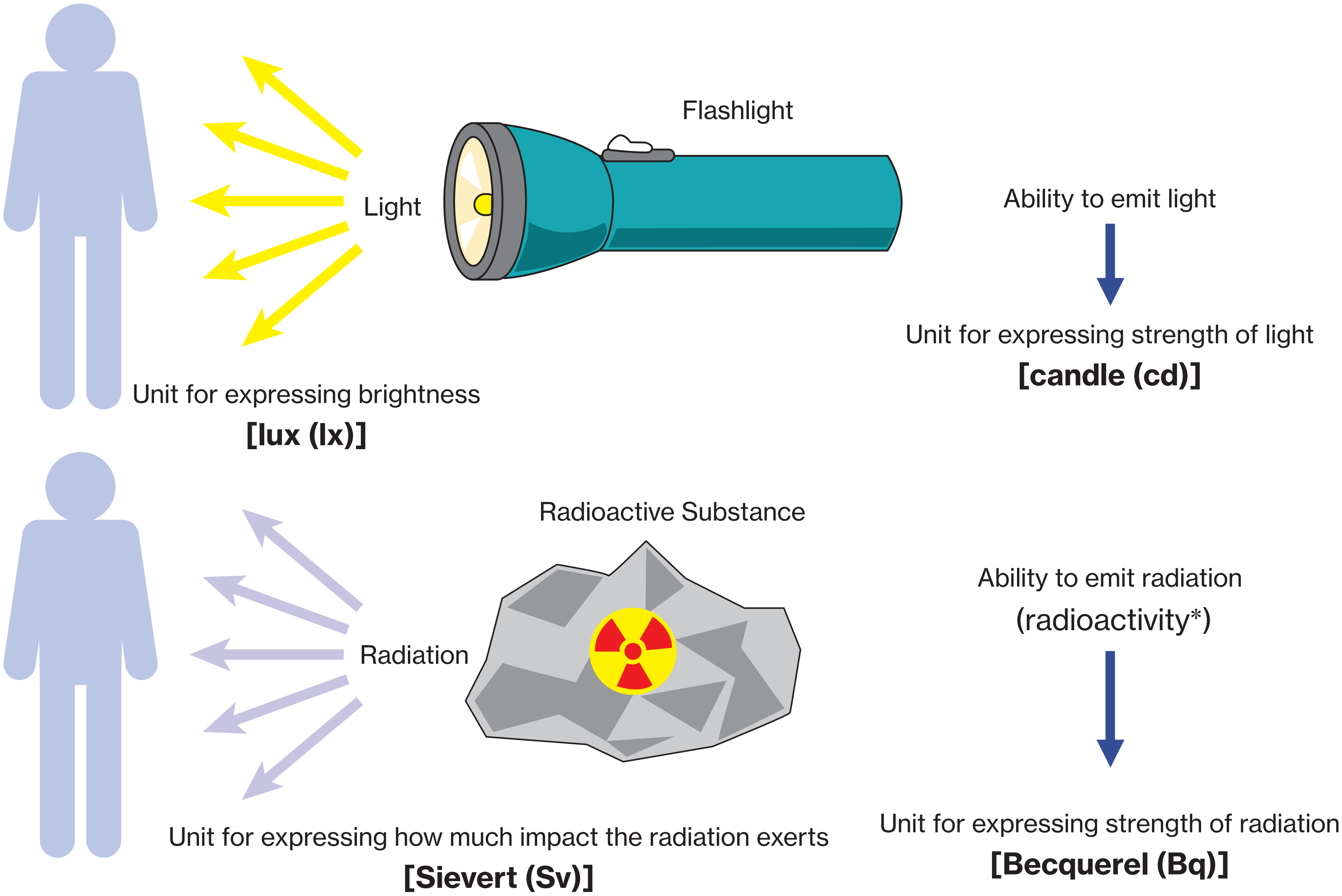
Radioactivity and Radiation

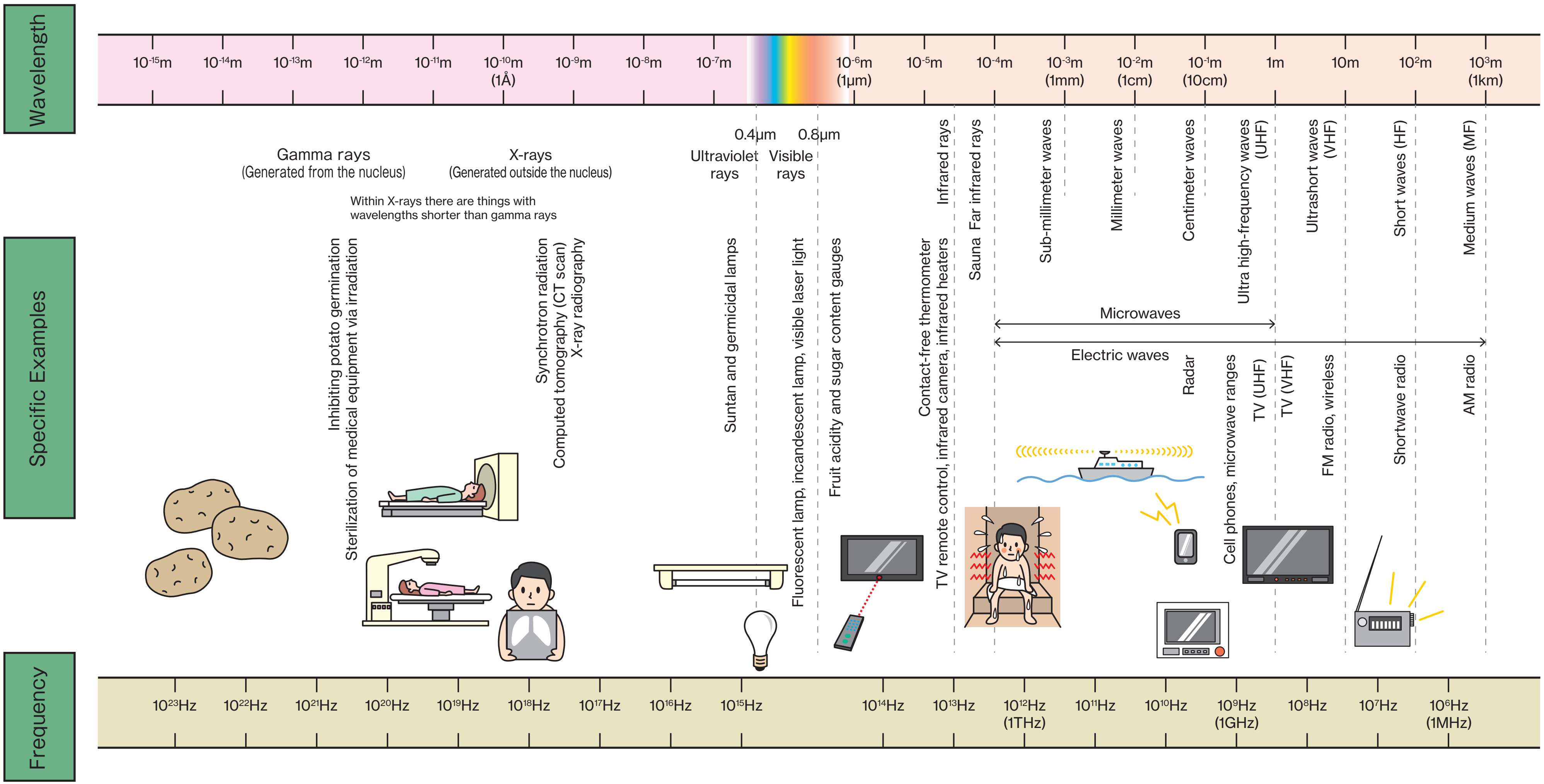


*May also be used to describe a substance (radioactive material) that is radioactive.

Units Used in Relation to Radioactivity

Name	Unit (Symbol)	Definition
Unit of Radioactivity International System of Units (SI)		
Radioactivity	Becquerel (Bq)	This unit represents the quantity of radioactive material in which one nucleus decays per second.
Unit of Radiation Dosage International System of Units (SI)		
Absorbed dose	Gray (Gy)	This unit represents how much energy is received by an object or person hit by radiation. A dose of 1 Gray corresponds to 1 joule of energy absorbed by 1 kilogram of matter.
Dose	Sievert (Sv)	This unit is used for assessing how much risk radiation poses to people in terms of inducing cancer or genetic damage. (1 Sievert = 1,000 mSv)
Unit of Energy International System of Units (SI)		
Energy	Joule (J)	Unit of energy that represents the energy of radiation (1J=6.2×10^{18}eV)

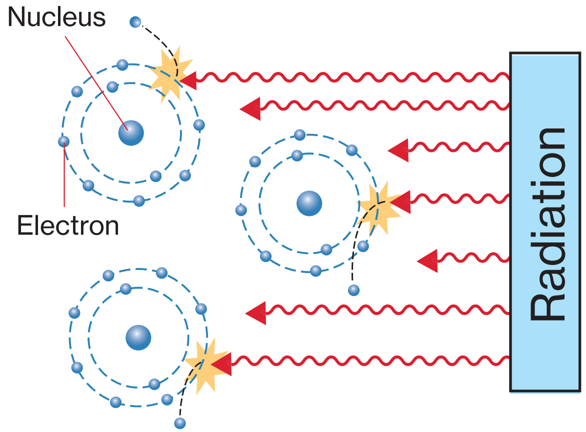
Types of Electromagnetic Waves



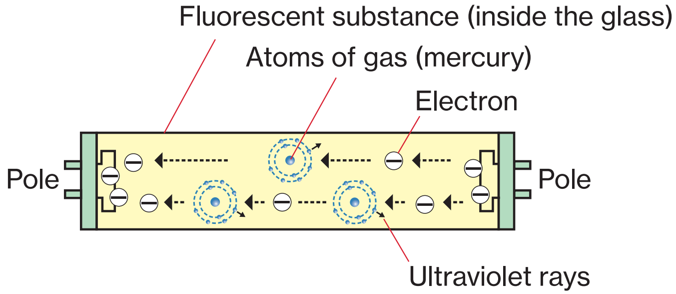
Source: Japan Atomic Energy Agency, What is Radiation?

Properties of Radiation

Ionization Effect



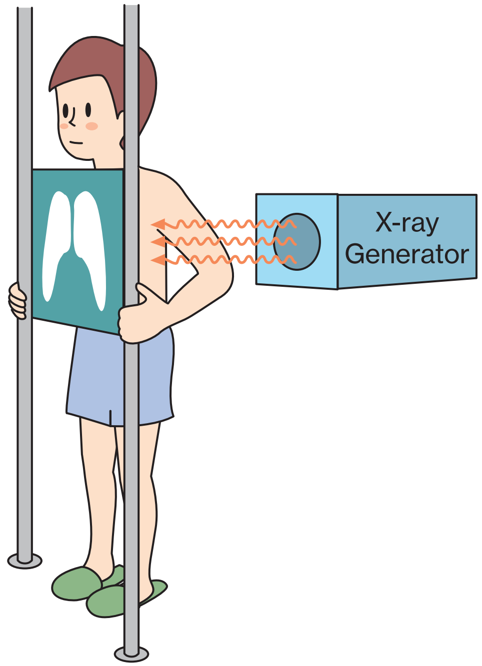
Fluorescence Effect



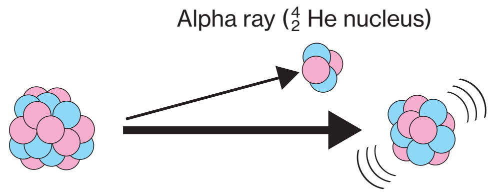
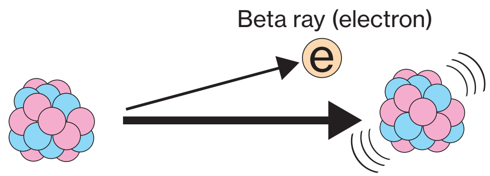
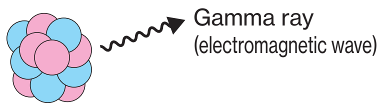
How Fluorescence Works

When voltage is applied across the poles of the tube, electrons flow from one pole to the other. When electrons crash into mercury enclosed in the tube, it produces ultraviolet light. The ultraviolet rays light up the fluorescent substance.

Permeation



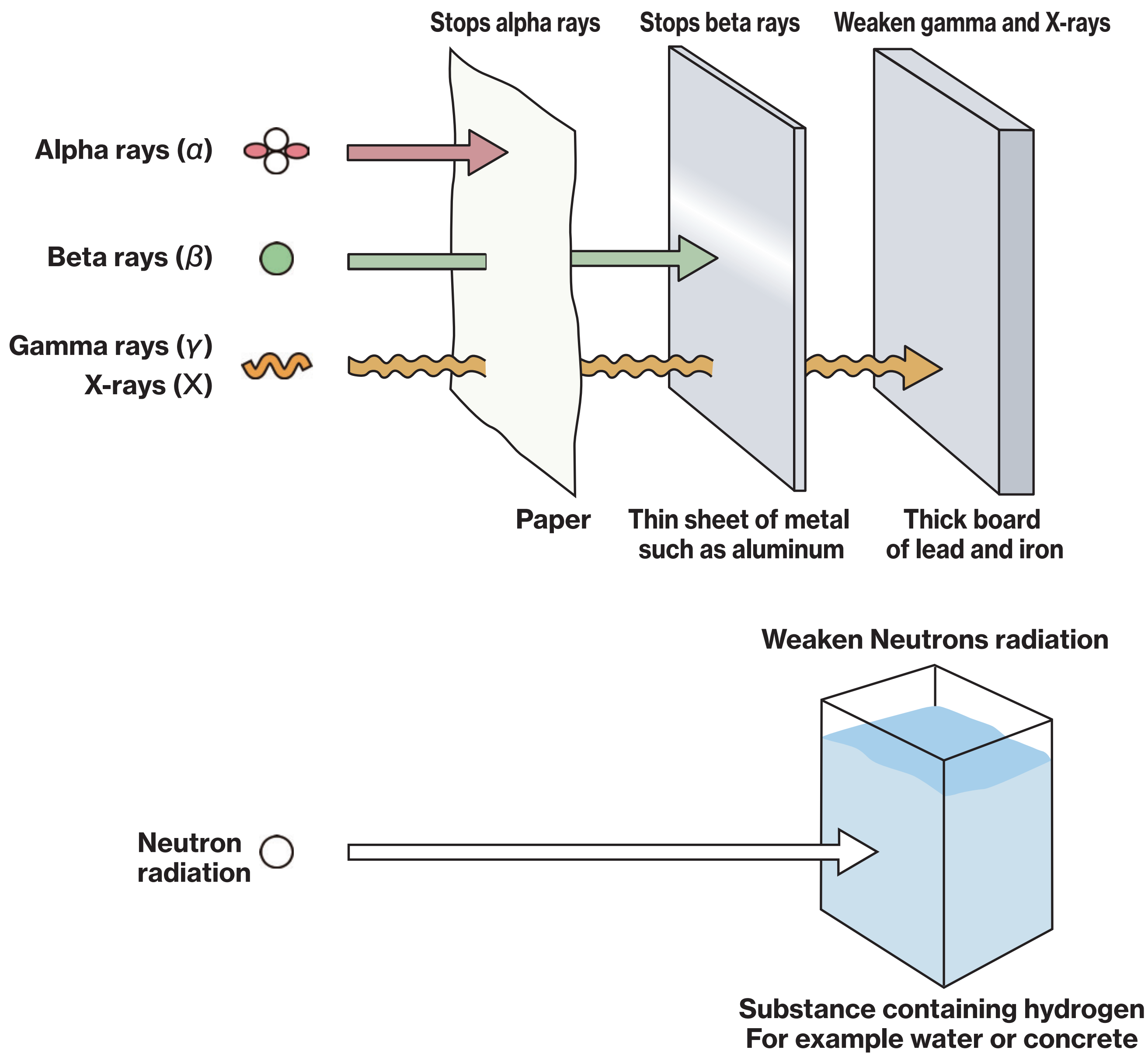
Types of Radiation

Alpha (α) decay		(Ex.) $^{226}_{88}\mathrm{Ra} \xrightarrow{\alpha} {}^{222}_{86}\mathrm{Rn}$
Beta (β) decay		(Ex.) $^{24}_{11}\mathrm{Na} \xrightarrow{\beta} {}^{24}_{12}\mathrm{Mg}$
Gamma (γ) ray emission		

