付録 1

みんなで学ぼう　放射線の基礎

―中学校生徒用―

Appendix 1

Let's Start Learning Radiation (Secondary School Students)

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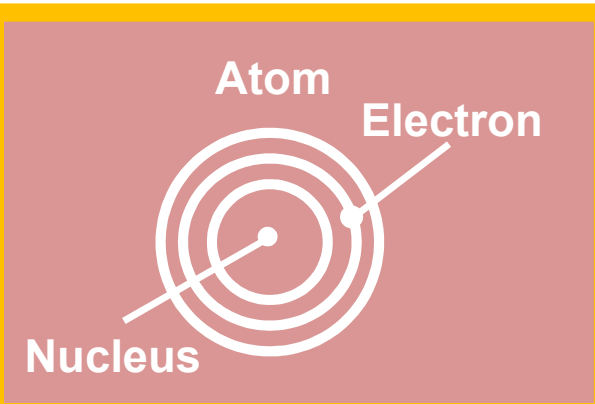
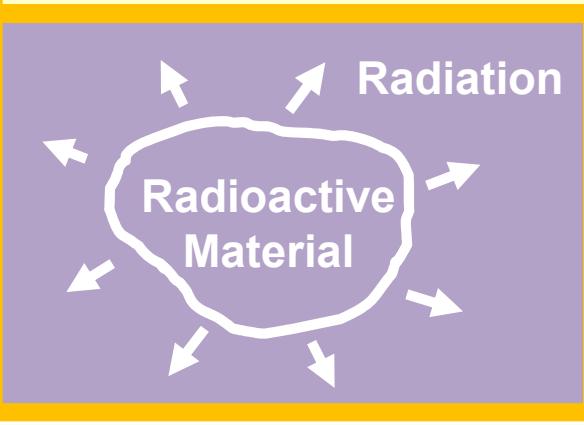
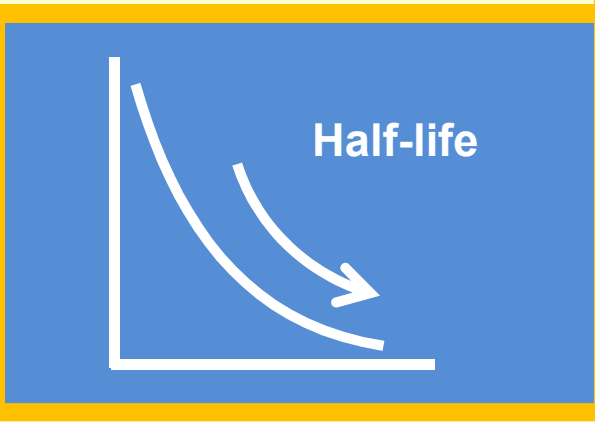
Supplementary Material on Radiation for Secondary School Students



Let's Start Learning Radiation





Preface

Following the Great East Japan Earthquake on 11th March 2011 (magnitude 9), a nuclear accident occurred at the Fukushima Daiichi Nuclear Power Station (NPS) of Tokyo Electric Power Company. The accident led to the release of radioactive materials (Iodine, caesium, etc.) into the atmosphere and the sea.

Through this experience, Ministry of Education, Culture, Sports, Science and Technology - Japan published supplemental learning material on radiation in Japanese in October 2011 as it would be useful to students who may have concerns about the possible impact of radiation on the human body, as well as interest in radiation.

Since the learning material is designed to give a clear explanation of radiation and covers various topics, it has been favourably evaluated by the International Atomic Energy Agency (IAEA). The IAEA expressed that this learning material could encourage young students to get interested in nuclear science, and this teaching scheme would be highly valuable to the education sector as the learning material consists of reading source for students and instruction material for teachers.

We also thought that it would be beneficial if a learning material in English was available as the material in Japanese covers the various contents of radiation, including the basics of radiation, the health effects of radiation on humans, measurement devices for different purposes, emergency preparedness, and various applications of radiation, are useful not only to Japanese students but also to students in the world.

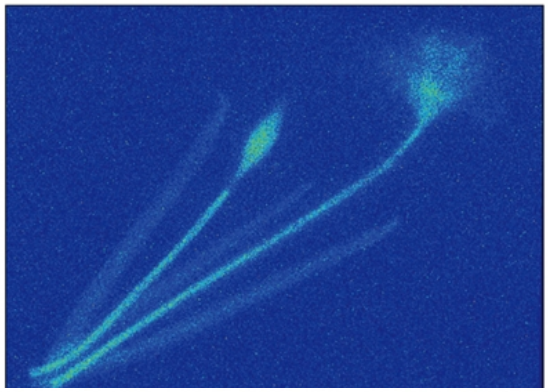
Therefore, we made a new learning material in English using the topics covered in supplemental learning material on radiation in Japanese as a reference. We also updated some data and considered the differences in cultural background to provide a better understanding of the content.

We hope this new material will offer the learning opportunities of radiation for young students in the world.

Dr. Kiyonobu Yamashita
General Advisor
Nuclear Human Resource Development Center
Japan Atomic Energy Agency
In Dec 2014

Contents

Mysterious World of Radiation



Radiation from Plants

The figure on the left shows the natural radiation emitted from a narcissus.

The more radiation the flower emits, the brighter the colour is shown on the plate. This is because the narcissus contains potassium-40*.

Potassium is an essential mineral element for living organisms, and is contained in plants and animals.

*Potassium contains the 0.012% of potassium-40 which emits radiation.

You can see radiation emitted from potassium-40 as in the figure by placing the narcissus between plates that are coated with fluorescent materials, and leaving for a few days to two months in a box made by thick lead. The box can block the natural radiation from the outside.

