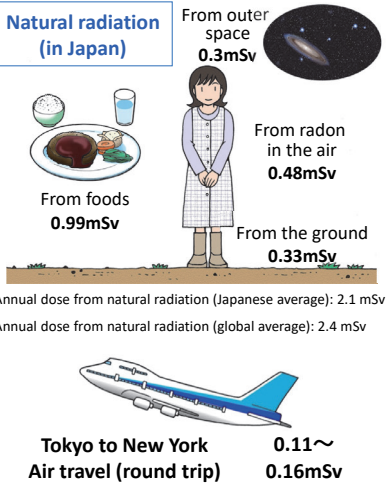


Exposure Dose from Natural and Artificial Radiation

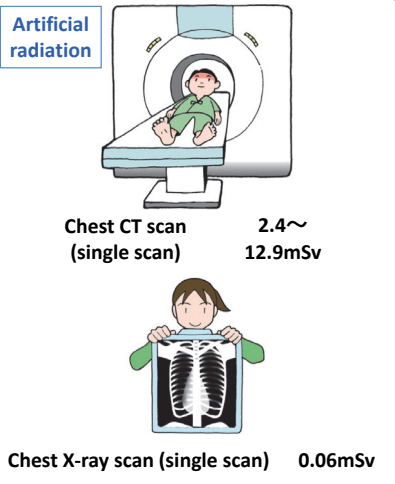
Natural radiation (in Japan)



mSv: millisieverts

Sources: Prepared based on the 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report; and "Environmental Radiation in Daily Life (2011)," new edition, Nuclear Safety Research Association; ICRP (International Commission on Radiological Protection) 103, etc.

Artificial radiation



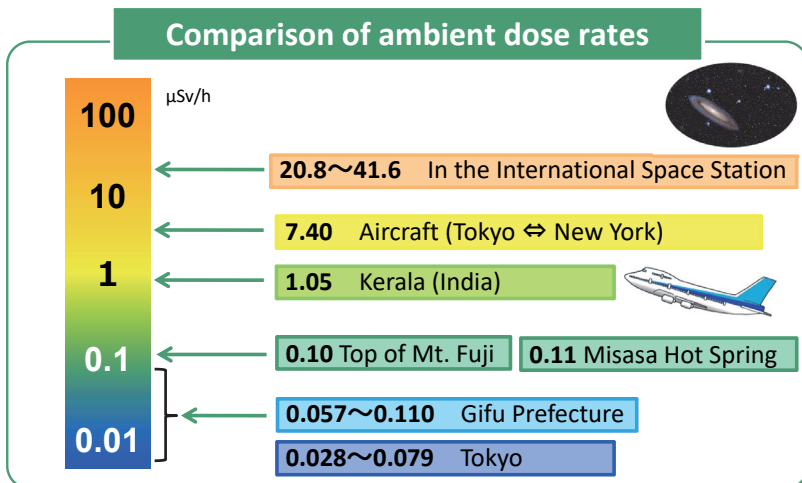
We are exposed to radiation in our daily lives without realizing it.

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

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

Included in this reference material on March 31, 2013

Updated on March 31, 2015



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

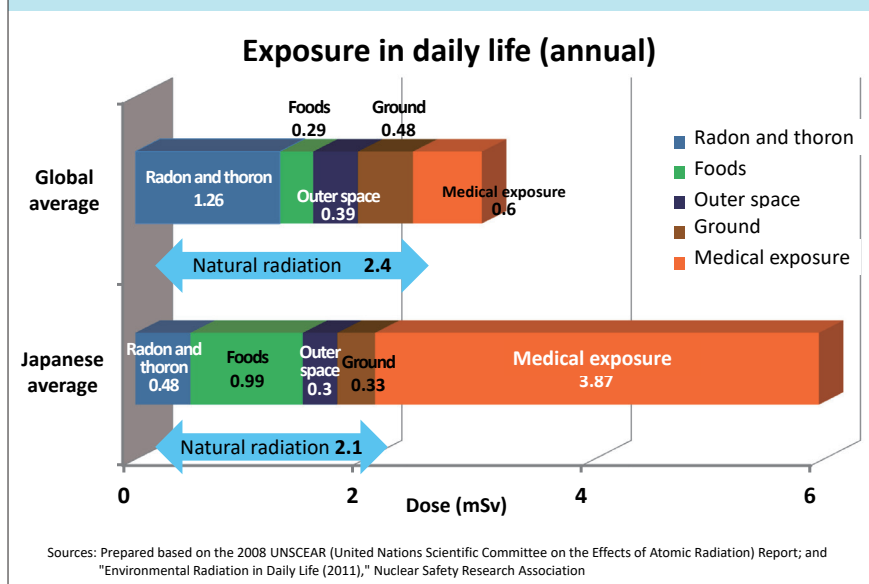
In outer space and aircraft, ambient dose rates are higher because of cosmic rays from galaxies and the Sun. Ambient dose rates are also high at high altitudes such as the top of Mt. Fuji, compared to low altitudes, because the influence of cosmic rays is stronger. At low altitudes, cosmic rays (radiation)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