● Proton ● Neutron

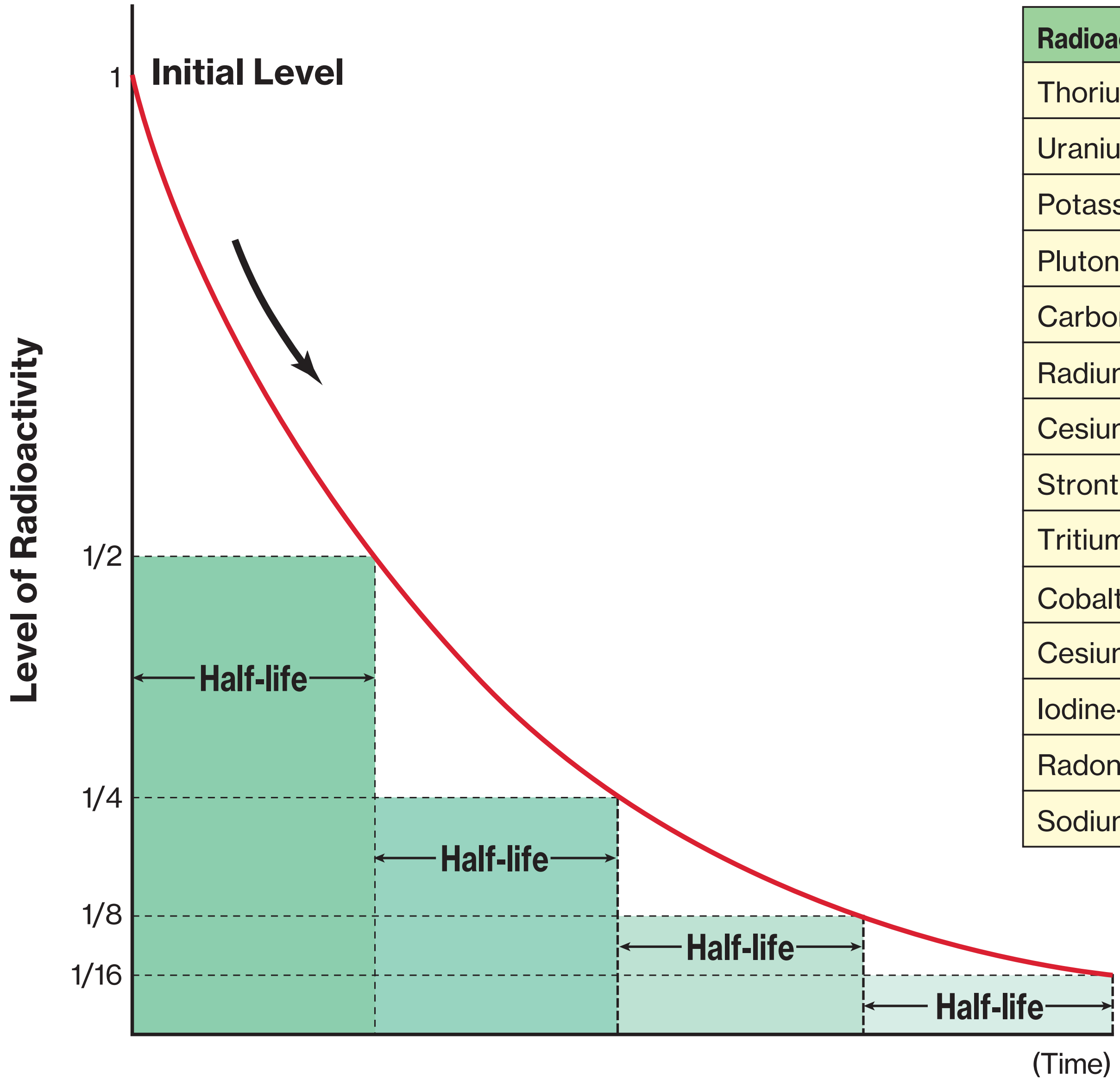
- **Radiation**
  - **Electromagnetic wave**
    - **X-rays…generated outside the nucleus**
    - **Gamma rays (γ)…come out of the nucleus**
  - **Charged particles**
    - **Beta rays (β)…electrons that escape the nucleus**
    - **Alpha rays (α)…Helium-$^{4}_{2}$ atom nuclei that escape the nucleus**
    - **Other**
  - **Uncharged particles**
    - **Neutrons…generated in the use of nuclear reactors, accelerators and radio isotopes (radionuclide)**

Permeability of Different Kinds of Radiation



Source: Ministry of the Environment, Unified Basic Data on Health Effects from Radiation (FY2017)

How Radiation Decays

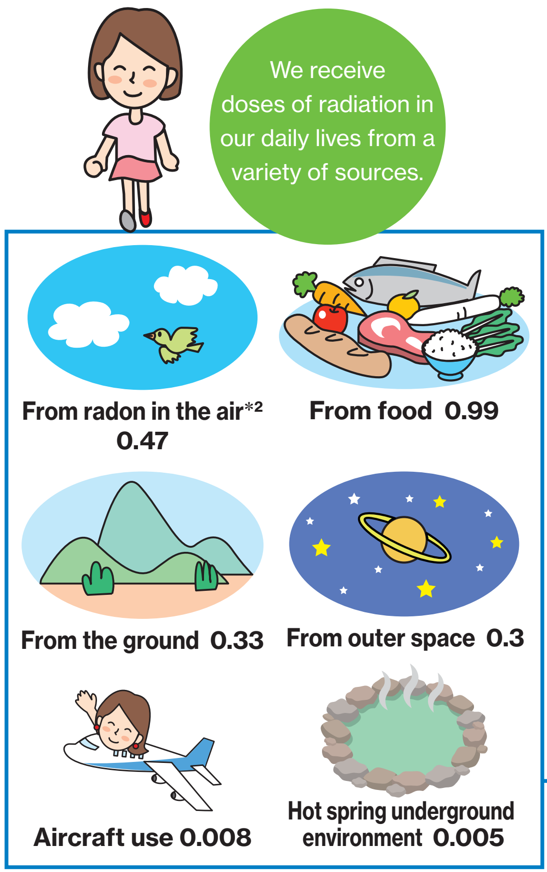


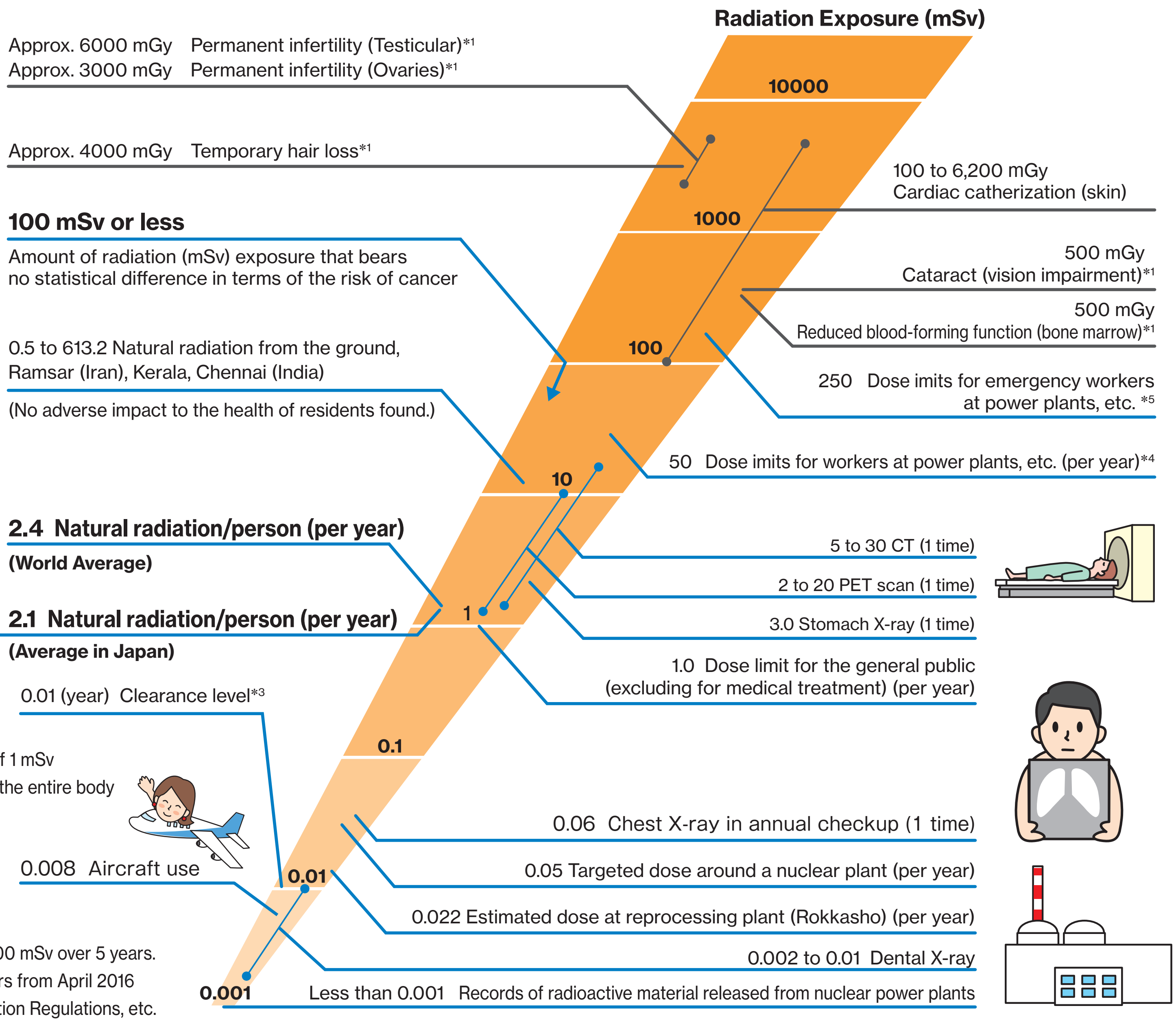
Radioactive Substance	Emitted Radiation*	Half-life
Thorium-232	$\alpha \cdot \beta \cdot \gamma$	14.1 billion years
Uranium-238	$\alpha \cdot \beta \cdot \gamma$	4.5 billion years
Potassium-40	$\beta \cdot \gamma$	1.3 billion years
Plutonium-239	$\alpha \cdot \gamma$	24,000 years
Carbon-14	β	5,700 years
Radium-226	$\alpha \cdot \gamma$	1,600 years
Cesium-137	$\beta \cdot \gamma$	30 years
Strontium-90	β	28.8 years
Tritium	β	12.3 years
Cobalt-60	$\beta \cdot \gamma$	5.3 years
Cesium-134	$\beta \cdot \gamma$	2.1 years
Iodine-131	$\beta \cdot \gamma$	8 days
Radon-222	$\alpha \cdot \gamma$	3.8 days
Sodium-24	$\beta \cdot \gamma$	15 hours

*Includes radiation from products of decay (Nuclides that emit radiation and become a different nuclide.)

Source: Japan Radioisotope Association, Radioisotope Pocket Data Book (2012)

Radiation in our Daily Lives





*1:When discussing radiation hazards, it is expressed as equivalent to an effective dose of 1 mSv, given that a dose of 1 mSv of gamma radiation is absorbed evenly by each part of the the entire body

*2:Radioactive substances naturally present in the air

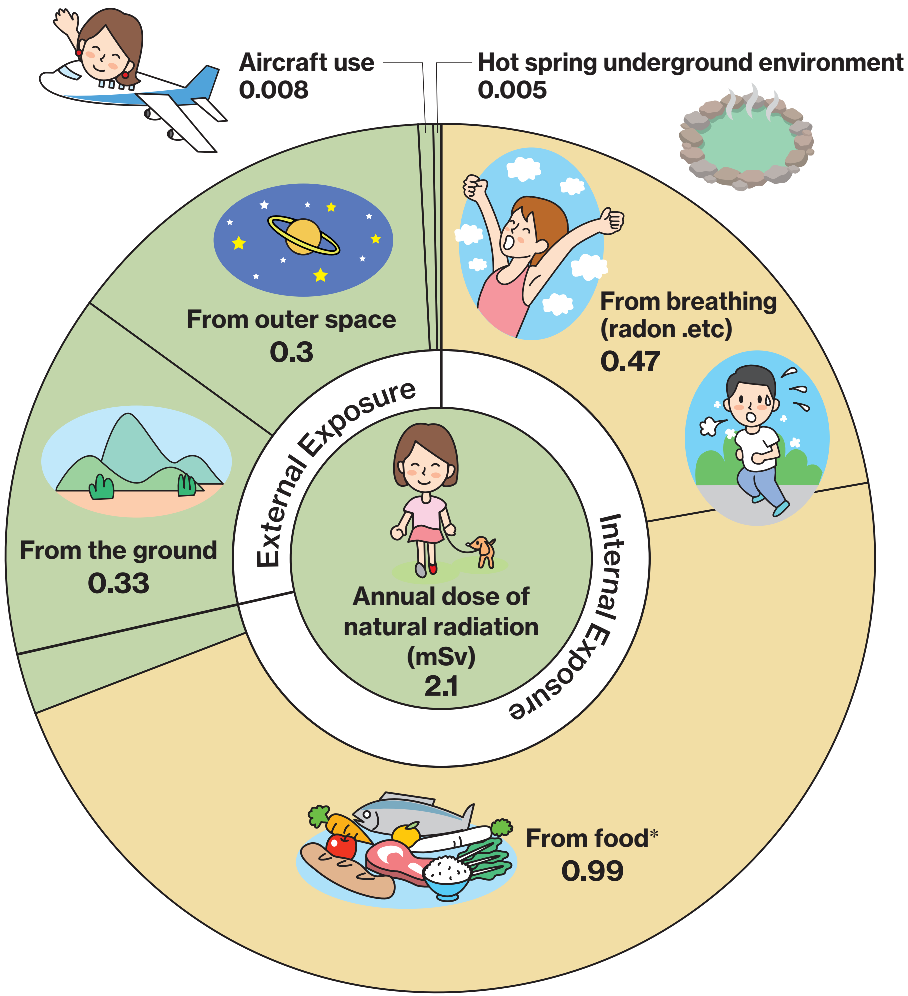
*3:Insignificant compared to naturally-occurring radiation levels, and the level does not require handling as a radioactive substance that presents a safety risk.

