radiation from the ground is generally less. In western Japan, where granite is directly exposed to the ground in many places, the amount of radiation from the ground tends to be about 1.5 times higher than in eastern Japan because granite is relatively rich in radionuclides such as uranium, thorium and potassium.

(Related to p.8 of Vol. 1, “Naturally Occurring or Artificial”)

Included in this reference material on March 31, 2013
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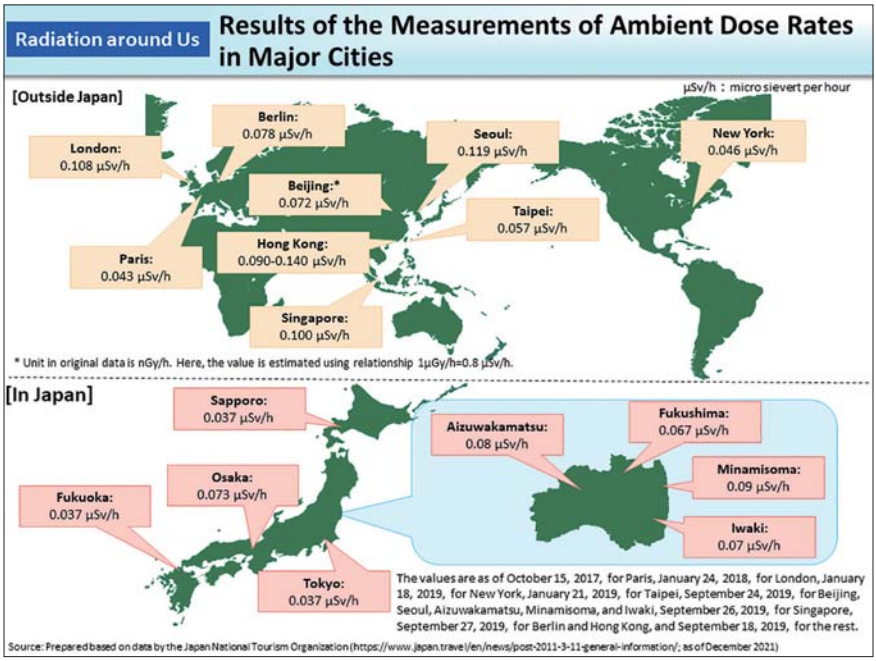

These figures show the results of the measurements of ambient dose rates at major cities in and outside Japan. Radiation doses shown in the figures are mostly from 0.03 μSv/h to 0.14 μSv/h, which reveals that radiation doses vary by region. This is mainly because radiation doses from the earth differ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

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

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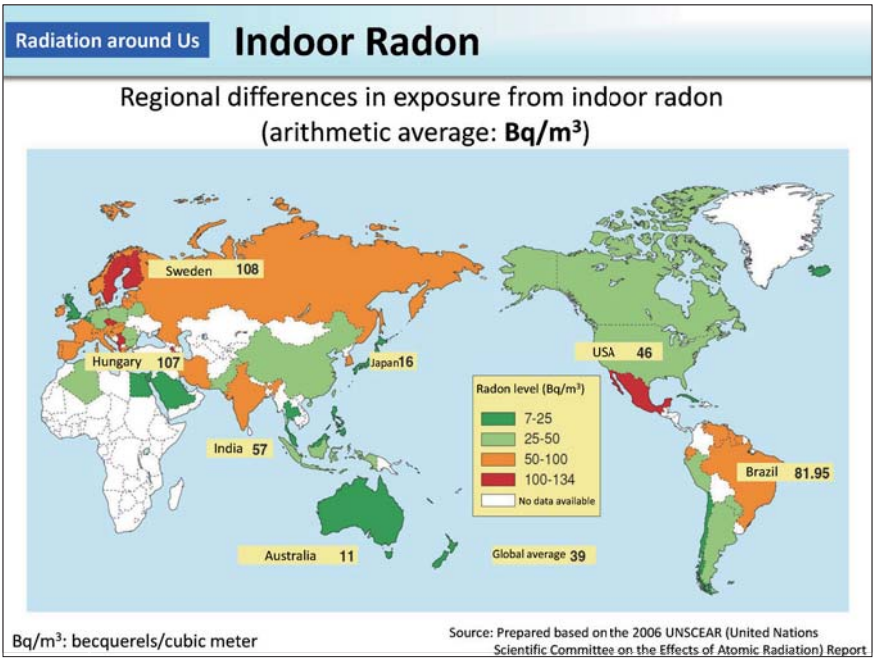