Ambient dose rates in most living spaces are in the range of 0.01 to 1 μSv/h, but there are areas where the level of natural radiation is high because soil there contains large amounts of radioactive materials, such as radium and thorium. Such areas are called high natural radiation areas (p.65 of Vol. 1, "Ground Radiation (World)").

While there is no high natural radiation area in Japan, ambient dose rates are slightly higher in places where soil contains a lot of radium, such as Misasa Onsen Hot Springs, which is famous for radon hot springs. In contrast, ambient dose rates tend to be low in the Kanto Plain, where a loam layer covers the ground, shielding radiation from the ground (p.66 of Vol. 1, "Ground Radiation (Japan)").

Included in this reference material on March 31, 2013

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In December 2011, the Nuclear Safety Research Association announced Japan's national doses for the first time in 20 years. The survey shows that the annual average dose of Japanese people is 5.98 millisieverts, of which 2.1 millisieverts are estimated to be caused by exposure to natural radiation.

Comparison with the global average shows that Japanese people's exposures to Radon-222 and Radon-220 (thoron) are relatively low while exposures from foods are relatively high. In preparing this report, it has been found that the Japanese people's exposure due to Lead-210 and Polonium-210 in foods amounts to 0.80 mSv, which is high compared to the global average, probably due to Japanese people's high intake of fish and seafood (p.64 of Vol. 1, "Breakdown of Natural Exposure Doses (Japanese)").

While exposure doses from radiological examinations vary widely among individuals, Japanese people's exposure doses are known to be significantly high on average. In particular, the widespread use of CT scans is a major contributing factor.

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

Included in this reference material on March 31, 2013

Updated on March 31, 2017

Breakdown of Natural Exposure Doses (Japanese)

Type of exposure	Breakdown of radiation sources	Effective dose (mSv/year)
External exposure	Cosmic rays	0.3
	Ground radiation	0.33
Internal exposure (inhalation)	Radon-222 (indoors and outdoors)	0.37
	Radon-220 (thoron) (indoors and outdoors)	0.09
	Smoking (Lead-210, Polonium-210, etc.)	0.01
	Others (uranium, etc.)	0.006
Internal exposure (ingestion)	Mainly Lead-210 and Polonium-210	0.80
	Tritium	0.0000082
	Carbon-14	0.01
	Potassium-40	0.18
Total		2.1

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

This table shows that the intake of Lead-210 and Polonium-210 through ingestion accounts for a significant portion of Japanese people's internal exposures. Lead-210 and Polonium-210 are created when Radon-222 in the air goes through the following process:

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

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

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

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

Internal exposure to Radon-222 and Radon-220 (thoron) through inhalation will be explained in "Internal Exposure to Radon and Thoron through Inhalation" on p.68 of Vol. 1.

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

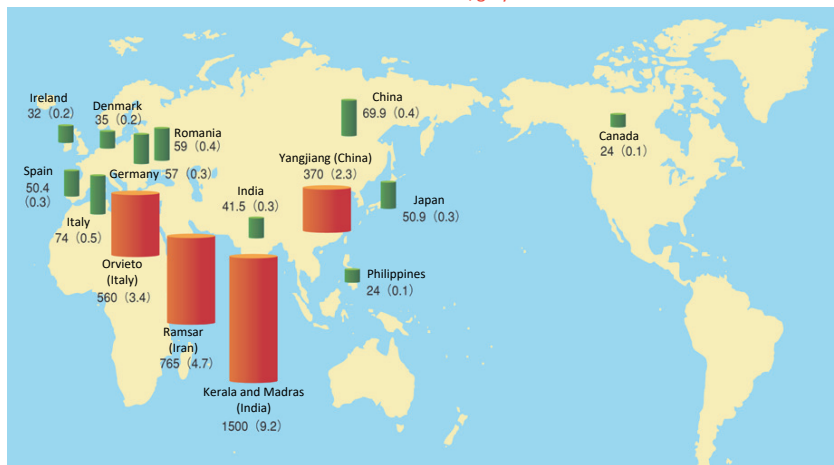
Included in this reference material on March 31, 2013