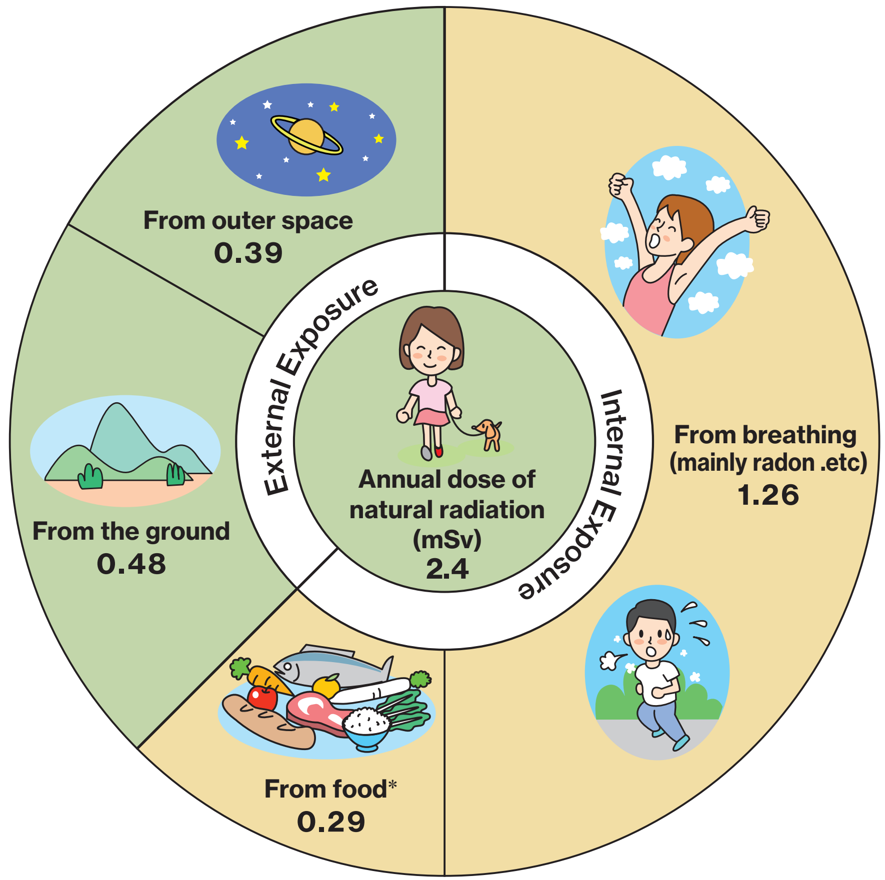
*4:Dose of radiation that must not be exceeded in 1 year is 50 mSV for workers at places such as power stations, or 100 mSv over 5 years.

*5:The dose limit was raised to 250 mSv to emergency workers from April 2016 due to the revision of the Ionizing Radiation Hazard Prevention Regulations, etc.

Sources: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2008 Report, Nuclear Safety Research Association, Radiation in the Environment, 3rd Edition, 2020, and ICRP, Publication 103, 2007, with others

Doses of Radiation from Natural Sources

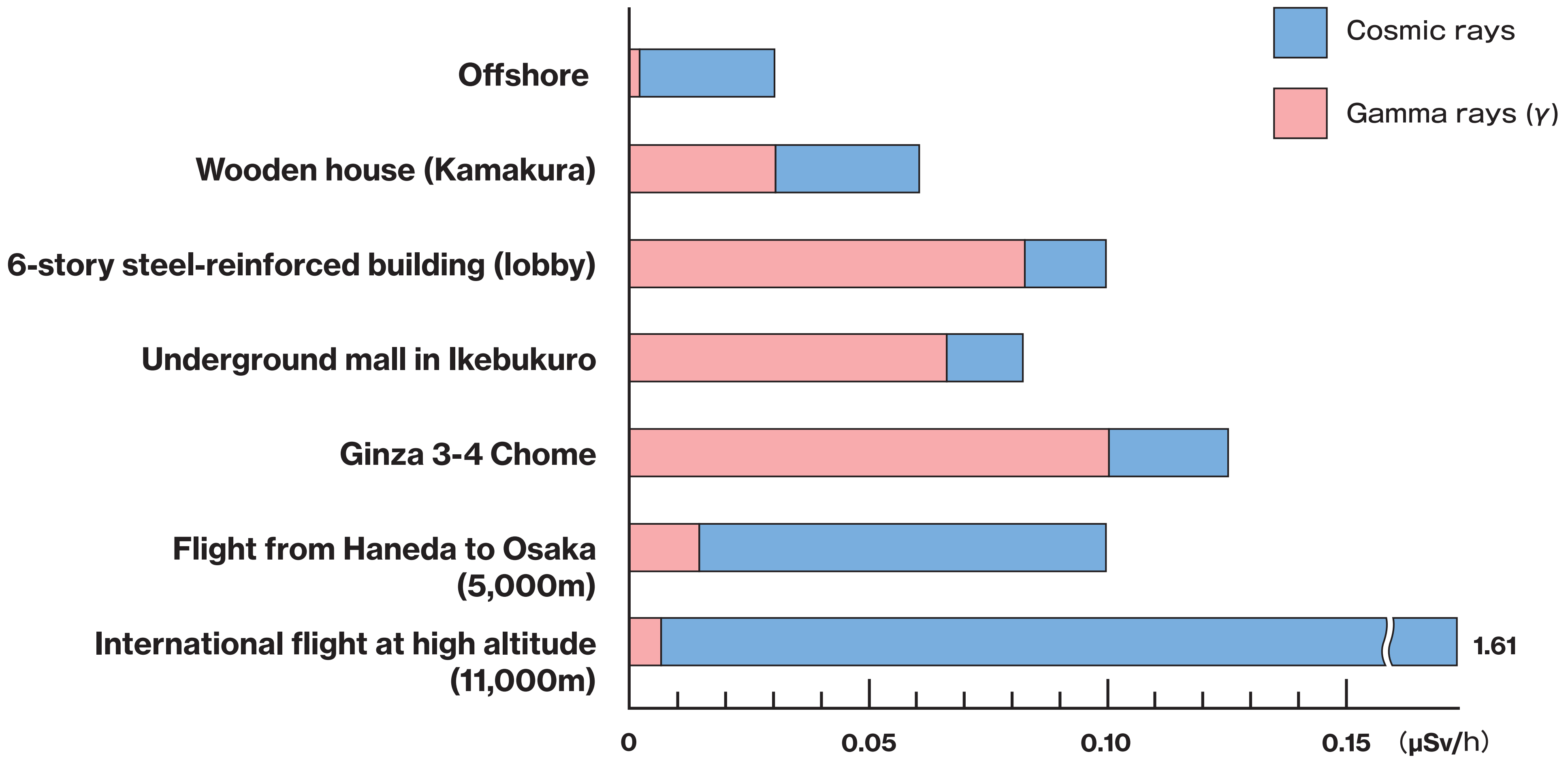




*Compared to Western countries, the Japanese diet of seafood results in a larger effective dose due to Polonium-210.

Sources: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2008 Report, and Nuclear Safety Research Association, Radiation in the Environment, 3rd edition, 2020

Differences in Natural Radiation Levels



*1μSv=1/1000 mSv
1μSv/h=365 days x 24hours x 1,000=8.75mSv/year

Source: High Energy Accelerator Research Organization Radiation Science Center, Trivia about Radiation--Radiation in our Daily Lives, (2005)

Naturally Occurring Radiation in the Body & Our Food

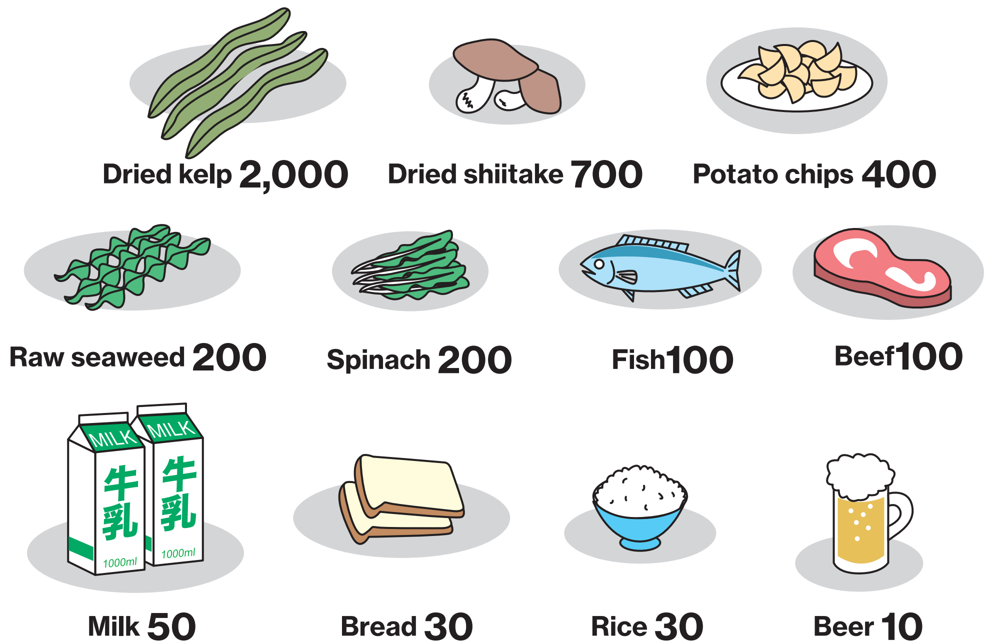
●Level of radioactive materials in the body

(based on a Japanese person weighing 60kg)

Potassium-40	4,000 Becquerel
Carbon-14	2,500 Becquerel
Rubidium-87	500 Becquerel
Lead-210/Polonium-210	20 Becquerel

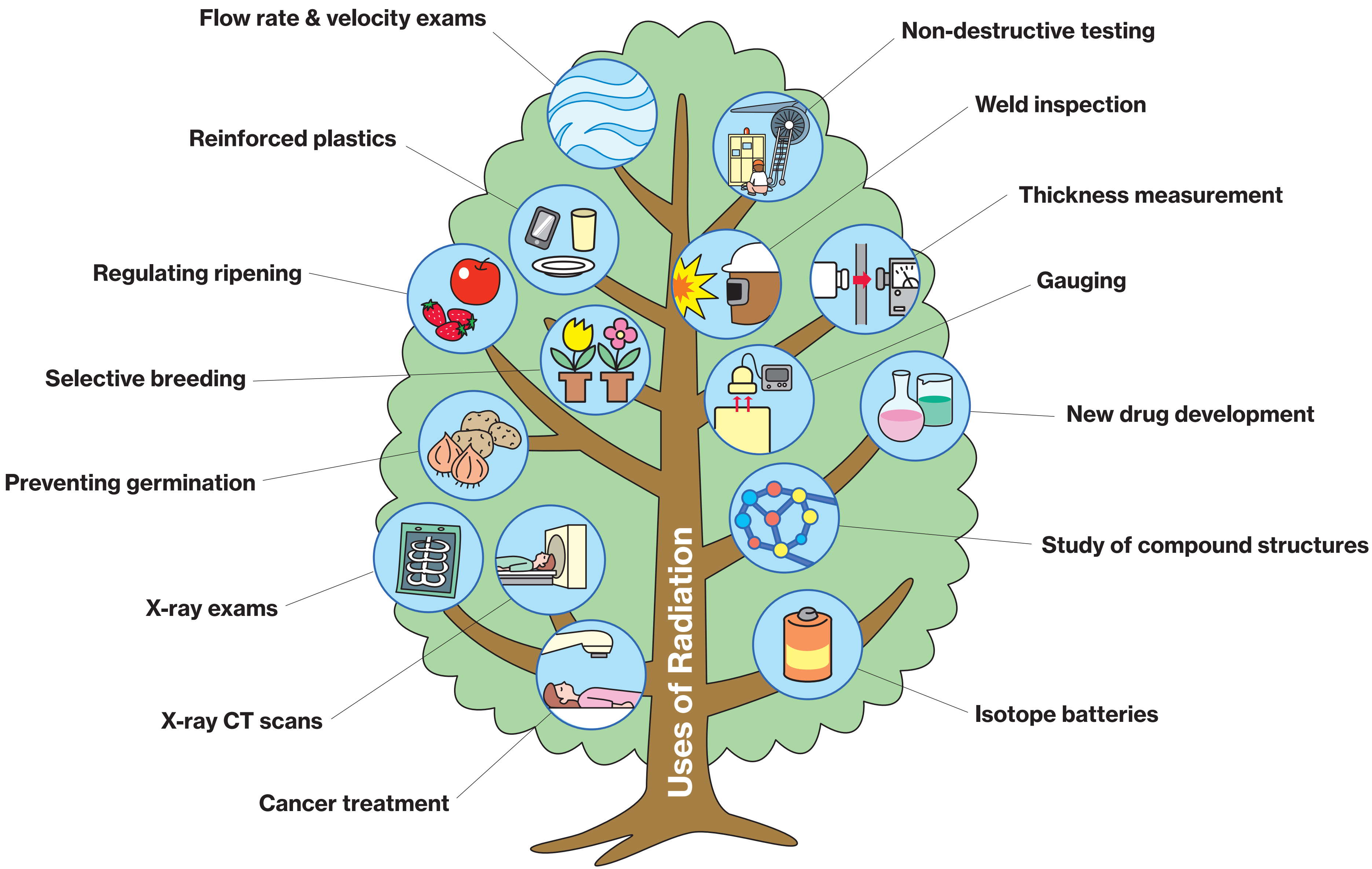
●Level of the radioactive material Potassium-40 in food (Japan)

(Unit: Becquerel/kg)

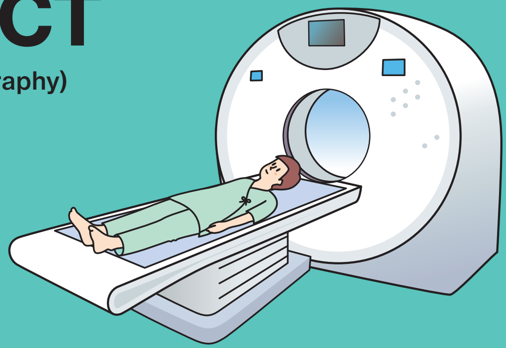
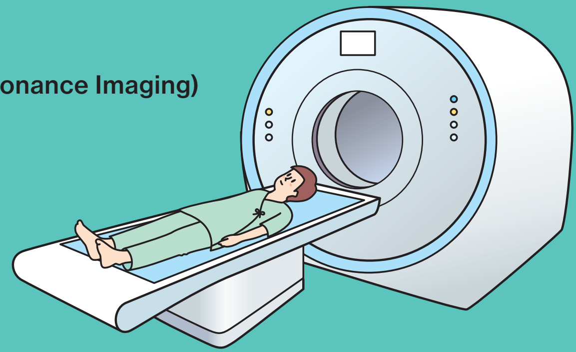