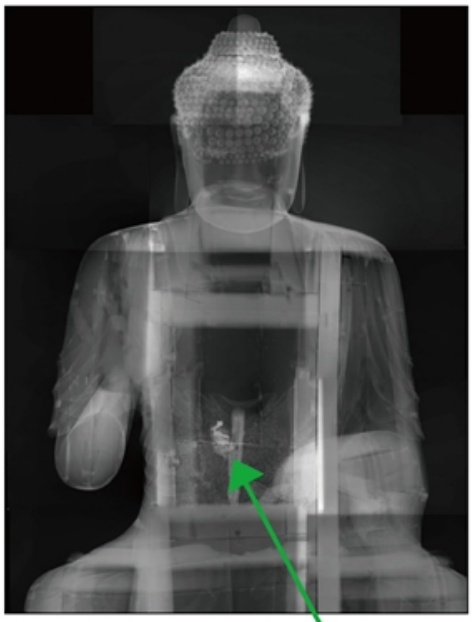
Neutron rays for Research on Liquid Flow

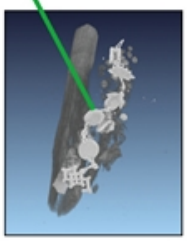
The picture on the right is made by exposing a lily to neutron rays. The white part shows the amount of water contained in the lily.

This method is useful to study how plants absorb water and grow.

Neutron rays are also applied to research on liquid flow in metal pipes, such as fuels and lubricants inside engines, and hydrogen and water in fuel cells.

3





New Discovery by X-rays

Archaeologists examined the inside of Buddhist statue without breaking its body by using the penetrating property of X-rays, and found hidden internal organs (liver, lungs, heart, kidneys and spleen) inside the statue.

3D Pictures by Advanced CT scan

CT (Computed Tomography) can produce a layered image of the human body by using radiation.

As image processing techniques improved, three-dimensional (3D), high quality images are available now. The figure on the right shows an artificial blood vessel (in blue), as part of a 3D image of human kidneys. Using the 3D image, a condition of the artificial blood vessel can be observed more effectively.

3D image of human kidneys

POINT

We cannot see radiation with the naked eye, but radiation is around us all the time and used for various areas of our life.

Radiation from the Natural World

From Outer Space

According to the Big Bang theory, the universe was born approximately 13.7 billion years ago. The earth where we live now, was formed around 9 billion years later.

Since the universe was formed, a large amount of radiation has existed in outer space. This radiation is known as cosmic rays, which also reach the earth.

We receive more cosmic rays at high altitudes. For example, there are more cosmic rays on a mountain than at the ground level, as the air becomes thinner and there are less materials exist to block cosmic rays.

From the Ground

Radioactive materials have been contained in the ground of the earth which emerged about 4.6 billion years ago, and in this environment, all creatures have been born and evolving.

On the ground, materials emitting radiation (radioactive materials) are contained in rocks and soil The level of radiation on the ground varies depending on how much radioactive materials are contained in rocks and soil. For example, in places such as Ramsar, Iran and Kerala, India, radiation is emitted from the ground more than twice as much as the world average.

There is also a regional difference within Japan. The annual natural radiation in the western part (Kansai region) is 20~30% higher than in the eastern part (Kanto region) as more granite* is found in the ground of the Kansai than other areas.

*Granite is one type of rock that contains a relatively large amount of radioactive materials.

POINT

Radiation has been present throughout human evolution, and we are exposed to radiation everyday.

From Air

A radioactive element called radon is mainly contained in air. Radon is a small amount of noble gas, which is released from some rocks, and can be generated from the ground all over the world. Therefore, the level of radon is relatively higher in stone-made houses than houses made of wood.

From Food

A radioactive element, potassium-40, is mainly contained in food. Potassium is one of the three major nutrients for plants, so we take potassium into our body by eating vegetables.

Potassium is an essential mineral for the human body and takes up about 0.2% of our weight.

What is Radiation

Atoms and Nucleus

All matter is formed by atoms.

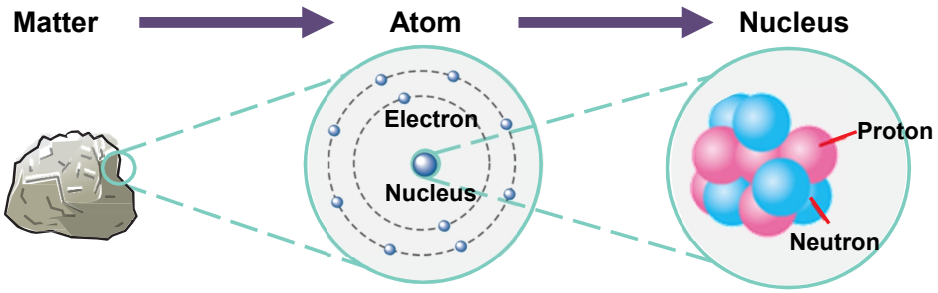
Approximately 110 types of elements* exist in the natural world, and everything such as the human body, food, air, water, clothes, desks, etc. is made up of atoms.

An atom contains a nucleus surrounded by electrons. The nucleus contains protons and neutrons.