Updated on February 28, 2018

Ground Radiation (World)

Nanograys/h (mSv/y)

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



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

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

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

Based on epidemiological studies in China and India, no significant increases in cancer deaths and incidence rates have been reported so far in these regions (p.119 of Vol. 1, "Effects of Long-Term Low-Dose Exposure"). In Ramsar, analysis on cancer risks is underway.

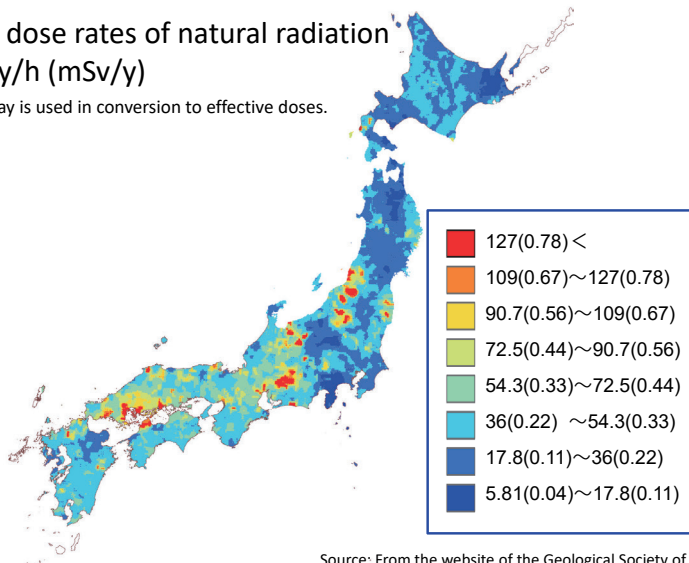
Included in this reference material on March 31, 2013

Updated on March 31, 2015

Ground Radiation (Japan)

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

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



Source: From the website of the Geological Society of Japan

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

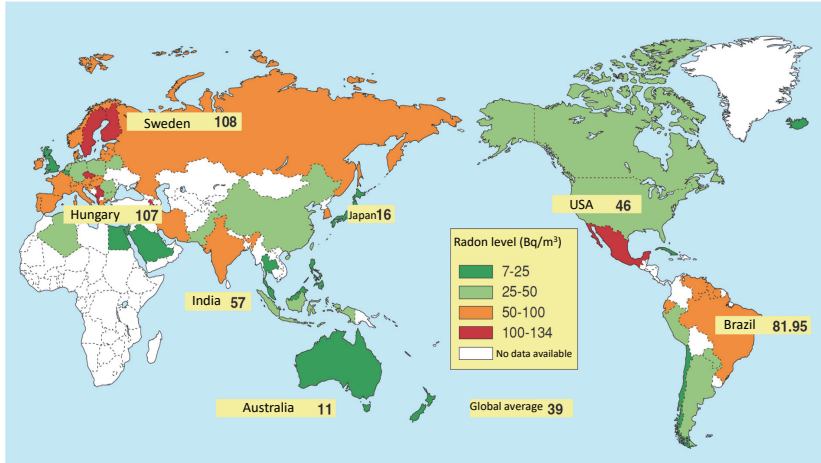
In the Kanto Plain, where a loam layer shields radiation from the ground, the amount of ground radiation is generally less. In western Japan, where granite is directly exposed to the ground in many places, the amount of radiation from the ground tends to be about 1.5 times higher than in eastern Japan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