Source: Nuclear Safety Research Association, Study on Radiation Data in the Living Environment (1983), New Edition - Radiation in the Living Environment 2011

Various Uses of Radiation



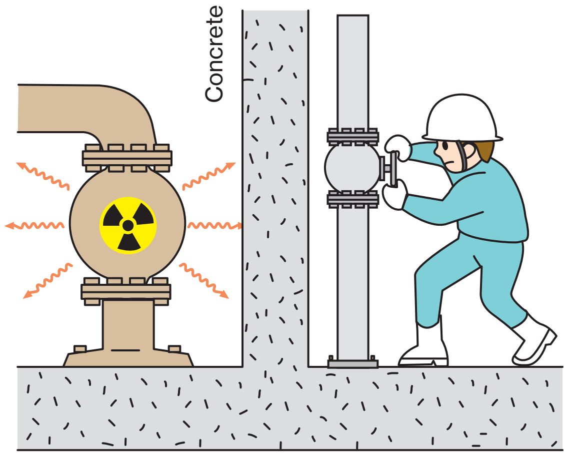
Medical Exams: Differences Between X-Ray CT and MRI

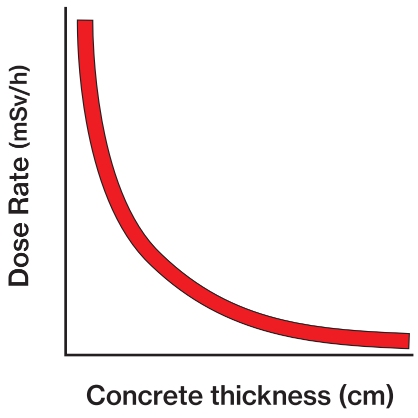
	X-Ray CT (Computed Tomography) 	**MRI** (Magnetic Resonance Imaging) 
Mechanism	Uses radiation (X-rays)	Uses magnetism and electromagnetic waves
Time required and effect of patient movement	Short examination time (1 body part: about 10 min.)	Long examination time (1 body part: about 20 to 60 min.), image becomes distorted easily if the patient moves
Noise	Quiet	Loud
Radiation exposure	Yes	No
Tissue contrast	Inferior to MRI for some body parts	Very clear contrast
Detailed rendering	Possible (better than MRI)	Possible
Body parts enclosed in bone	Highly distorted image	Low distortion of image
Imaging of bleeding condition	Possible	Possible (better than X-ray CT)
Imaging of condition of blood vessels	Not possible (but possible by using radiocontrast agent)	Possible
If metal is inside body	Imaging is possible (but may not be possible if there is a pacemaker or other device)	Imaging not possible (but may be possible if the metal inside body is non-reactive to magnets)

Basics of Protection from Radiation

1. Protection via shielding

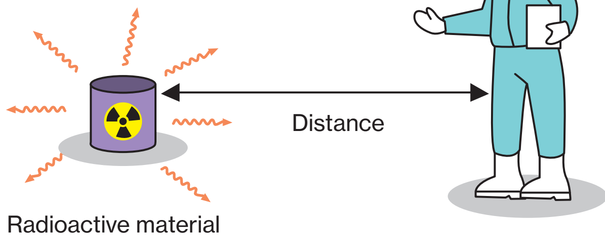
Dose Rate = drops as the shield becomes thicker

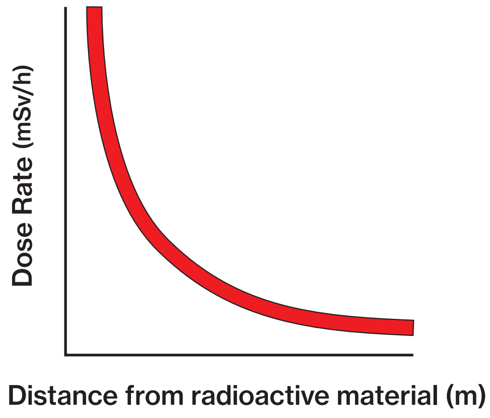




2. Protection via distance

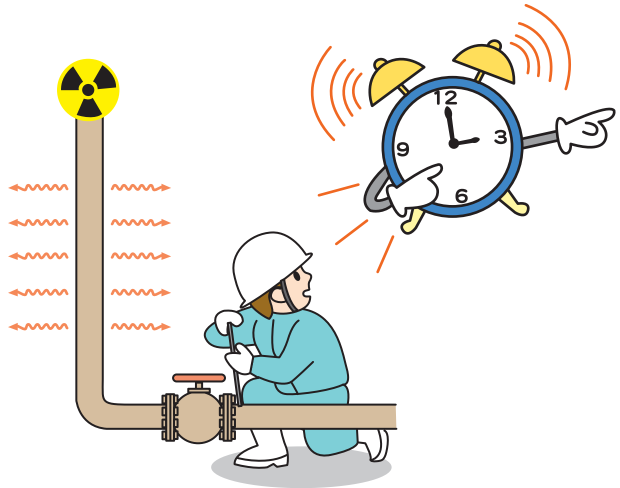
Dose Rate = inversely proportional to the distance



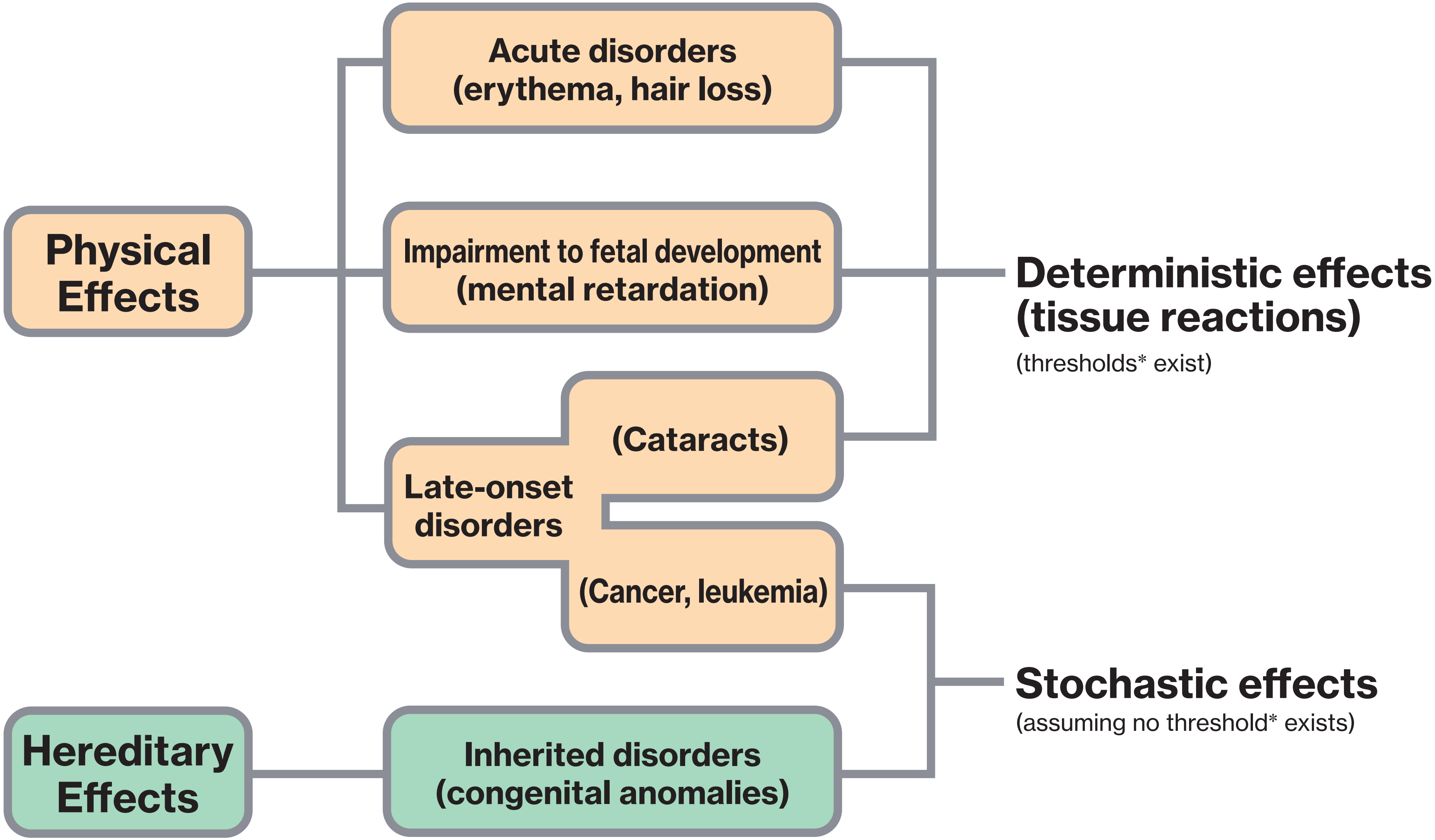


3. Protection via time

Dose = (dose rate in work zone) X (working hours)

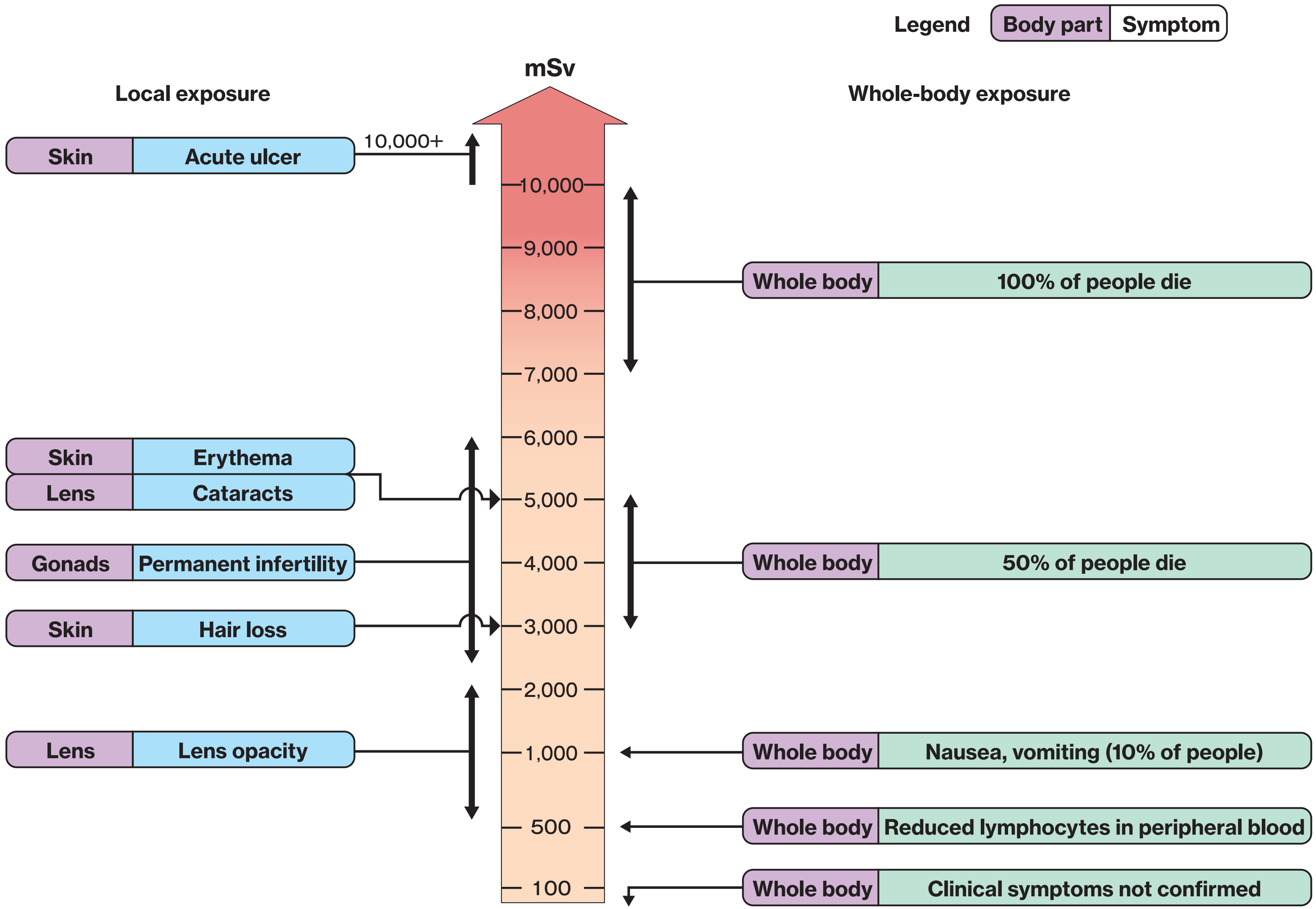


Effects of Radiation on Human Health



*Threshold: value that constitutes a turning point at which a reaction occurs or not.

Symptoms from a Single Exposure to Radiation

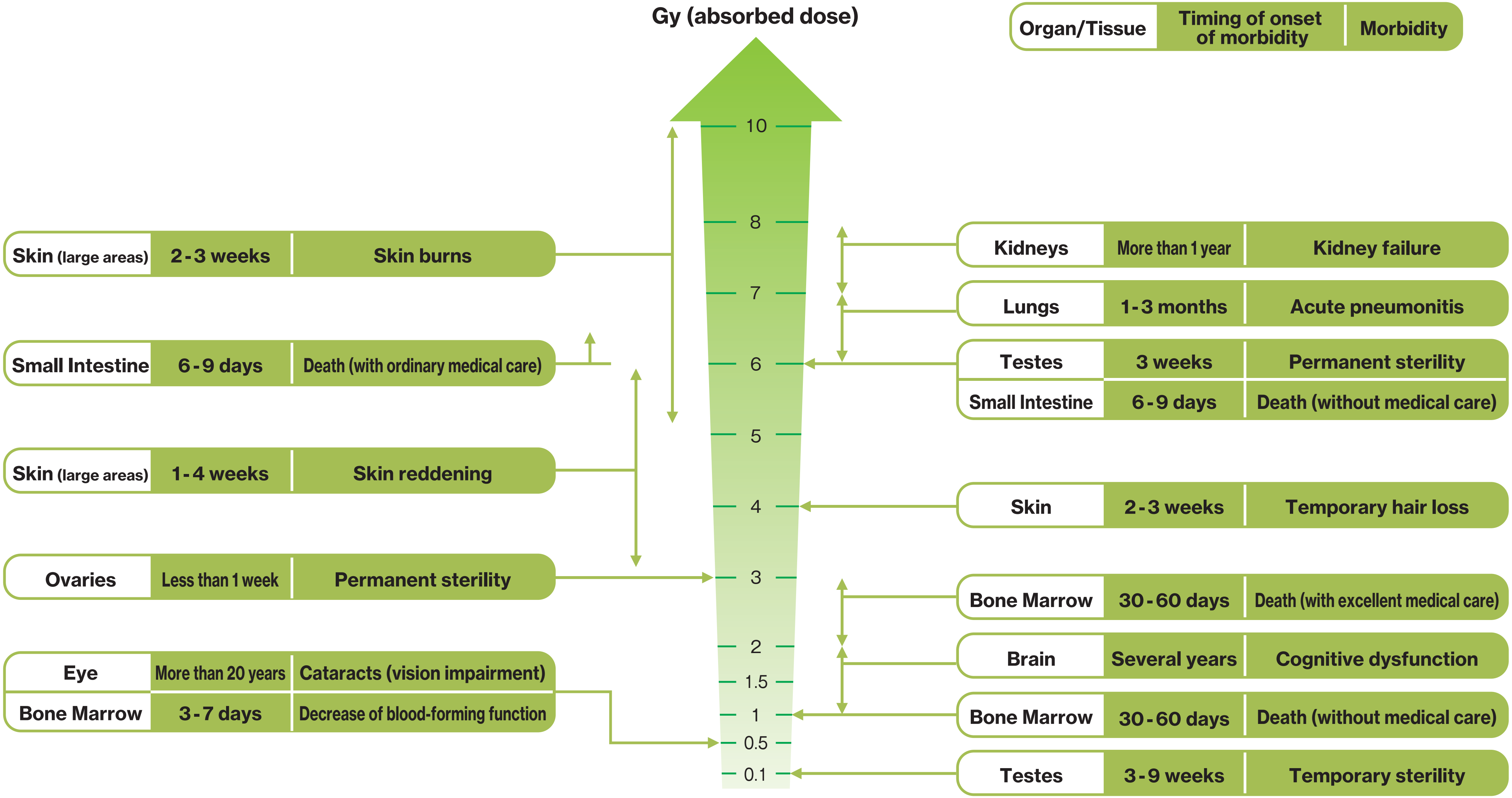


(Note 1) Deterministic effects (tissue reaction) are described, except for cancer and hereditary effects.
(Note 2) General public dose limit is 1.0mSV/year, dose limit around a nuclear plant is 0.05mSV/year.