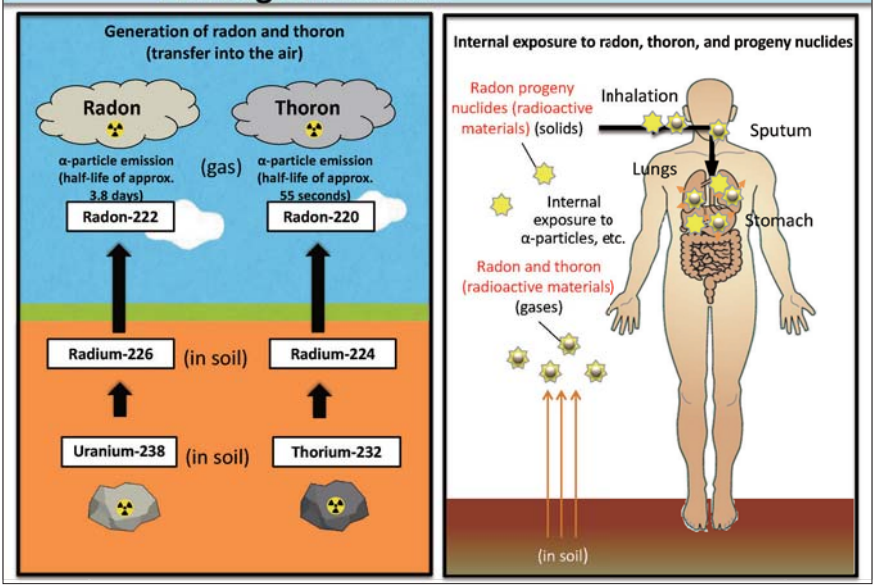
Radon is a radioactive noble gas produced by the alpha-decay of radium, which is universally present under the ground. Since radon is a gas, it is emitted from the ground and seeps into houses (p.71 of Vol. 1, “Internal Exposure to Radon and Thoron through Inhalation”).

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

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

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

Internal Exposure to Radon and Thoron through Inhalation



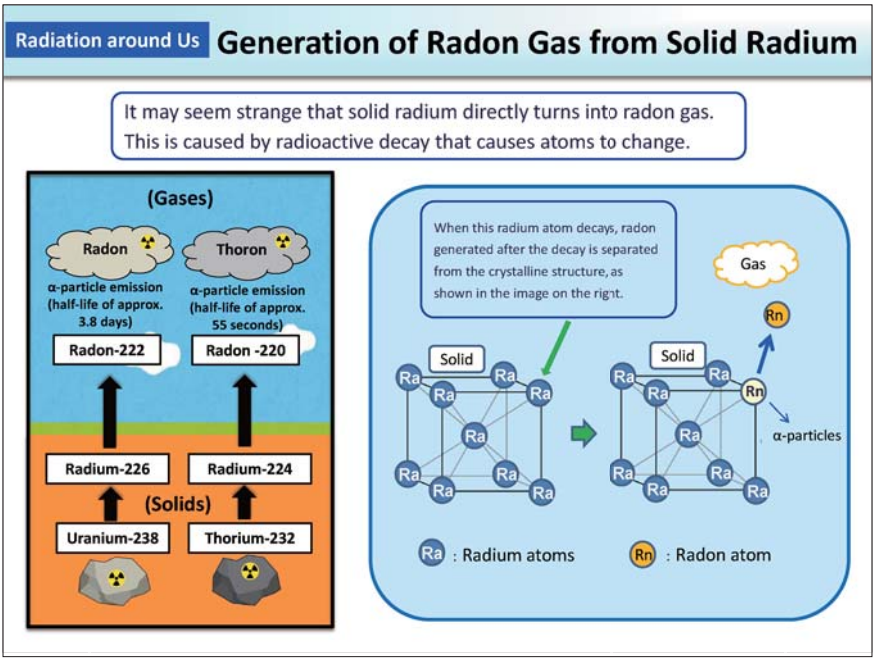
Radon (Radon-222) and thoron (Radon-220) are gaseous radioactive materials produced through radioactive decay of a radium ore. They enter the human body through inhalation. Radon results from decay of Radium-226 produced in a decay chain (uranium series) that starts from uranium, and thoron results from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