Included in this reference material on March 31, 2013

Updated on March 31, 2015

Indoor Radon

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



Bq/m³: becquerels/cubic meter

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

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

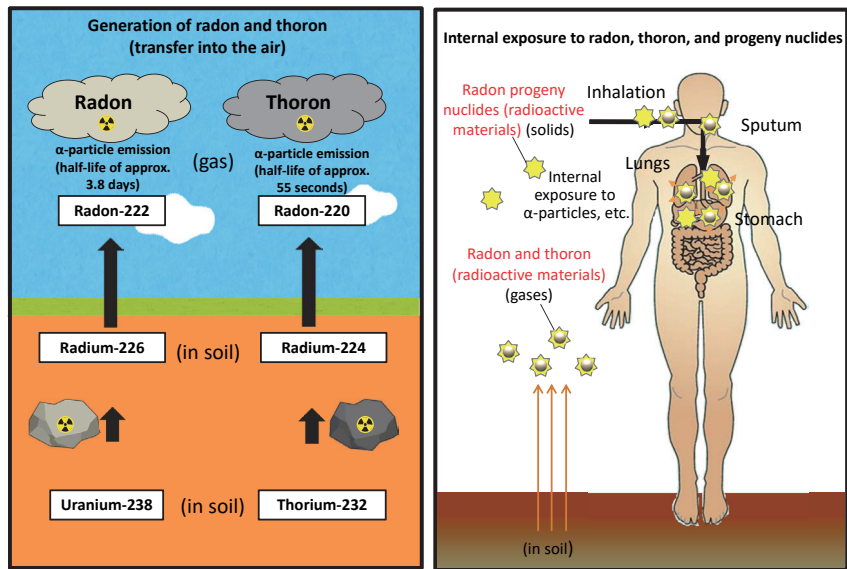
In areas where people live in masonry houses, such as Europe, indoor radon concentrations are high and exposure doses tend to be high as a result.

The global average of indoor radon concentrations is 39 Bq/m³, while Japan has an average value of 16 Bq/m³. There are also large regional differences in internal exposure doses from indoor radon.

Included in this reference material on March 31, 2013

Updated on March 31, 2015

Internal Exposure to Radon and Thoron through Inhalation



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

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

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

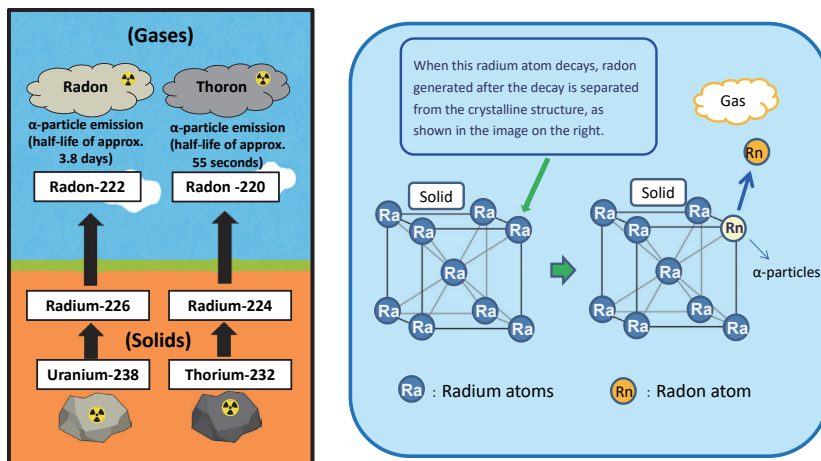
Radon contributes less to internal exposure than its progeny nuclides. This is because radon, being a gas, is easily exhaled, while radon progeny nuclides, i.e., radioactive Polonium-218 and Lead-214 that is created through decay of the former, are solids and therefore not easily expelled out of the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

Included in this reference material on March 31, 2015

Updated on March 31, 2016

Radiation around Us **Generation of Radon Gas from Solid Radium**

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



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

Natural Radioactive Materials in the Body and Foods

Radioactive materials in the body



When body weight is 60kg

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

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

Radioactivity concentrations (Potassium-40) in foods



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

Bq: becquerels Bq/kg: becquerels/kilogram

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

Potassium is an element necessary for life and is contained in most foods. Because 0.01% of potassium is radioactive, most foods contain radioactive potassium. Radioactive potassium emits β -particles and γ -rays, causing internal exposure from food intake (p.73 of Vol. 1, "Visualized Radiation"). The internal potassium concentration is held constant, so exposure doses from potassium in foods depend on individuals' physiques and are considered unaffected by diet (p.8 of Vol. 1, "Naturally Occurring or Artificial").