Source: Radiation Effects Association, Understanding the Effects of Radiation

Acute Radiation Effects

Threshold for 1% incidence of major morbidity and death after acute exposure to gamma rays※

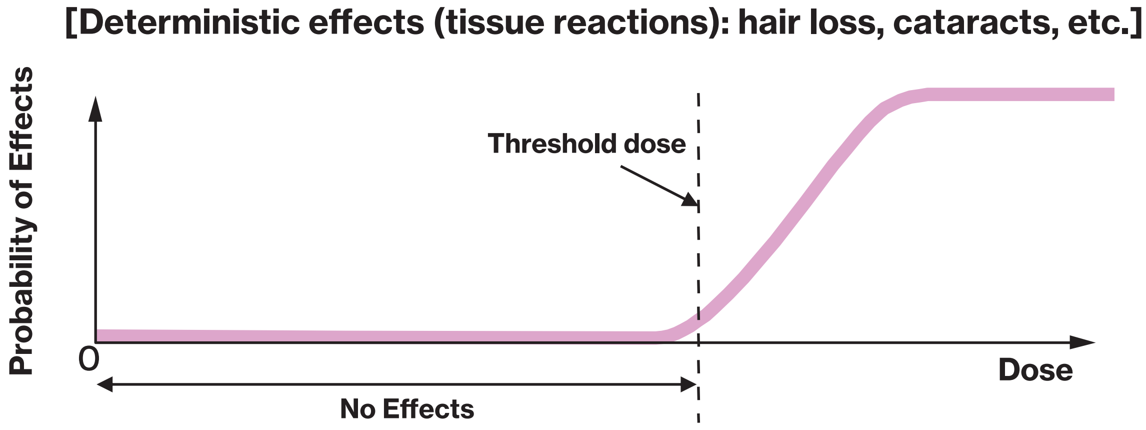


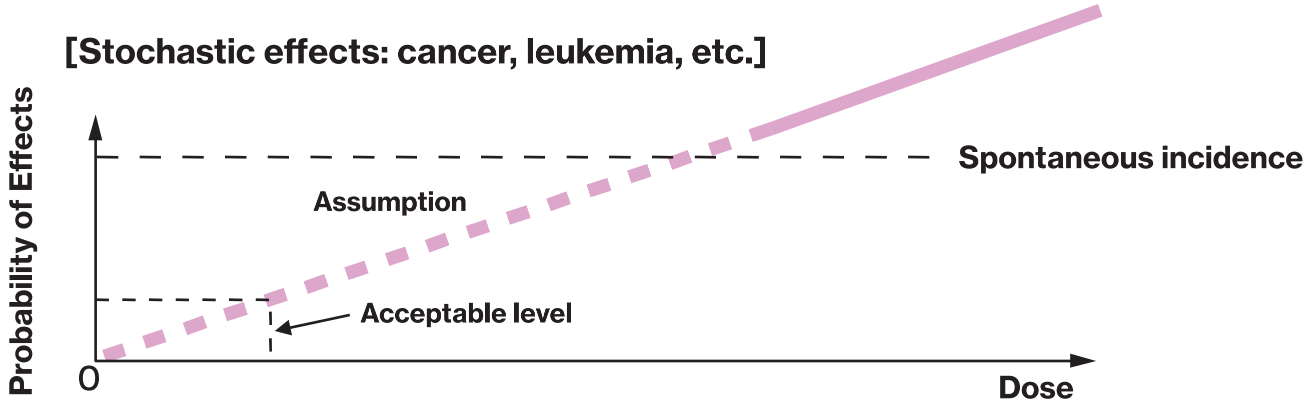
※Threshold : The maximum level of radiation considered to be acceptable or safe

Source: ICRP, Publication 103,118

Principles of Protection from Radiation

Below the threshold dose* for deterministic effects, the effect of radiation is suppressed and/or eliminated.
For stochastic effects, the assumption is that there is no threshold dose below which radiation can be suppressed and be relatively certain that an adverse effect cannot occur.





*Threshold dose: value that constitutes a turning point at which a reaction occurs or not.

Source: Radiation Effects Association, Understanding the Effects of Radiation

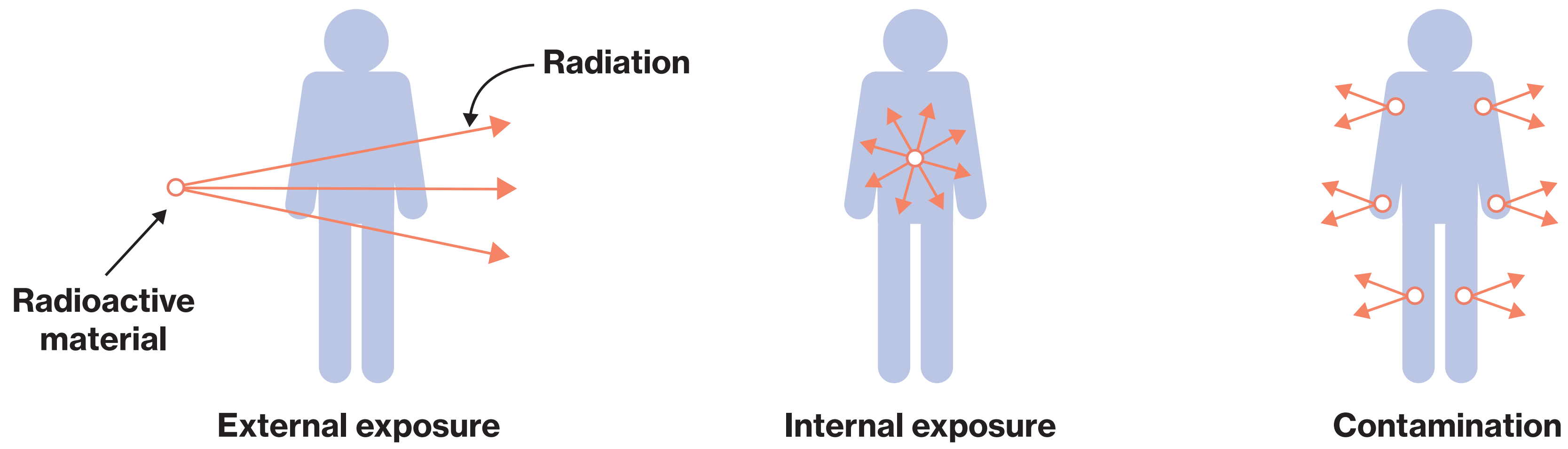
The Difference between Exposure and Contamination

Exposure

Being exposed to radiation

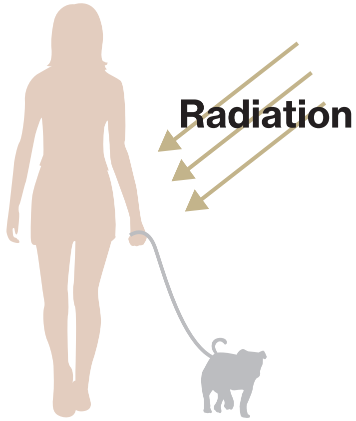
Contamination

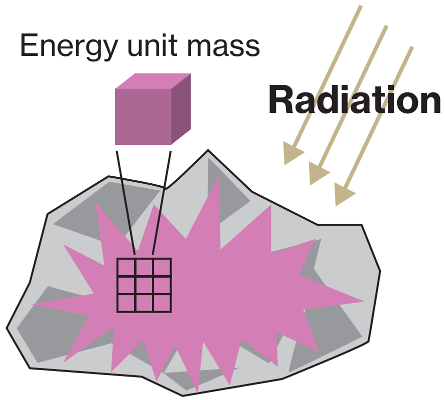
Radioactive materials have adhered to matter, such as skin or clothes.



The Relationship between Gray & Sievert Units

Sievert value = **Gray value** × **Radiation weighting factor** *1 × **Tissue weighting factor** *2





Sievert (Sv)

This unit is used for assessing how much risk radiation poses to people in terms of inducing cancer or genetic damage.
(1 Sievert = 1,000 mSv)

Gray (Gy)

This unit represents how much energy was received by an object or person hit by radiation.
A dose of 1 gray corresponds to 1 joule of energy absorbed by 1 kilogram of matter.

◆Radiation weighting factor

Types of Radiation	Radiation weighting factor
Photon (gamma or x-rays)	1
Electrons (beta rays)	1
Proton	2
Alpha particles, fission fragments, heavy nuclei	20
Neutron radiation	2.5-20 (Determined by the continuous function of energy)

*1: Represents the difference in effect according to the type of radiation.
*2: Represents how susceptible different tissues, such as internal organs, are to radiation.

◆Tissue weighting factor

Tissue/Organ	Tissue weighting factor	Tissue/Organ	Tissue weighting factor
Breast	0.12	Esophagus	0.04
Red bone marrow	0.12	Thyroid	0.04
Colon	0.12	Salivary gland	0.01
Lung	0.12	Skin	0.01
Stomach	0.12	Bone surface	0.01
Gonads	0.08	Brain	0.01
Bladder	0.04	Remaining tissues /organs	0.12
Liver	0.04		

Source: ICRP, Publication 103 (2007)

Conversion Method for Internal Exposure to Radiation (Committed Dose)

Committed Dose (mSv) = **Food Intake (kg/day)** × **Intake Days (days)** × **Effective Dose Coefficient (mSV/Bq)** × **Concentration of Radionuclides (Bq/kg)**

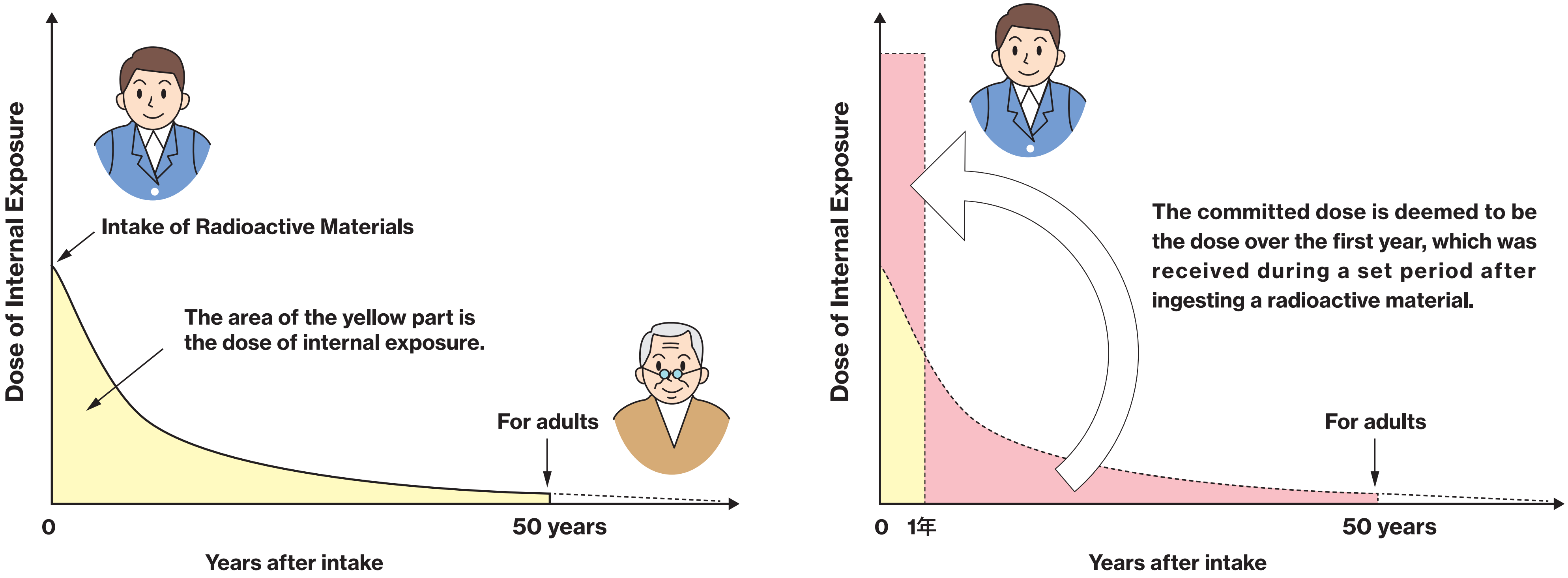
Radionuclide	Half-life	Effective dose coefficient when 1Bq is taken orally or inhaled by an adult (mSv/Bq)	
		Taken orally	Inhaled
Plutonium-239	24,000 years	2.5×10^{-4}	1.2×10^{-1}
Cesium-137	30 years	1.3×10^{-5}	3.9×10^{-5}
Iodine-131	8 days	2.2×10^{-5}	7.4×10^{-6}
Strontium-90	29.1 years	2.8×10^{-5}	1.6×10^{-4}
Tritium*	12.3 years	4.2×10^{-8}	2.6×10^{-7}

* The effective dose coefficient of tritium shows OBT (organically bound tritium), which is important for dosimetric evaluation, because it is easily absorbed by living bodies and has a long biological half-life.

(Note) 1 is used for the market dilution factor (percentage of contaminated food intake relative to food intake of the evaluated subject) or for correction downwards, such as due to cooking. When more than one value is indicated for the nuclide of a chemical form, the largest effective dose coefficient is shown.