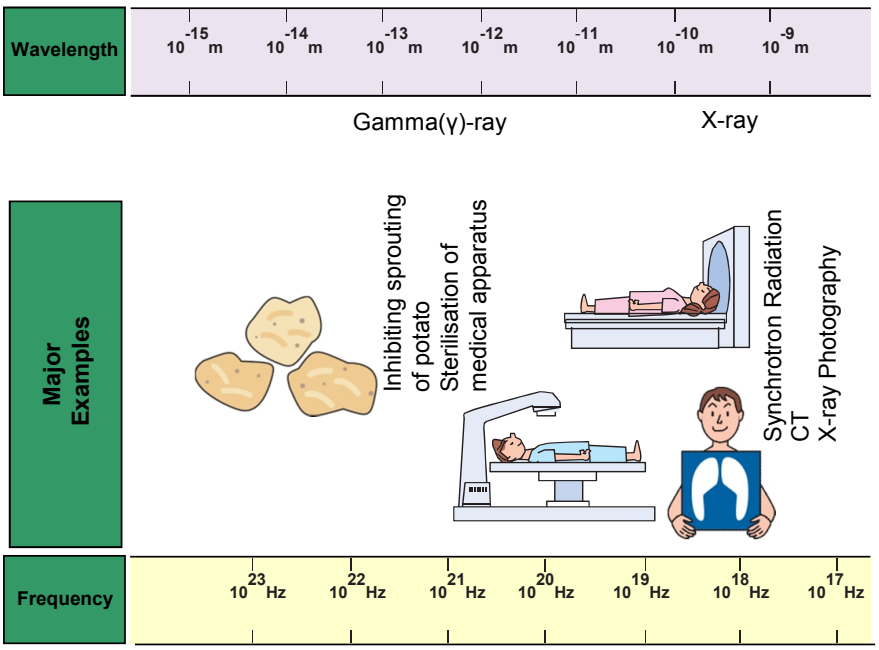
The atom is very small, only about 0.1 nanometer (1 x 10^{-10} m). The nucleus is much smaller, only about 2 femtometers (2 x 10^{-15} m).

Atoms, which have the same number of protons but a different number of neutrons, are called isotopes.

*An element consists of an atom with a specific number of protons in its nucleus.



◆**The group of electromagnetic waves**



POINT
Let's find out which materials are radioactive.

Radiation from Atoms

Some atoms emit radiation.

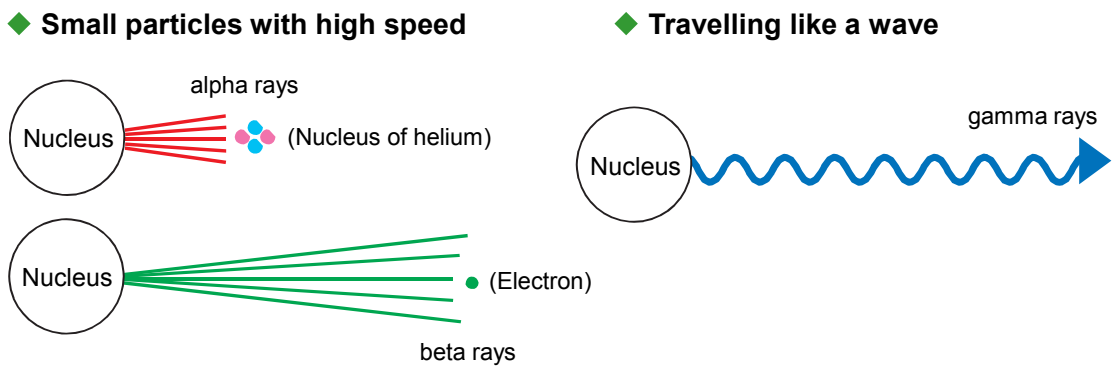
Radiation can be a particle or a wave with high energy.

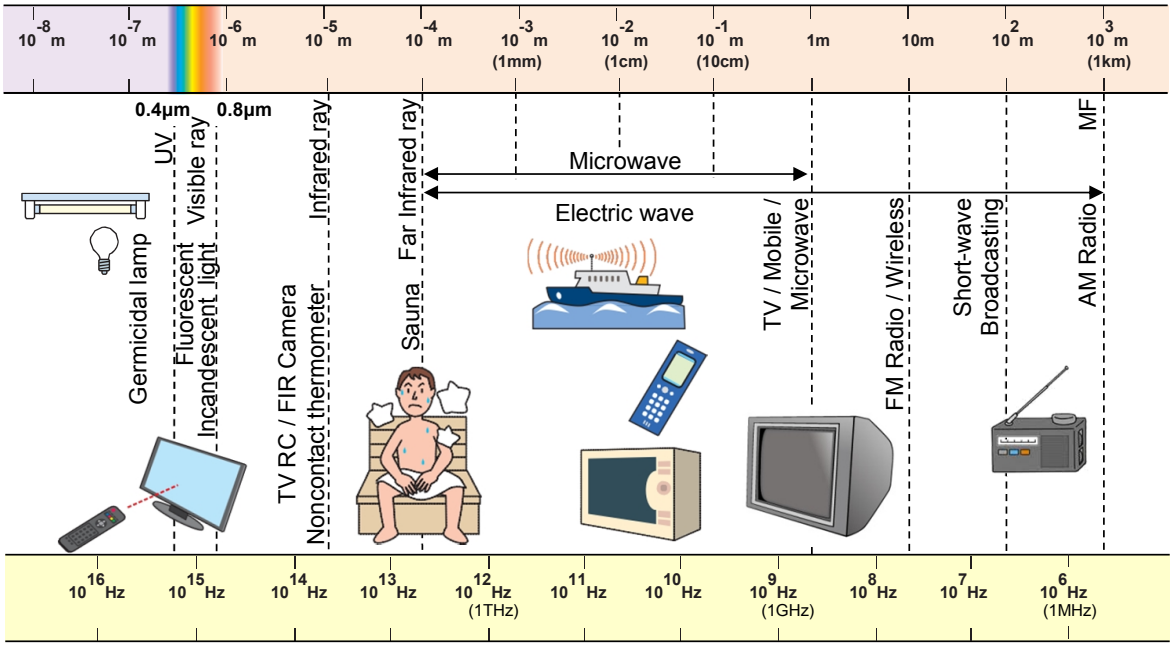
Radiation cannot be seen by the naked eye.