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

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

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

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

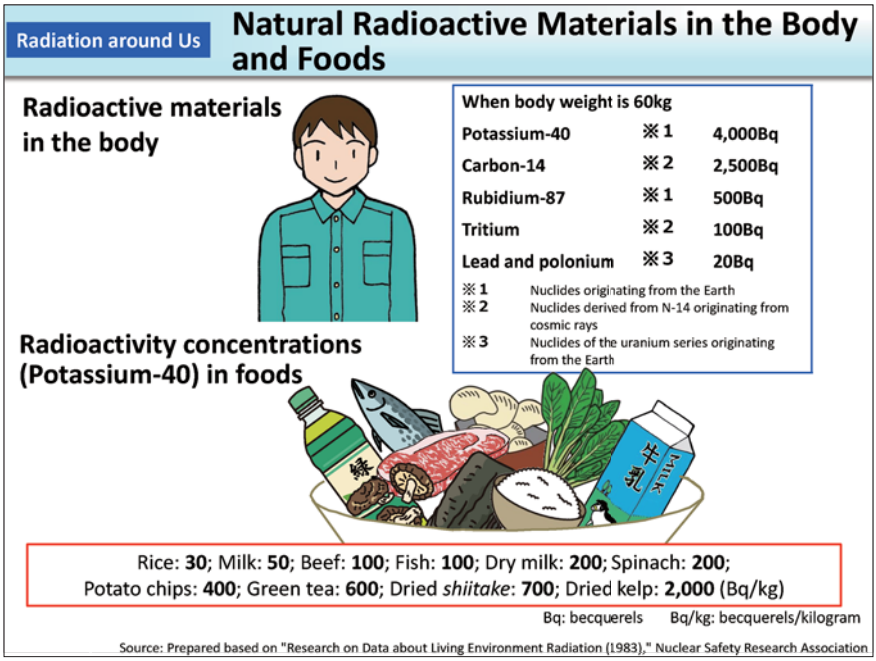


Radium, a radioactive material, is present in a crystal structure called body-centered cubic at room temperature and normal pressure, as shown in the right image.

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



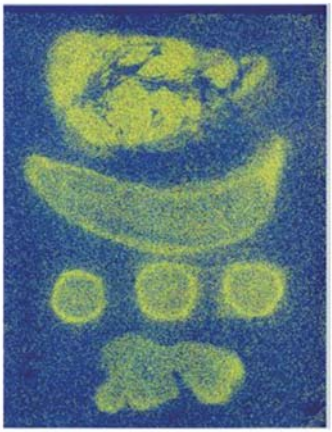
Potassium is an element necessary for life and is contained in most foods. Because 0.01% of potassium is radioactive, most foods contain radioactive potassium. Radioactive potassium emits β-particles and γ-rays, causing internal exposure from food intake (p.74 of Vol. 1, “Visualized Radiation”). The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

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

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

Radiation around Us

Visualized Radiation



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

Radiation from foods

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

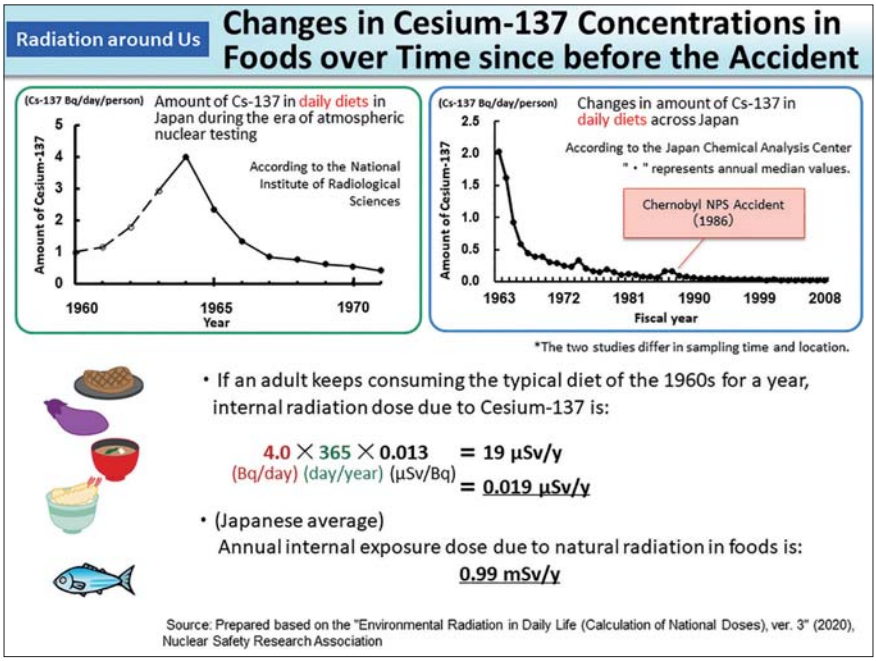
Potassium-40 contained in foods emits β-particles and γ-rays.