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

Included in this reference material on March 31, 2013

Updated on February 28, 2018

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

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

(<http://www.radher.jp/J-RIME/>)

* 2 : "Q&A on Medical Exposure Risks and Protection Regarding Medical Exposure from CT Scans, etc.," National Institutes for Quantum and Radiological Science and Technology (<http://www.nirs.qst.go.jp/rd/faq/medical.html>)

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

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

Exposure doses from radiological examinations vary by the types of examinations. Some examinations, such as dental imaging, only involve very slight, local exposure, while some other examinations, such as X-ray CT scans and nuclear scanning, involve relatively high exposure doses. Even with the same type of examination, doses could vary widely depending on the medical institution. It is therefore recommended to use diagnostic reference levels as criteria for determining whether doses might be too high for diagnosis. If the average radiation dose of a medical institution greatly deviates from the diagnostic reference levels, the International Commission on Radiological Protection (ICRP) recommends that irradiation conditions for the examination be reconsidered.

Some countries are already using the diagnostic reference levels. In Japan, the Japan Association of Radiological Technologists issued a medical exposure guideline (reduction targets) in 2000, in which they compiled values equivalent to the diagnostic reference levels. It was updated in 2006 as the 2006 medical exposure guideline. The Japan Network for Research and Information on Medical Exposures (J-RIME)* created Japan's first diagnostic reference levels based on the results of surveys conducted by participating organizations ("Diagnostic Reference Levels based on the Results of the Latest National Survey," Japan Association on Radiological Protection in Medicine, etc., June 7, 2015 (partially updated on August 11, 2015)).

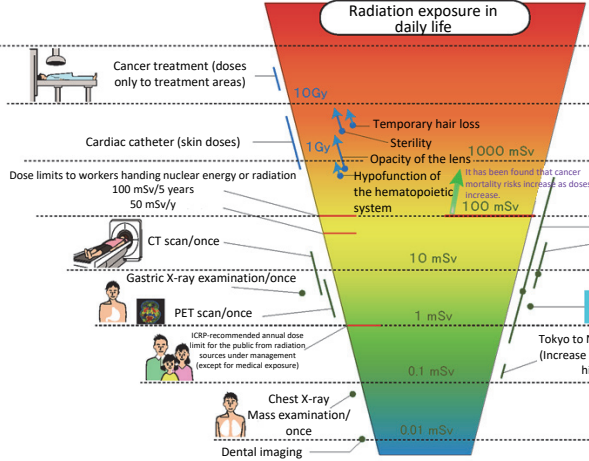
Note*: The Japan Network for Research and Information on Medical Exposures (J-RIME) started in 2010 as a base for establishing a medical exposure protection system that matches Japan's circumstances, by gathering expert opinions through cooperation from academic societies and associations, and collecting and sharing domestic and international research information on medical exposures. J-RIME's activities include collecting data on medical exposure, such as exposure doses from radiation therapy and risk assessment, to get a picture of medical exposures in Japan, and building an appropriate protection system for medical exposure in Japan while taking international trends into account (source: website of the National Institute of Radiological Sciences of National Institutes for Quantum and Radiological Science and Technology: <http://www.nirs.qst.go.jp/rd/structure/merp/j-rime.html>, in Japanese).

Included in this reference material on March 31, 2013

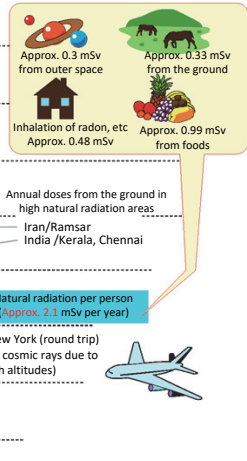
Updated on March 31, 2017

Comparison of Exposure Doses (Simplified Chart)