Source:ICRP “Publication 72”, Ministry of Economy, Trade and Industry “Tritiated Water Task Force Report (June 2016)”

Evaluation of Internal Exposure to Radiation (Conceptual Diagram of Committed Dose)



(Note) Adults : 50 years; children: from ingestion until 70 years old

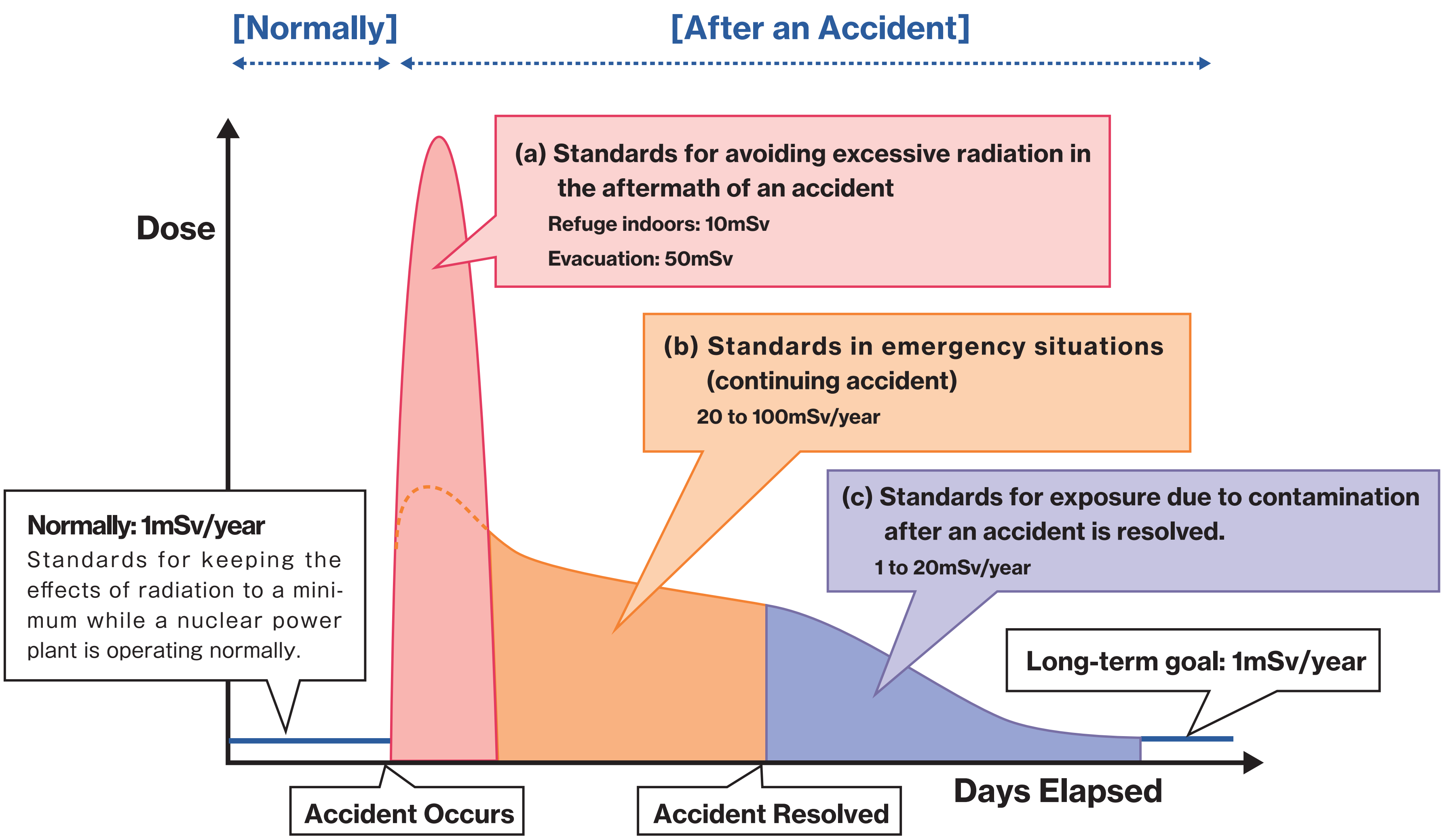
An International Comparison of Food Reference Values

(Unit: Becquerel/kg)

Nuclide	Food group \ Country	Japan	U.S.A.	EU
Radioactive cesium	Baby food	50	1,200	400
	Milk	50		1,000
	Drinking water	10		1,000
	Foods in general	100		1,250
Principles of Food Reference Values		Established dose of radiation will be less than 1 mSv per year. Values are calculated under the assumption contamination for foods in general will be 50%; for drinking water and milk as well as baby foods, it will be 100%.	Established dose of radiation will be less than 5 mSv per year. Values are calculated under the assumption contamination for foods in general will be 30%.	Established dose of radiation will be less than 1 mSv per year. Values are calculated under the assumption contamination for foods in general will be 10%.

Source: Ministry of Health, Labour and Welfare, New Reference Values for Radioactive Substances in Food

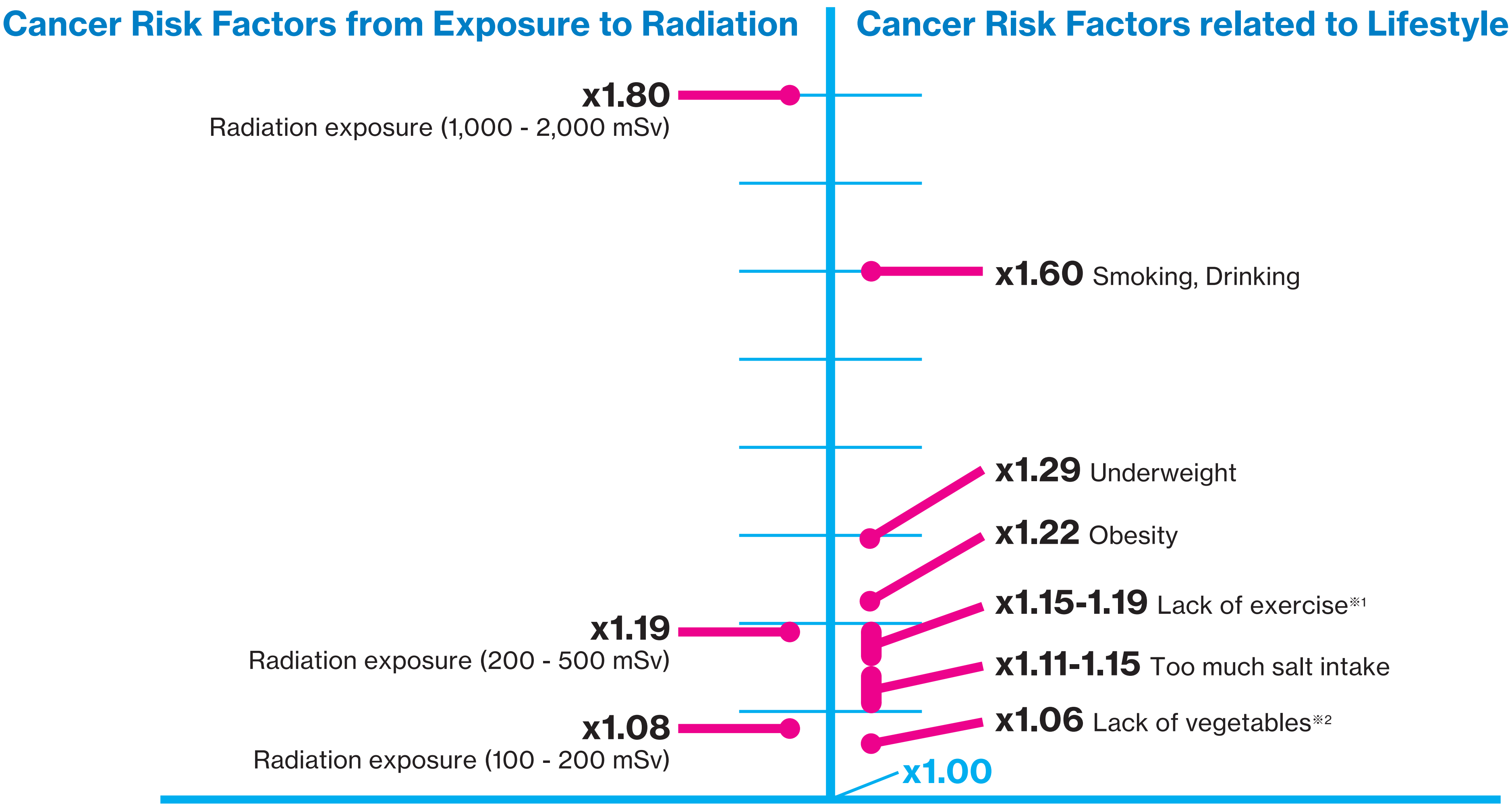
Standard Principles for Protection from Radiation



Source: Nuclear Safety Commission materials

Relative Cancer Risk Estimation for Radiation Exposure and Lifestyle Factors

(Targeted for Japanese between the ages of 40 and 69)



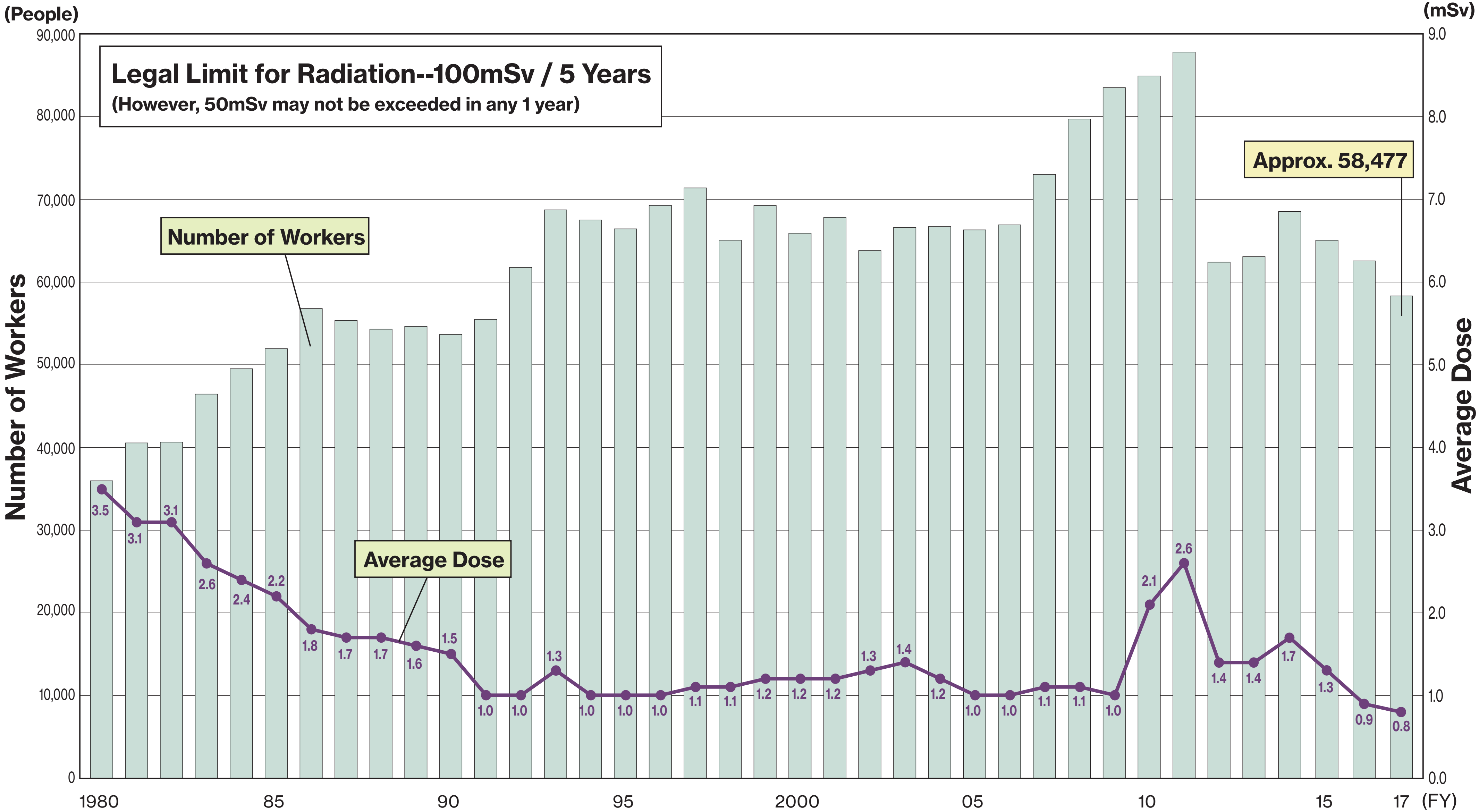
(Note) Risk estimates for radiation exposure are based on the analysis of instantaneous dose effects in the case of A-bomb at Hiroshima and Nagasaki (solid cancer incidence only) and not based on the observations on prolonged dose effects.

※1 Lack of exercise: a very small amount of physical activity

※2 Lack of vegetables: vegetable intake is very low

Source: National Cancer Center

Radiation Dosages Received by Radiation Workers



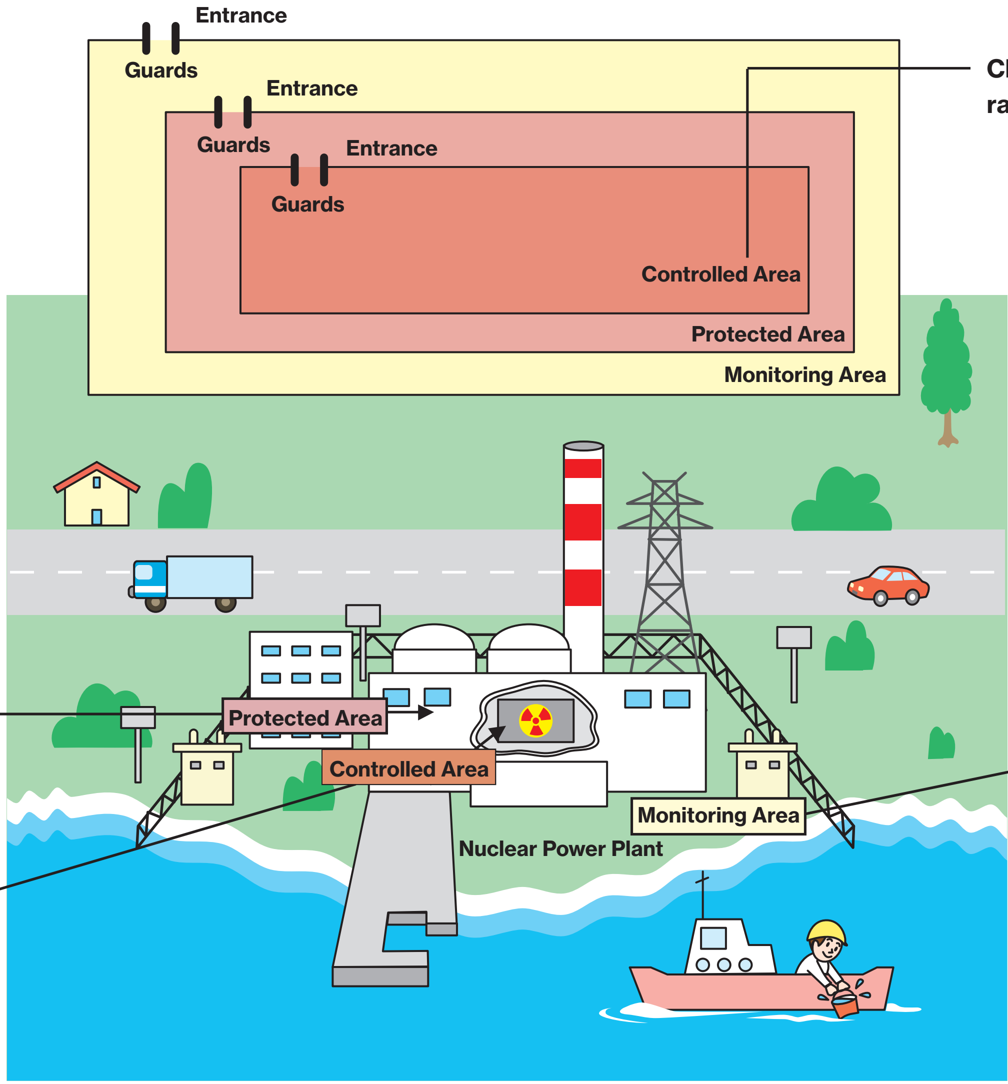
＊ People who work with radiation at commercial nuclear power reactor facilities.