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

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

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

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



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

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

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

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

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

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

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

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

Included in this reference material on March 31, 2017
Updated on March 31, 2022

Radiation around Us — Radiation Doses from Medical Diagnosis

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

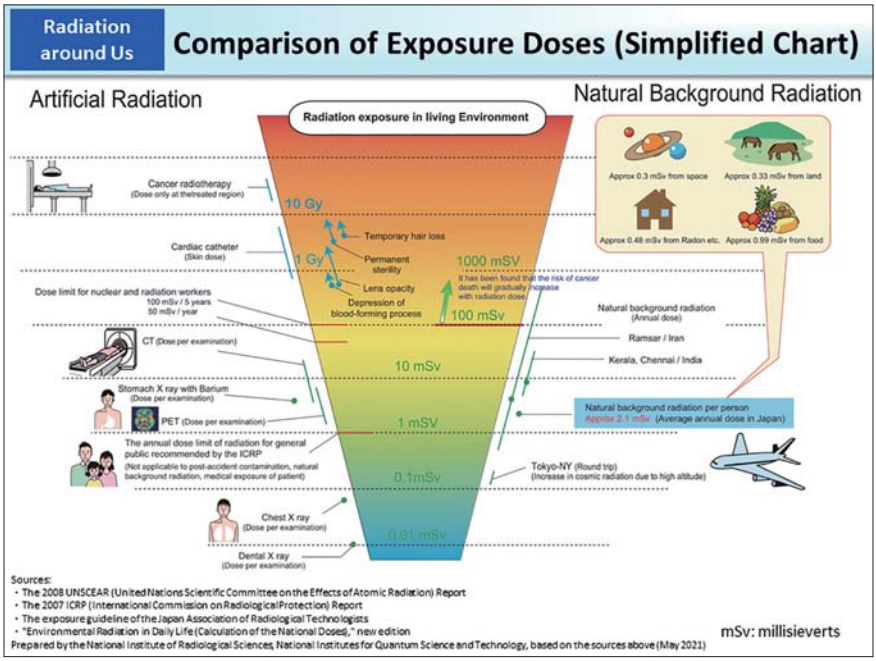
*1: "National Diagnostic Reference Levels in Japan (2020) (Japan DRLs 2020)," J-RIME, July 3, 2020 (partially updated on August 31, 2020) (http://www.radher.jp/J-RIME/)
*2: "Q&A on Medical Exposure Risks and Protection Regarding Medical Exposure from CT Scans, etc.," National Institutes for Quantum and Radiological Science and Technology (https://www.qst.go.jp/site/qms/1889.html)
*3: "Gastric Fluoroscopy" in "X-ray Medical Checkup" in "Basic Knowledge on Medical Radiation," Kitasato University Hospital, Radiology Department
Prepared based on materials *1, *2 and *3 above