Radiation can pass through materials (penetrating properties) and can change the structure of atoms (ionisation).

Alpha rays, beta rays and neutron rays are considered as particles.

Radio waves, TV signals and natural light are considered as waves. However, waves with high frequencies (high energy), such as X-rays and gamma rays, are separated from other waves, and are categorised as radiation.





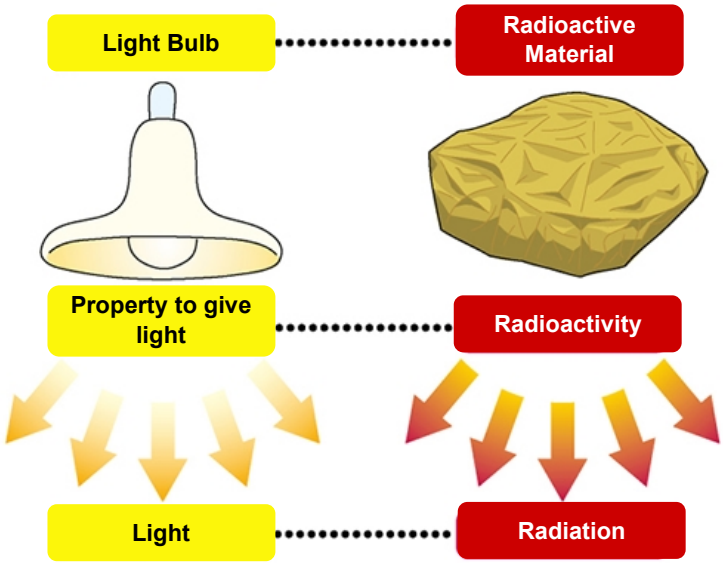
Source: Japan Atomic Energy Agency “what is radiation?”

Basic Knowledge of Radiation

Radioactive Material / Radioactivity / Radiation

Radiation is divided into two main types; “particle emission” and “wave with short wavelength”.

A material emitting radiation is called “radioactive material” and its emitting property is known as “radioactivity”. Comparing to a light bulb, a radioactive material is the light bulb, a power giving light from the bulb is radioactivity, and radiation is the equivalent of light itself.

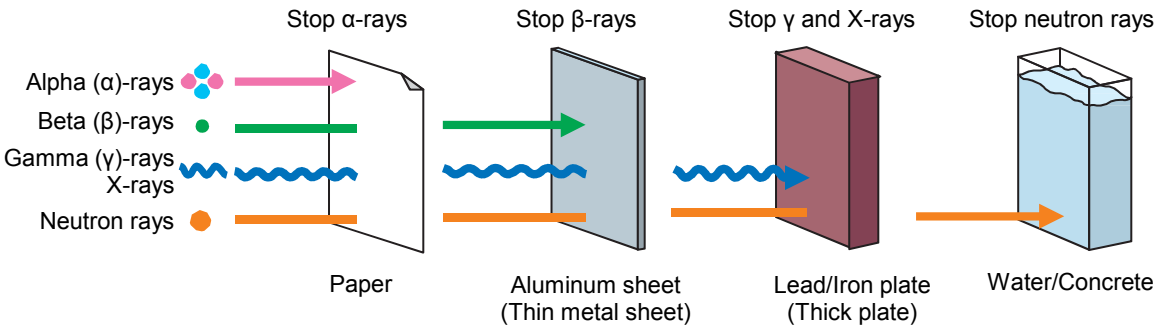


Penetrating Properties of Radiation

There are several types of radiation; alpha (α)-rays, beta (β)-rays, gamma (γ)-rays, X-rays, and neutron rays. All of them can penetrate materials but their properties are different depending on their types. Radiation can be stopped by choosing the right type of materials and thickness.

For example, alpha (α)-rays can be stopped by a piece of paper, and beta (β)-rays can be stopped by an aluminium sheet.

Stopping radiation by materials is called shielding.



POINT

The law of half-life is used to estimate the age of organic materials, so let’s find out how to determine their age.

Units of Radioactivity / Radiation

As you may have heard "Becquerel" or "Sievert" from TV and radio, these are units for the intensity of radioactivity and the level of radiation.

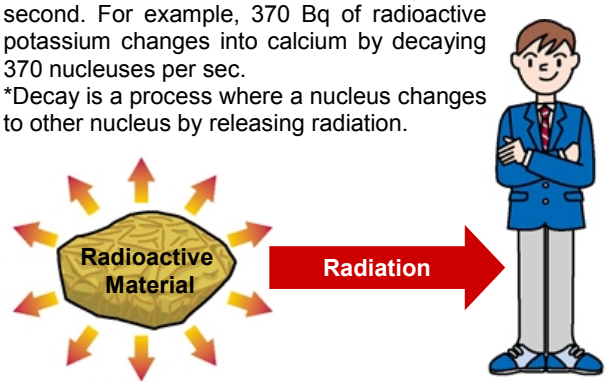
The power (intensity) that radioactive materials emit radiation is measured in a unit called "Becquerel (Bq)". The biological effects of radiation on the human body is measured in "Sievert (Sv)". The amount of radiation energy absorbed by materials and human tissues is measured in "Gray (Gy)".

Becquerel (Bq)

The power of radioactive materials emitting radiation

One Bq means that one nucleus decays* per second. For example, 370 Bq of radioactive potassium changes into calcium by decaying 370 nucleuses per sec.

*Decay is a process where a nucleus changes to other nucleus by releasing radiation.



Gray (Gy)

The amount of radiation energy absorbed by materials and human tissues

When radiation reaches to materials and the human body, releasing its energy which is absorbed by materials. One gray is one Joule of energy absorbed by 1kg of material.