Source: Nuclear Regulation Authority, 2017--Status of Managing Dosages of Radiation Workers at Commercial Power Reactor Facilities, Research and Development Stage Power Reactor Facilities, Processing Facilities, Reprocessing Facilities, and Nuclear Waste Disposal Facilities, October 2018, with others

Controls in a Nuclear Power Plant by Area

Control is especially needed to preserve a nuclear power plant (except a controlled area).

Entry is restricted to prevent amage by radiation and radioactive materials.



Classified in detail according to the extent of radiation or contamination

Within the area, unnecessary entry of the general public is restricted to prevent them from being exposed to more doses emitted from nuclear facilities than regulated by laws.

Radiation Exposure Control for Radiation Workers

Radiation Control Flow

Radiation workers

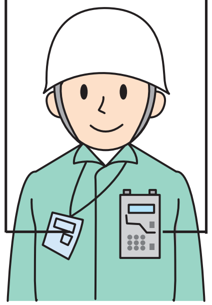
Medical examination / Education / Exposure records check

↓

Controlled-area entry permit

↓

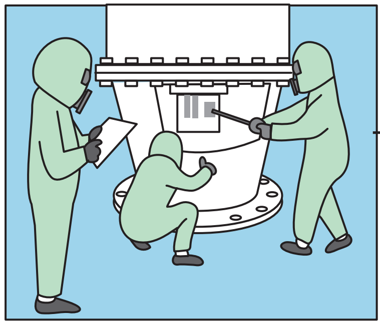
Carrying a portable individual dosimeter



Left : Glass badge
Right : Alarm-equipped dosimeter

↓

To wear protective clothing (wearing a protective mask, if necessary)



Employees with protective clothing working

Section responsible for an assignment

Making a work plan ← Experts in radiation control

Setting dose equivalent target

Measures to reduce radiation exposure (ex. Installation of shields)

Experts in radiation control

To instruct radiation protection

↓

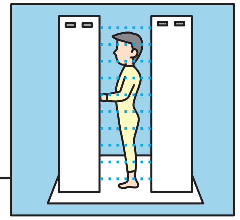
Work within a controlled area

↓

Completion of work

↓

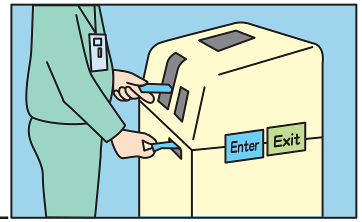
Surface contamination test



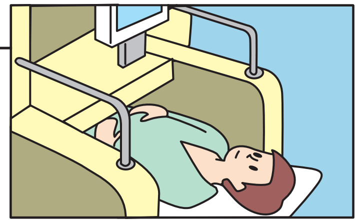
Surface contamination test to check workers' body

↓

Measure and evaluate individual effective dose



Individual effective dose is measured by the entrance and exit control equipment.



Radioactive materials in the body are periodically checked by a whole body counter.

↓

Recording measurement results and notifying individuals about them

↓

Registering the data to the Radiation Dose Registration Center for Radiation Workers

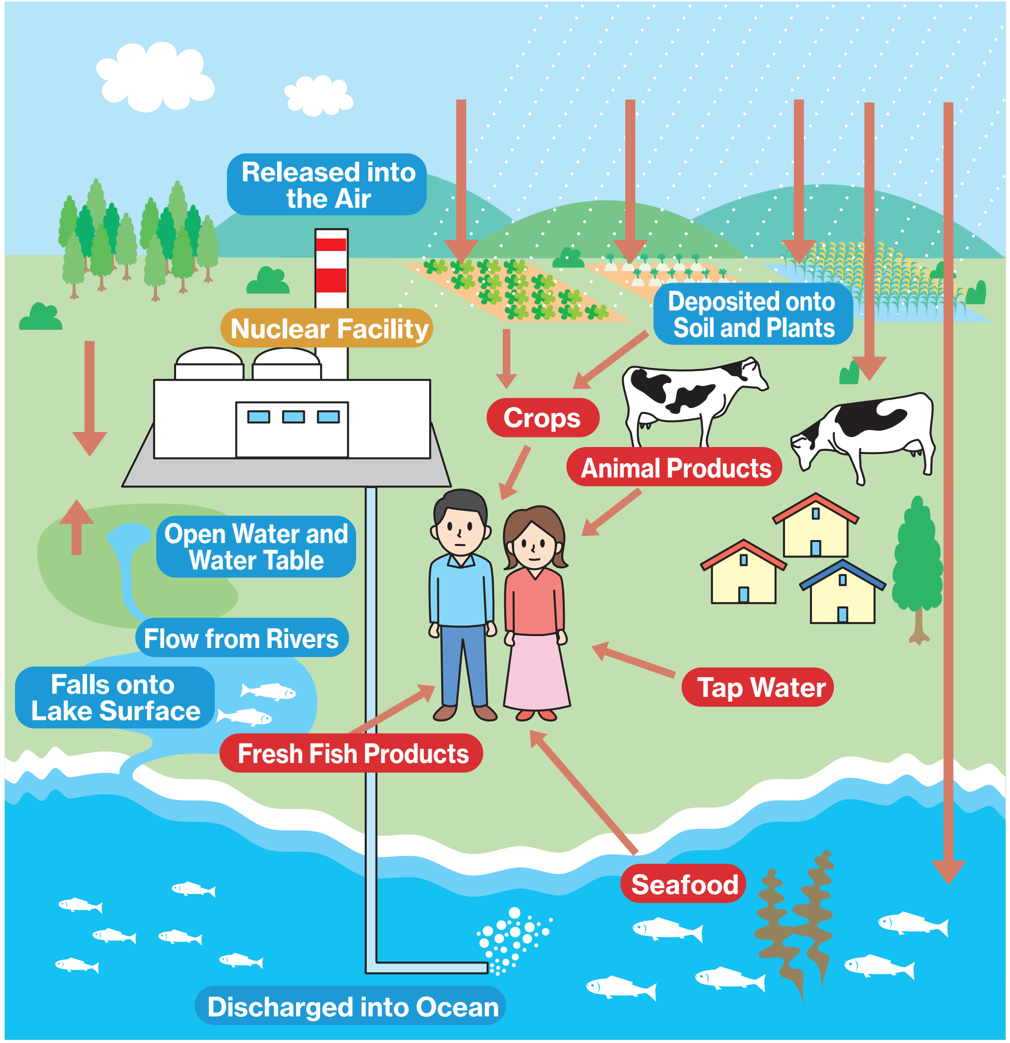
Radiation Dosage Limits

Category		Effective Dose Limit (Whole Body)	Equivalent Dose Limits (Tissues and Organs)
Radiation Workers	Normally	100mSv/5 years*1 50mSv/year*2 Females 5mSv/3 months*3 Pregnant women 1mSv (Internal exposure until birth)	Lens of eyes 100mSv/5 years*1, and 50mSv/year*2 Skin 500mSv/year*2 Pregnant women 2mSv (Abdominal surface until birth)
	Emergency*4	① 100mSv ② 250mSv	Lens of eyes 300mSv/year Skin 1Sv*5
General Public	Normally	1mSv/year*2	Lens of eyes 15mSv/year*2 Skin 50mSv/year*2

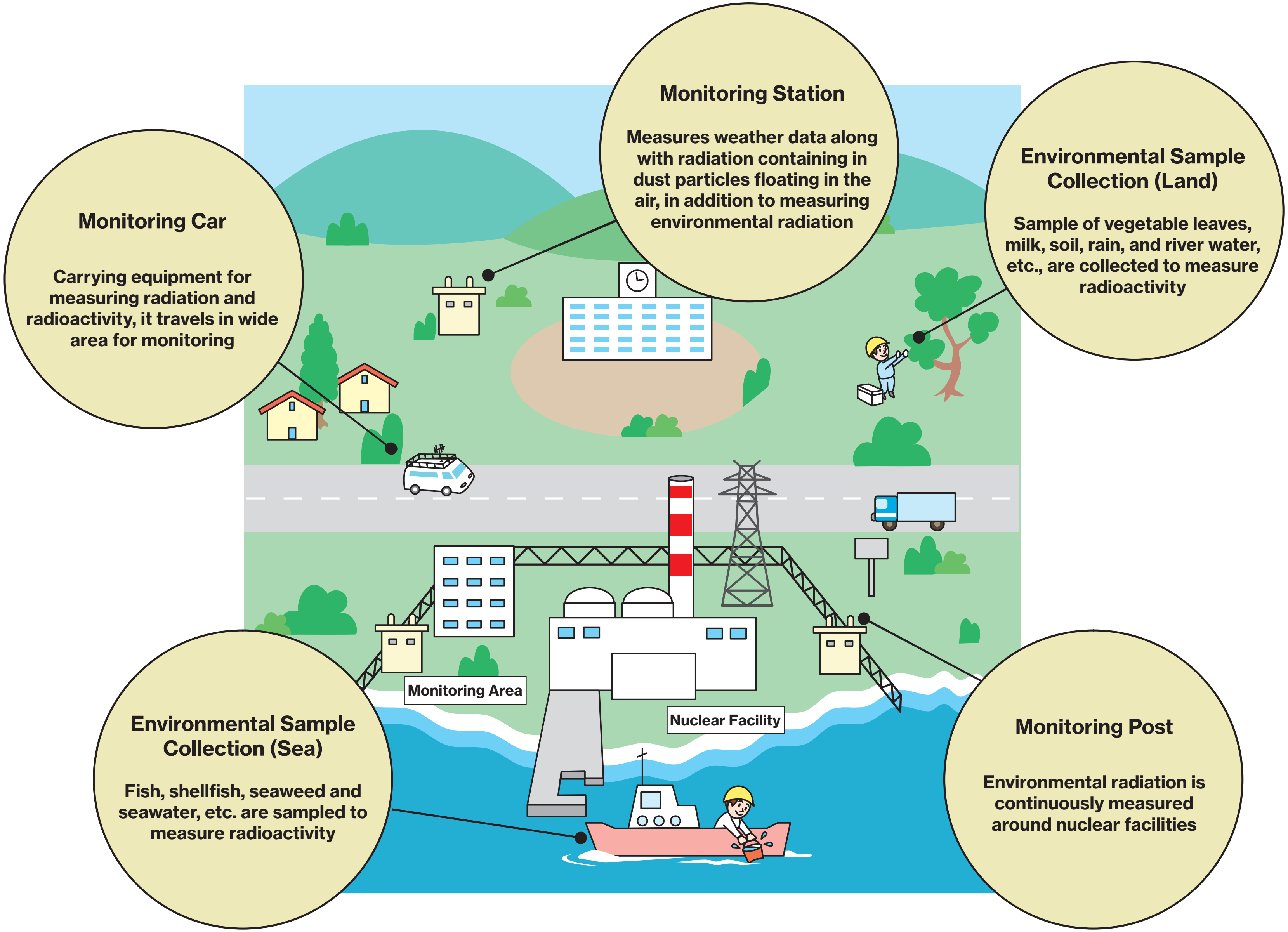
(Note) The values in the table above are total doses of external and internal exposure. (They do not include naturally occurring radiation or exposure during medical procedures.)
*1: Classification every 5 years after April 1, 2001
*2: One year starting April 1
*3: Every 3 months, starting on the 1st of April, July, October and January
*4: • Engaging in emergency work on equipment and facilities, etc. targeted by the Act on Special Measures Concerning Nuclear Emergency Preparedness is restricted to workers in occupations that involve radiation exposure who have received information pertaining to radiation exposure in advance and have expressed their intention to take part, and who have received the necessary training.
• Regulated limits on radiation exposure are governed in the two stages of ① the conventional effective dose of 100 mSv, and the addition of ② an effective dose of 250 mSv in the event of there being a high probability of radioactive materials being discharged outside of the site.
*5: 1Sv (Sievert) =1,000mSV (milli-Sieverts) = 1 million Sv (micro-Sieverts)

Source: Created from the notification to establish dose limits in accordance with the provisions of the ordinance on activity of refining nuclear source or nuclear fuel materials, etc.

Migration of Radioactive Materials in the Environment



Environmental Radiation Monitoring Around Nuclear Facilities



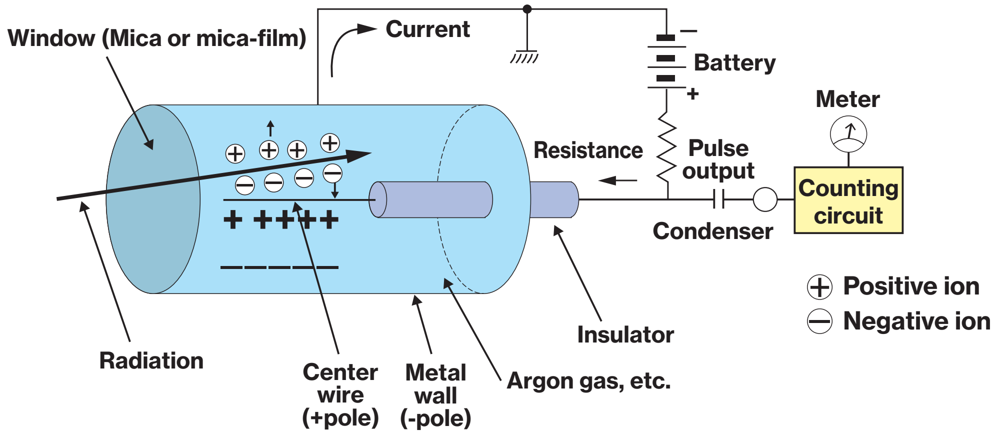
Monitoring of Radiation in the Environment (Example)

- ○ Monitoring post and TLD post
- □ TLD* post
- ★ Meteorological stations
- △ Seawater radiation monitoring
- ■ Monitoring stations

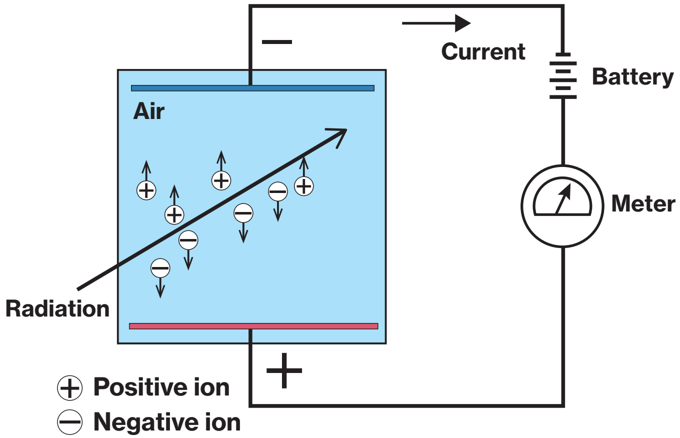
***TLD：Thermoluminescence dosimeter**
Some substances emit light if they are heated after being subject to radiation.
A TLD dosimeter uses this to measure radiation.