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

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

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

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

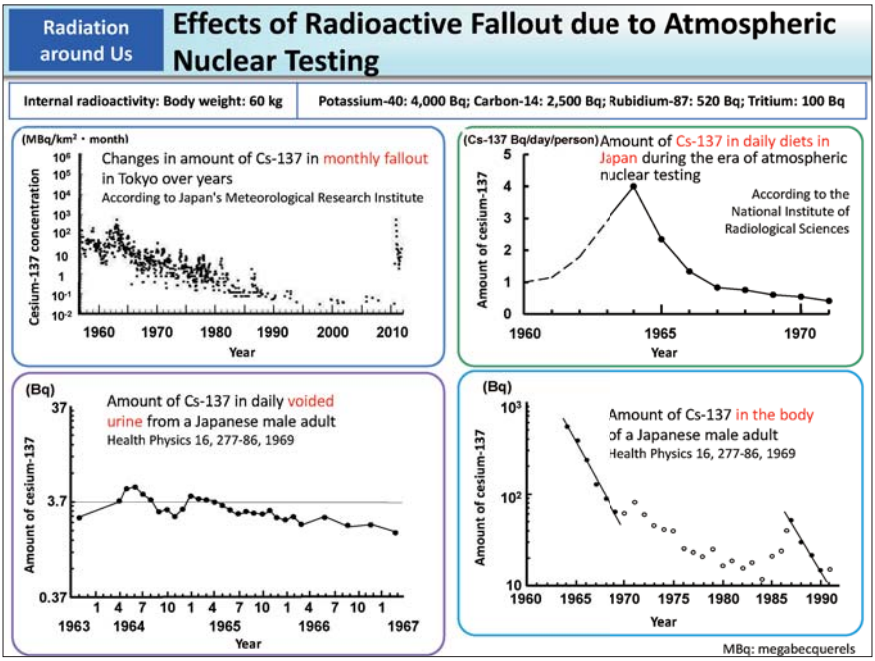


Comparison of radiation doses in daily life shows that doses from one single event and annual doses are mostly on the order of millisieverts, except for special cases such as radiation therapy (p.76 of Vol. 1, "Radiation Doses from Medical Diagnosis").

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

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

Radiation around Us — Effects of Radioactive Fallout due to Atmospheric Nuclear Testing



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

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

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

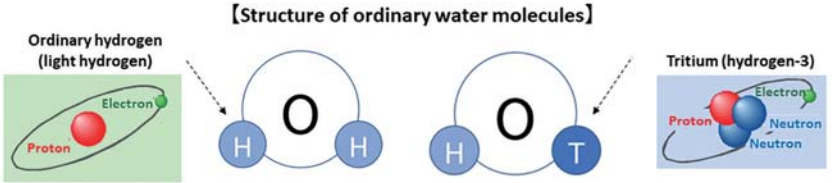
As a result of atmospheric nuclear testing during the aforementioned era, plutonium and Strontium-90, etc. were released into the environment, in addition to radioactive cesium. These radionuclides still exist in soil, albeit only slightly.

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

Radiation around Us

Characteristics of Tritium

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



Water molecule solely consisting of ordinary hydrogen

Water molecule consisting of ordinary hydrogen and tritium

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

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

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

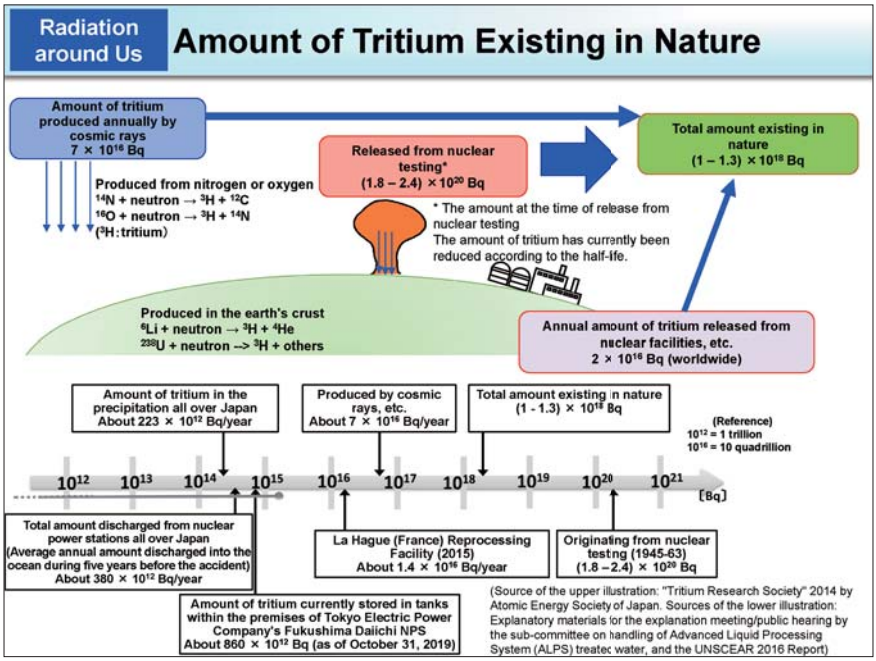
Tritium emits β-particles, a type of radiation, but β-particles emitted from tritium have low energy and can be shielded with a sheet of paper. Therefore, external exposure to tritium is unlikely to exert any influence on the human body. A biological half-life for water containing tritium is ten days,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

In April 2021, the Government of Japan announced the Basic Policy on the handling of the ALPS treated water purified by the Advanced Liquid Processing System (ALPS), etc. to be discharged into the sea after a preparation period of about two years, on the premise that safety will be ensured, and that the government will take all necessary measures to prevent adverse impacts on reputation.