*Joule is a unit of energy.

Sievert (Sv)

The biological effects of radiation on the human body

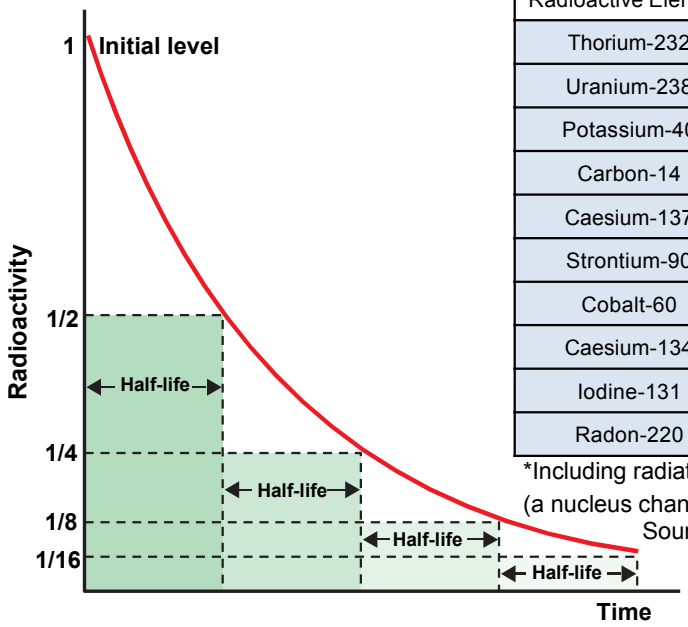
Using as an indicator for safety control of radiation

Half-life of Radioactivity

Radioactivity gets weaker with time, and the amount of radioactive material also decreases.

Half-life is the time in which the amount of radioactivity is reduced by half of its initial value, and there is a regular decrease pattern.

Radioactive elements have different half-lives ranging from a few seconds to 10bilion years.



Radioactive Element	Radiation*	Half-life
Thorium-232	α, β, γ	14.1 billion years
Uranium-238	α, β, γ	4.5 billion years
Potassium-40	β, γ	1.3 billion years
Carbon-14	β	5,730 years
Caesium-137	β, γ	30 years
Strontium-90	β	28.7 years
Cobalt-60	β, γ	5.3 years
Caesium-134	β, γ	2.1 years
Iodine-131	β, γ	8 days
Radon-220	α, γ	55.6 sec

*Including radiation from decay products

(a nucleus changes to other nucleus by releasing radiation)

Source: Japan Radioisotope Association "Radioisotope Pocket Data Book 10th ed."

Radiation Measurement Devices

We cannot feel radiation with our five senses (sight, hearing, smell, taste and touch), but we can detect radiation with appropriate equipment.

There are three main types of measuring methods:

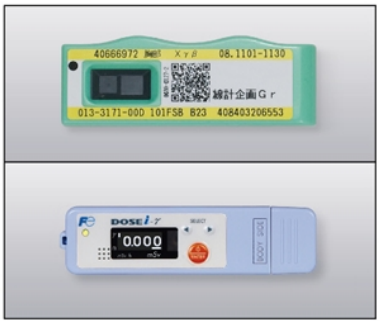
1) To check the presence of radioactive materials
2) To check the radiation levels in the air (including the natural and non-natural radiation)
3) To check an individual radiation exposure

1) Geiger-Müller counter (GM tube)

Measure radiation emitted from radioactive materials on the surface of things.
Unit: cpm (the number of radiation counted per minute)

2) Scintillation-type survey meter

Measure the radiation levels in the air. Use to check the biological effects of radiation on the human body. Unit: μSv/h



3) Personal dosimeter

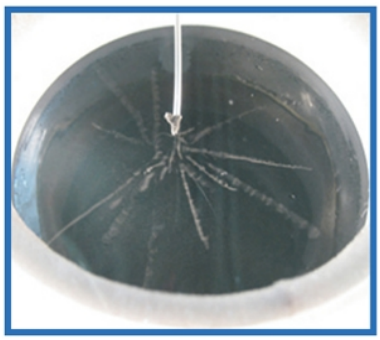
Measure the individual radiation dose. Also use to monitor the radiation levels. Unit: mSv/h
Note: Electric personal dosimeter may show an error value due to electric noise when placing next to a mobile phone.

◆ Let's measure radiation surrounding us

2) Simplified radiation survey meter

Measure the radiation levels in the air. This type of survey meter can be used as study materials to measure radiation around us such as γ-rays. Unit: μSv/h

X-Gamma Silicon Survey Meter



You can see lines like an airplane trace from the centre. This is the track of radiation.
(Equipment showing the pass way of radiation is called "Cloud Chamber".)

POINT
When measuring radiation, it is important to choose the right device for an accurate reading.

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History of Radiation & Radioactivity

Discovery of X-rays In 1895
Wilhelm Conrad Röntgen

During the experiment on vacuum discharge, Röntgen found invisible rays from the electrode of discharge tube. The rays had mysterious characteristics to pass through materials, to expose photographic plates and to light fluorescent materials. He named the invisible rays as “X-rays”. Now, X-rays are widely used for medical purposes and contribute to the accurate diagnosis and the effective treatment of illness and injury. For his discovery, he was later received the Nobel Prize in Physics.

Discovery of Radioactivity In 1896
Henri Becquerel

Becquerel put a cross shaped paperweight and uranium compound crystals on a photographic plate and left them in his desk drawer. He later found that the cross was projected to the photographic plate, and realised that the uranium released some form of radiation like X-rays.

Discovery of Radium In 1898
Marie Curie and Pierre Curie

Marie Curie worked together with her husband, Pierre Curie, to extract radioactive elements from pitchblende (uranium mineral), and found two new radioactive elements, polonium and radium.