Operating Principles of Radiation Measuring Instruments

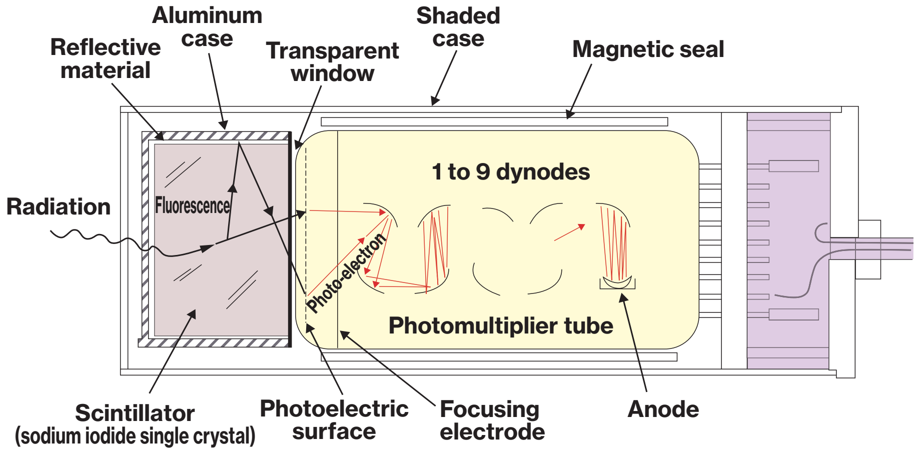
Geiger Counter



Ionization chamber



Scintillation Detector



(Note) It is necessary to measure microcurrents in the range of 10^{-9}~10^{-14} with the ionization chamber.

When fluorescence strikes the photoelectric surface of the scintillation detector, electrons are kicked out and this is multiplied by the dynodes (multiplier electrodes), which allows a greater electrical signal to be obtained.

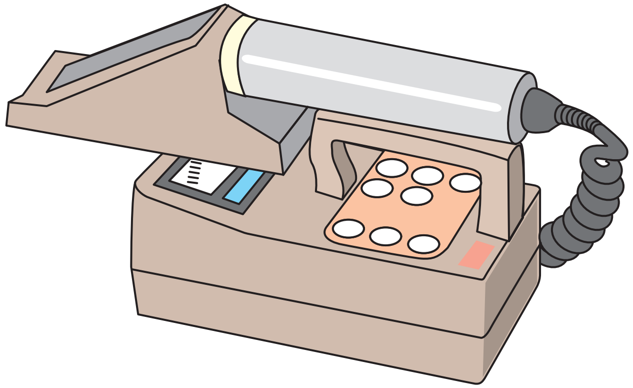
Source: Japan Atomic Energy Agency, Nuclear Power Basic Glossary, (1997)

Classifications of Radiation Measurements

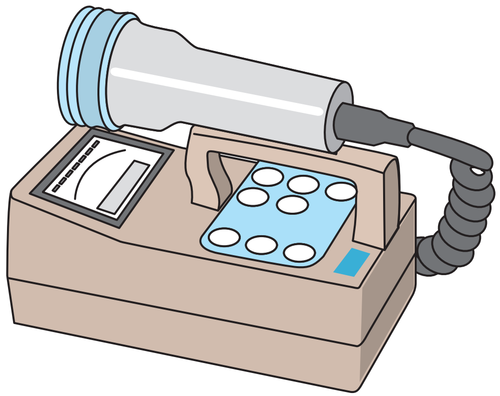
Category	Radiation	Measurement method	Purpose
Surface Contamination	Alpha rays	Gas-flow proportional counter tube type ZnS scintillation type, etc.	Measurement of alpha rays
	Beta rays (gamma)	Plastic scintillation type Geiger counter type, etc.	For testing contamination of bodies, the ground, etc.
Ambient Radiation Level	Gamma rays	NaI/CsI scintillation type	Mainly measures low-level radiation
		Geiger counter type	Measures low to mid-level radiation
		Ionization chamber type	Measures low to high-level radiation
		Ge/Si semiconductor detector	Spectral analysis and nuclide identification
	Neutron radiation, etc.	^{3}HE proportional counter tube type	Neutron radiation
	Beta rays	Ionization chamber type	Measures low to high-level radiation
Individual Level of Exposure	External exposure	Si semiconductor detector Glass dosimeter Individual track detector, etc.	Measures the cumulative dose attached to the surface of the body
	Internal exposure	NaI scintillation type Ge/Si semiconductor detector, etc.	Measures the outside of the body via a whole body counter or biological sample measurement (bioassay)

Measuring Surface Contamination

Radiation Screening



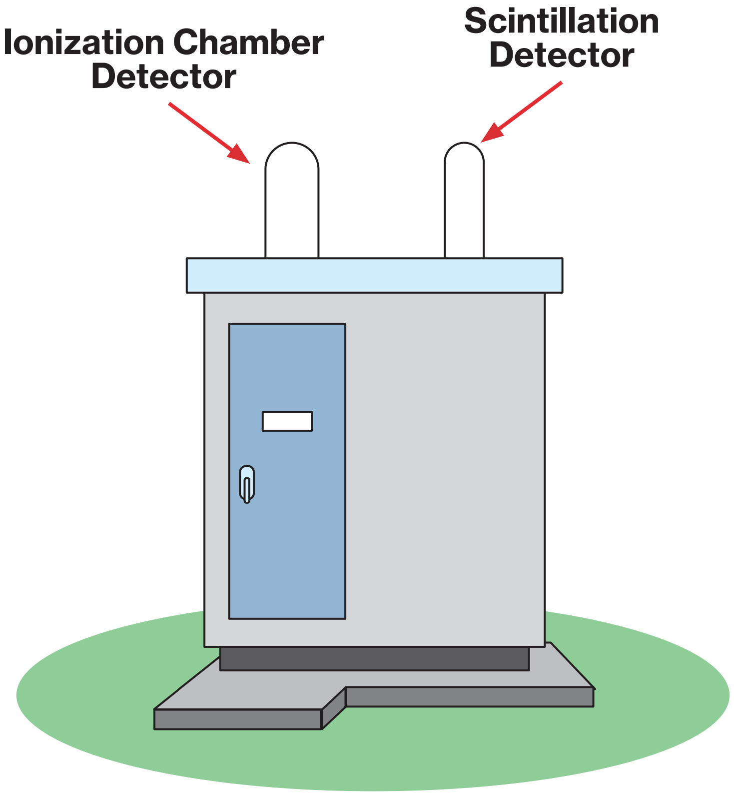
ZnS scintillation type, etc.
(measures alpha rays)



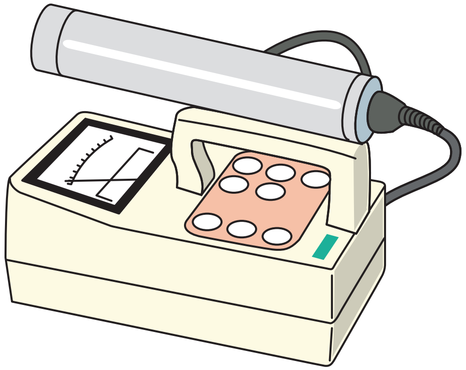
Geiger counter type
(measures beta rays)

Measuring Ambient Radiation Levels

Monitoring Post

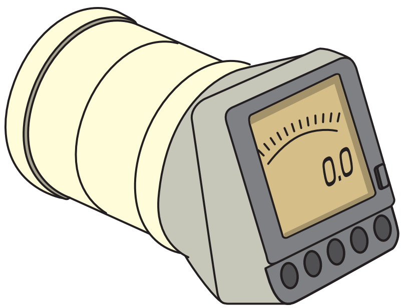


Survey Meters

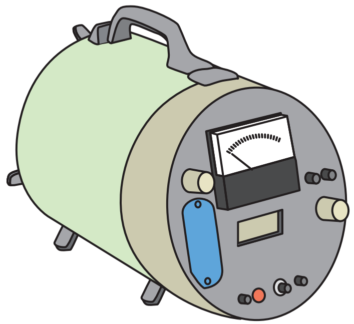


NaI Scintillation type
(mainly measures low-levels)

CsI Scintillation type, etc.
(mainly measures low-levels)



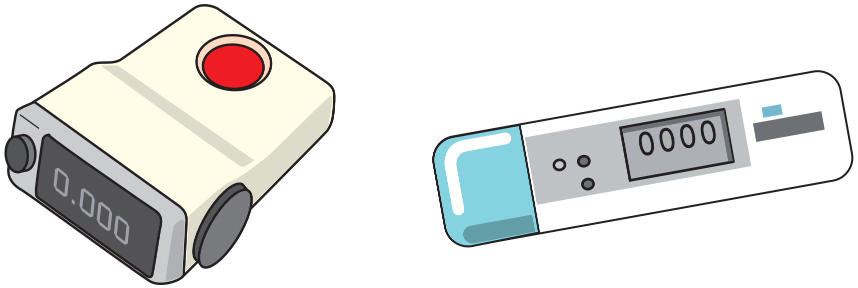
Ionization Chamber
(measures low to high-level radiation)



^{3}He Counter Tube type
(measures neutron radiation)

Measuring Individual Levels of Exposure Level of Exposure

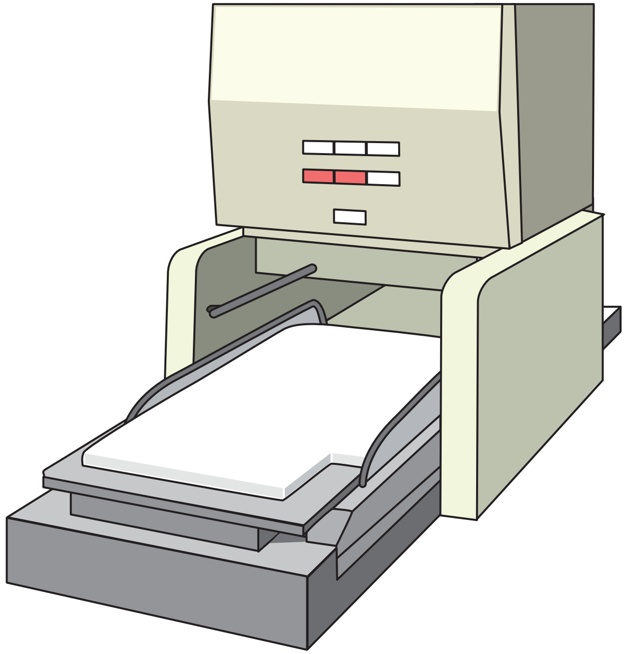
Measuring External Exposure



Electronic Dosimeter (personal dosimeter)

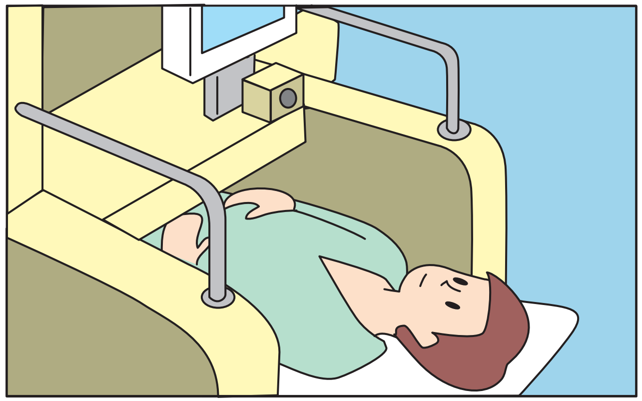
[Example of Use]

Measuring Internal Exposure



Whole Body Counter

[Example of Use]

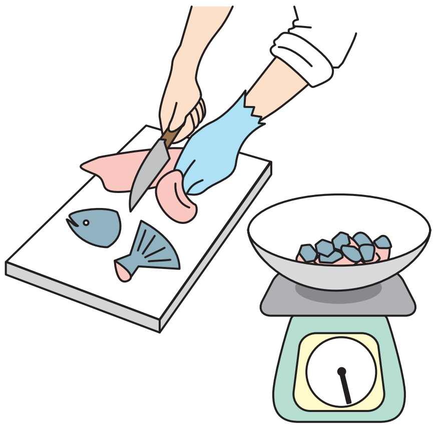


Measuring Radioactivity Contained in Food

Workflow using a germanium semiconductor detector

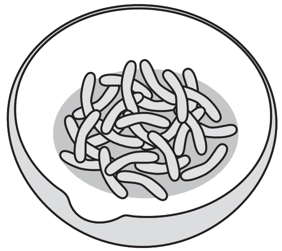
①Sample dissection
↓
②Dry at high temp
↓
③Carbonize/turn to ash at super high temp
↓
④Pressure form
↓
⑤Measure gamma rays
↓
⑥Pulse height analysis

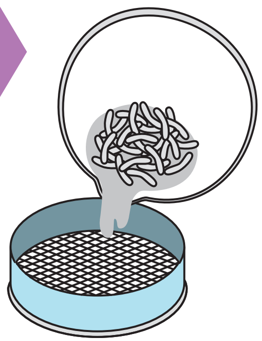
①Sample dissection



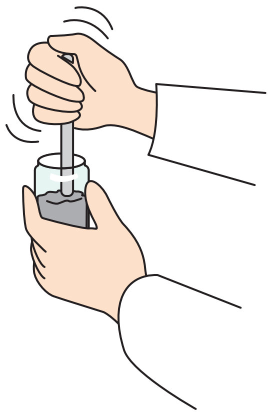
②Dry at high temp

③Carbonize/turn to ash at super high temp

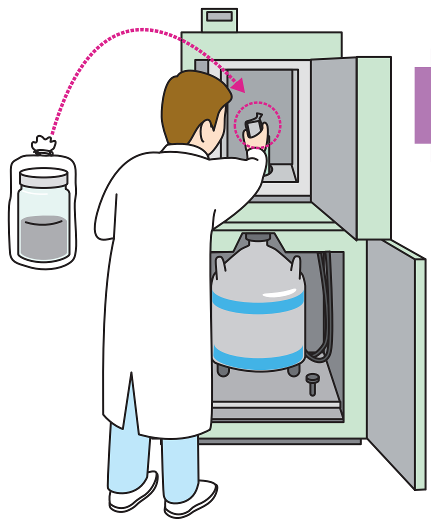




④Pressure form



⑤Measure gamma rays



⑥Pulse height analysis