[Reference materials]
Basic knowledge on tritium:
- Contaminated water management in Fukushima: Top priority on safety and security; Measure (ii) What is "tritium"?
  https://www.enecho.meti.go.jp/about/special/johoteikyo/osensuitaisaku02.html (in Japanese)
- Top priority on safety and security; Measure (iii) Explanation of tritium and radiation exposure
  https://www.enecho.meti.go.jp/about/special/johoteikyo/osensuitaisaku03.html (in Japanese)

Portal Site for Decommissioning and Countermeasures for Contaminated Water and Treated water:
- ALPS Treated Water
  https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/atw.html

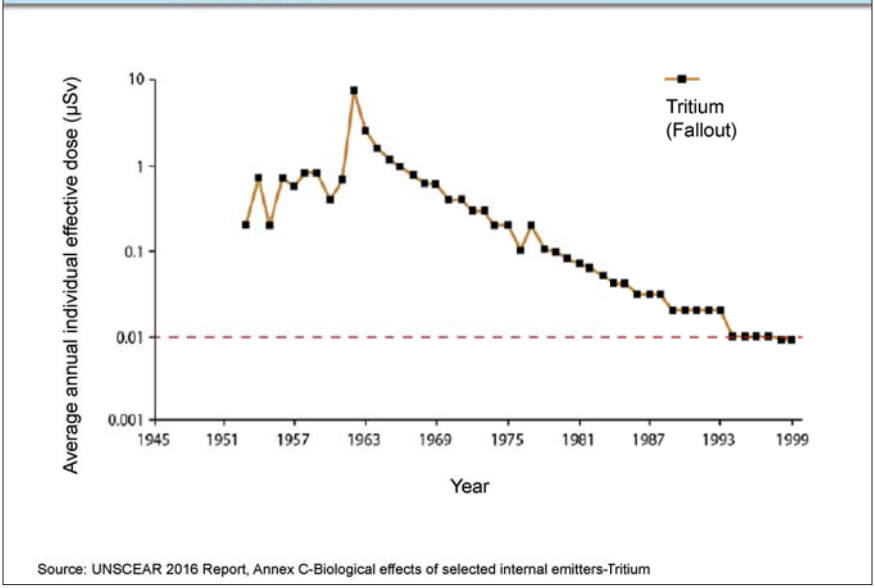
Included in this reference material on March 31, 2019
Updated on March 31, 2022



Tritium (^{3}H) is a radioisotope of hydrogen (with a half-life of about 12.3 years) and emits weak radiation (β-particles) (p.79 of Vol. 1, "Characteristics of Tritium"). In nature, about seventy quadrillion (7×10^{16}) Bq of tritium is produced annually by cosmic rays, etc. on earth. In the past nuclear testing (1945 to 1963), tritium of 1.8 to 2.4 × 10^{20} Bq was released. In addition, tritium is discharged daily from facilities such as nuclear power stations around the world and the annual amount of tritium released from nuclear power stations around the world is 2×10^{16} Bq. Before the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident, the annual amount of tritium released from nuclear power stations all over Japan was 380×10^{12} Bq (which is the average annual amount discharged into the ocean during the five years before the accident). The total amount of tritium existing in nature is estimated to be 1 to 1.3 × 10^{18} Bq. The released tritium exists mostly as hydrogen that makes up water molecules and it is also contained in water vapor in the atmosphere, rainwater, sea water and tap water. The annual amount of tritium contained in the precipitation in Japan is estimated to be about 223×10^{12} Bq.

Included in this reference material on March 31, 2021

Changes in Tritium in Radioactive Fallout over Time



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

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

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

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

(Related page: p.78 of Vol. 1, “Effects of Radioactive Fallout due to Atmospheric Nuclear Testing”)

Included in this reference material on March 31, 2021