Marie Currie named the properties of radioactive elements (i.e. releasing radiation) as “Radioactivity”.

Discovery of Radiation Types In 1899
Ernest Rutherford

Rutherford found that radiation emitted from radium showed different features when a magnet was brought closer to it. By the magnetic force, one was curving to the left and the other was to the right, and he named them “alpha rays” and “beta rays”. Later he found other radiation and named it as “gamma rays”.

Effects of Radiation

Internal Exposure and External Exposure

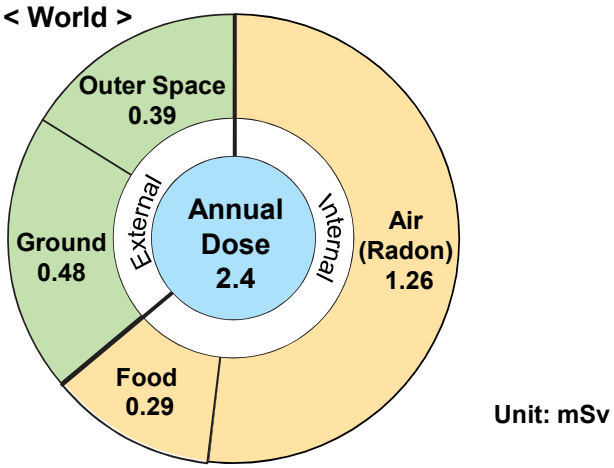
Exposure to radiation (to receive radiation) from radioactive materials that exists outside the body is called “external exposure”. On the other hand, exposure to radiation from radioactive materials that exist inside the body is called “internal exposure”.

External exposure refers to radiation received from; 1) the natural radiation from the ground and cosmic rays, 2) the non-natural radiation such as an X-ray, and 3) radioactive materials attached (contamination) on the body surface (skin) or clothes.

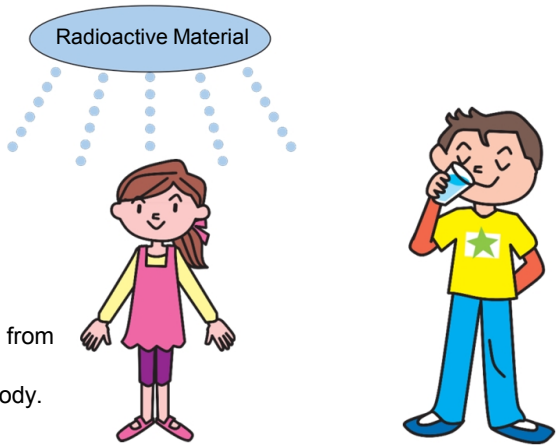
Radiation can pass through the body but does not remain inside, so the body or things will not become a source to release radiation. If you get contaminated with radioactive materials, these can be washed away by having a shower or washing clothes.

Internal exposure occurs when you eat contaminated foods and drinks or inhale contaminated air. Therefore, preventing radioactive materials from entering the body is the most important way for the protection from internal exposure.

◆ **Radiation dose* from the natural world** (the annual average dose per person)
*The amount of radiation to which you are exposed.



Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), “Report 2008”



External Exposure
Exposure to radiation from radioactive materials existing outside the body.

Internal Exposure
Exposure to radiation from the intake of radioactive materials contained in air, food and drink to the body.

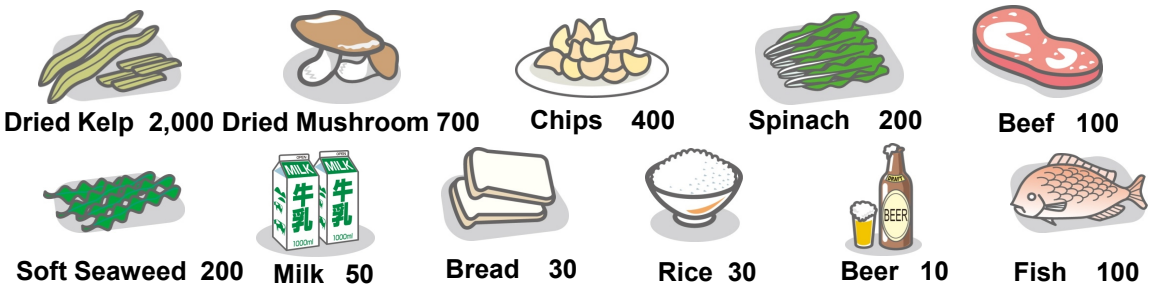
13

◆ Natural radioactivity in the human body and food

Radioactive materials in the body
(for an average Japanese weighing 60 kg)

Potassium-40	**4,000 Bq**
Carbon-14	**2,500 Bq**
Rubidium-87	**500 Bq**
Lead-210 & Polonium-210	**20 Bq**

Potassium-40 in Japanese foods per kg (Bq/kg)



Source: Nuclear Safety Research Association "Research on environmental radiation data (1983)"

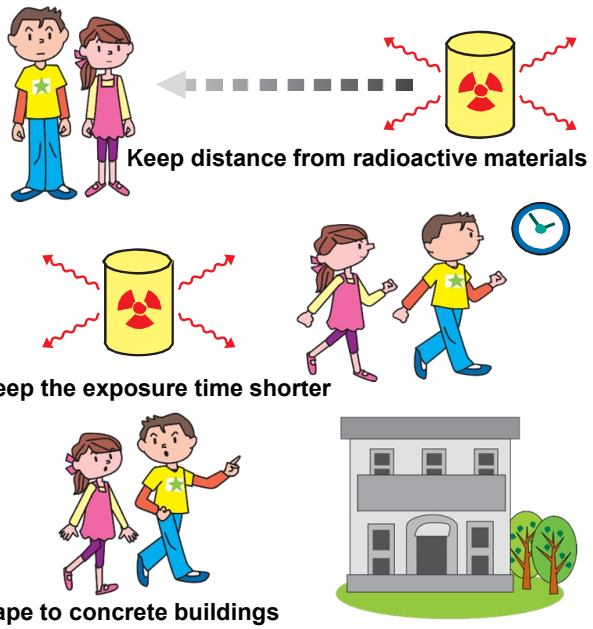
How to Protect from Radiation

There are three ways to protect ourselves from radiation; 1) to keep distance from radioactive materials, 2) to reduce the time of being exposed to radiation, and 3) to block (shield) radiation.