Artificial radiation



Natural radiation



Sources:
 • The 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report
 • The 2007 ICRP (International Commission on Radiological Protection) Report
 • The exposure guideline of the Japan Association of Radiological Technologists
 • "Life Environmental Radiation (Calculation of the National Dose)," new edition
 Prepared by the National Institute of Radiological Sciences based on the sources above (May 2013)

mSv: millisieverts

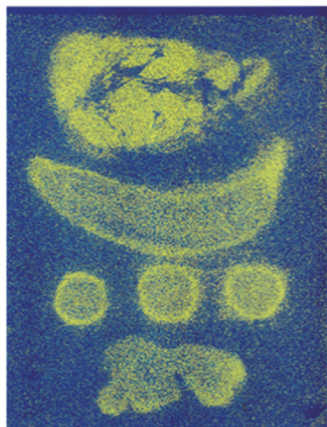
2.5 Radiation around Us

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

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

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Updated on March 31, 2015



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

Radiation from foods

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

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

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

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

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

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

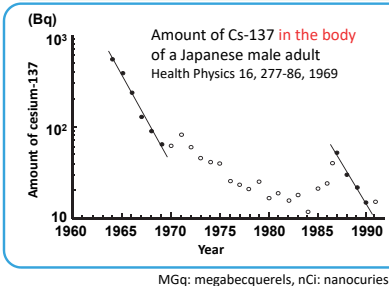
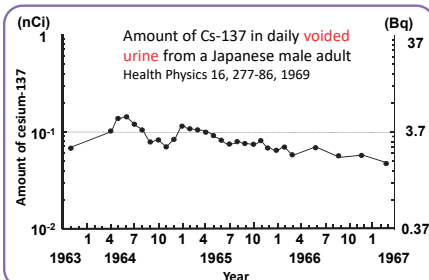
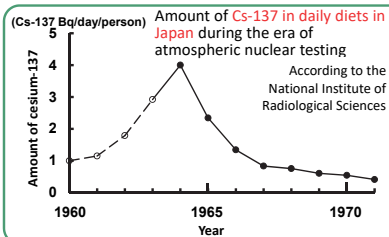
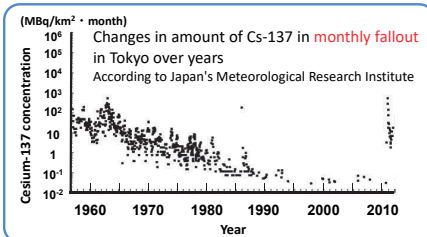
Included in this reference material on March 31, 2013

Updated on March 31, 2015

Effects of Radioactive Fallout due to Atmospheric Nuclear Testing

Internal radioactivity: Body weight: 60 kg

Potassium-40: 4,000 Bq; Carbon-14: 2,500 Bq; Rubidium-87: 520 Bq; Tritium: 100 Bq



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

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

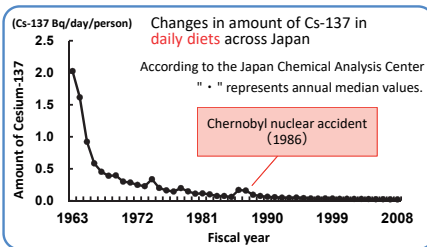
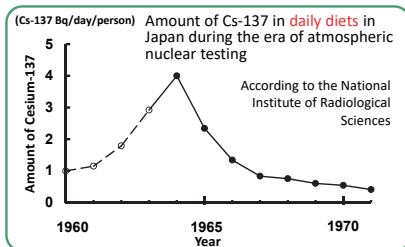
Like the amount of cesium in daily diets, the amounts of Cesium-137 in urine and the body were also highest in 1964. An increase in the amount of cesium in the body was also found among Japanese people as a result of the influence of the Chernobyl nuclear disaster.

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

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Updated on February 28, 2018

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



*The two studies differ in sampling time and location.



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

$$4.0 \times 365 \times 0.013 = 19 \mu\text{Sv/y}$$

$$(\text{Bq/day}) (\text{day/year}) (\mu\text{Sv/Bq}) = \underline{0.019 \mu\text{Sv/y}}$$

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

$$\underline{0.99 \text{ mSv/y}^*}$$

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

Atmospheric nuclear tests were carried out around the world from 1945 to 1980. As a result, large amounts of artificial radionuclides were released into the air and fell to Japan as well. Radioactivity in daily diets has been measured across Japan in order to find out what effects the artificial radionuclides would have on health.

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

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

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

$$4.0 (\text{Bq/day}) \times 365 (\text{day/year}) \times 0.013 (\mu\text{Sv/Bq}) = 19 \mu\text{Sv/y} = 0.019 \text{ mSv/y}$$

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