The radiation dose differs by distance from radioactive materials. The further away you are from radioactive materials, the less the radiation dose you have.

For example, if the distance becomes twice the radiation dose will be a quarter of its original value. Besides, the radiation dose can be reduced by shortening the exposure time and using shielding materials.

◆ Protection methods from radiation



POINT
Let's measure radiation around us with a simplified survey meter, and find out how it will be changed by distance and shielding materials.

Effects of Radiation

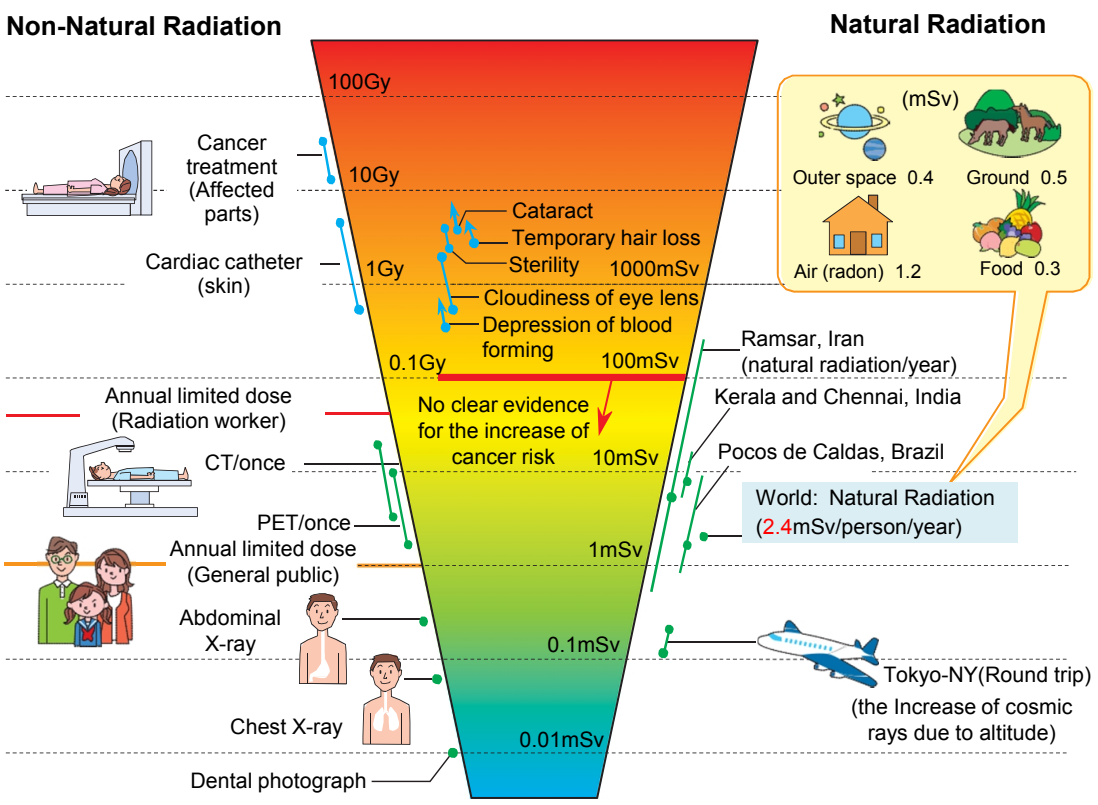
Relationship between Radiation Levels and Health

It is known that there are health effects on the human body when exposed to a large amount of radiation at once. However, there is no clear evidence on whether some illnesses such as cancer will develop at the low dose of radiation (below 100mSv) for a short time.

Since lifestyle-related cancer risks have been established now, it is difficult to determine a critical link between low levels of radiation and the increase of cancer risks.

The International Commission on Radiological Protection (ICRP) recommends that we should keep the radiation dose as low as possible in our life, even though it is unknown whether the radiation dose up to 100mSv at once and the accumulated dose up to 100mSv in a year increase the cancer risks.

◆ Radiation exposure in everyday life



Units of radiation dose

Gray (Gy) : The amount of radiation energy absorbed by materials and humans

Millisievert (mSv) : Radiation risks (cancer, hereditary effects*) on the human body

Note:
1) Values are shown in round numbers based on significant values.
2) Scale(dotted line) in graph is logarithmic. 10 times as large by one scale rises.
* Hereditary effects: Health effects will be transmitted to one's children and is distinguished from genetic effects (as genetic effects includes its effects on cells).

Source: Documents from National Institute of Radiological Sciences and others

According to various research results, the possibility of developing cancer is halved when receiving a small amount of radiation or exposing to radiation slowly, as compared with a large amount at once like radiation exposure from an atomic bomb.

The ICRP estimates that if 1,000 people were exposed to 100mSv of radiation (accumulated dose in a year), about 5 people would die from cancer. In fact, 30% of Japanese die from cancer during their lifetimes. It means that 300 people out of 1,000. Therefore, the cancer death in Japan would increase from 300 to 305 in total when 1,000 people were exposed to 100mSv of radiation.

When exposing to the same amount of radiation, the degree of biological effects on the body is the same either from the natural radiation or non-natural radiation.

Risk Factors of Cancer

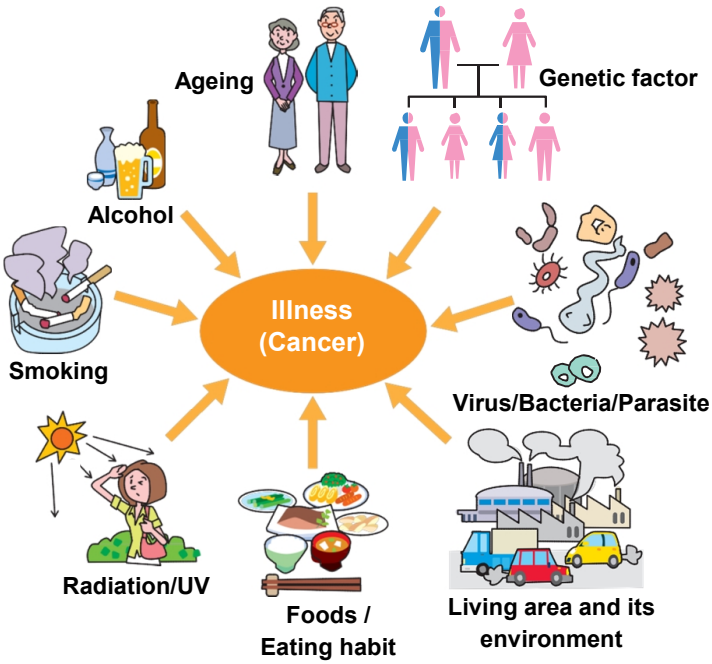
Our body is made up of living cells that can live with genetic information coding in DNA (deoxyribonucleic acid).

DNA can be damaged by physical and chemical causes, and radiation is one of them. However, cells have the ability to repair damaged DNA, and the repeated process of damage and repair is always happening in cells.

When DNA gets damage, cells may carry incorrect genetic information. If the affected cells fail to repair the information, they will die or some remained cells (mutant cells) may repeatedly change and turn into cancer cells.

Various cancer risks have been identified, such as smoking, eating habits, virus, and air pollution. It is therefore important to be aware of these risks, and to reduce the level of radiation exposure as low as possible.

◆**Various risk factors for illness (cancer)**



Source: Japan Radioisotope Association “Radiation’s ABC (2011)” and others

POINT

You do not need to worry about the health effects of radiation that you normally receive from the natural radiation or an X-ray at hospitals, but it is better to keep the levels lower.

Uses of Radiation in Our Life and Industry

Radiation Properties

Radiation has the ability to pass through substances (penetrating property), also to change the structure of materials. Therefore, radiation is widely applied to many fields today.

In Medicine

Medical check with X-rays at hospitals is using the penetrating properties of radiation.

Uses of X-rays for medical purposes have a long history; Marie Curie helped to save the lives of injured soldiers during wartime. She used the vehicle with X-ray equipment to diagnose broken bones.

Radiation is also used for the sterilisation of medical apparatus such as surgical knife and injector, as well as for cancer treatment.

In advanced cancer treatment, radiation can selectively kill cancer cells without damage on surrounding healthy organs (cells).

Sterilisation of medical apparatus


Heavy ion radiotherapy

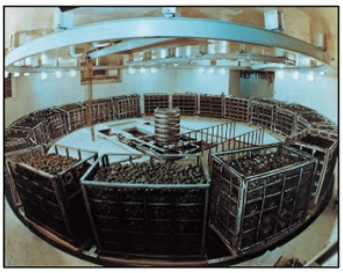
In Agriculture

Sprouting in potatoes can be inhibited by exposing to radiation, so these potatoes can be kept for a long period.

Selective breeding of plants is achieved by using radiation; developing pears with disease resistance and rice with cold resistance.

In Okinawa prefecture, Japan, radiation is used to control pests and to protect farm products.

By sterilising, male melon flies cannot produce its offsprings so the number of melon flies has been gradually decreased.


Radiation exposure to potato


Melon fly

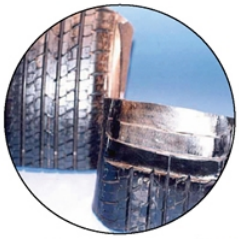
POINT
Radiation is used in various ways according to its features.

In Industry

Radiation is used for producing car tires, as when plastic and rubber materials are exposed to radiation, its material features such as heat, water, shock resistance and strength can be enhanced.

Moreover, by exposing to radiation, materials can hold more moisture within, so clear and elastic coating sheets for medical uses can be produced as an alternative to cotton gauzes.

Electrons are used to develop a new technology for the system of removing harmful chemicals from exhaust gases and waste water.



Enforced car tire

Medical coating sheet

In Natural Science and Humanities

The penetrating property of X-rays is used for archaeological research to study the inside of Buddhist statue while sustaining its shape (without breaking it).

The age of earthenware can be determined by "radiocarbon dating method" that examines the amount of radioactive isotope (carbon-14) contained in its material. This method takes advantage of longer half-life of carbon-14 (5,730years) to estimate the age of organic materials.

Examination of Buddhist statue

Dating method

Advanced Science Technology

Super Photon Ring-8 GeV (SPring-8) in Japan is a large synchrotron radiation research facility where strong electromagnetic waves called "synchrotron radiation" are generated. Synchrotron radiations are used for nanotechnology, biotechnology and industrial applications. Major applications are; the analysis of asteroid particles brought back by Hayabusa Asteroid Probe, and the development of anti-influenza agents.

Spring-8

Radiation Control and Protection

Monitoring in Normal Situation

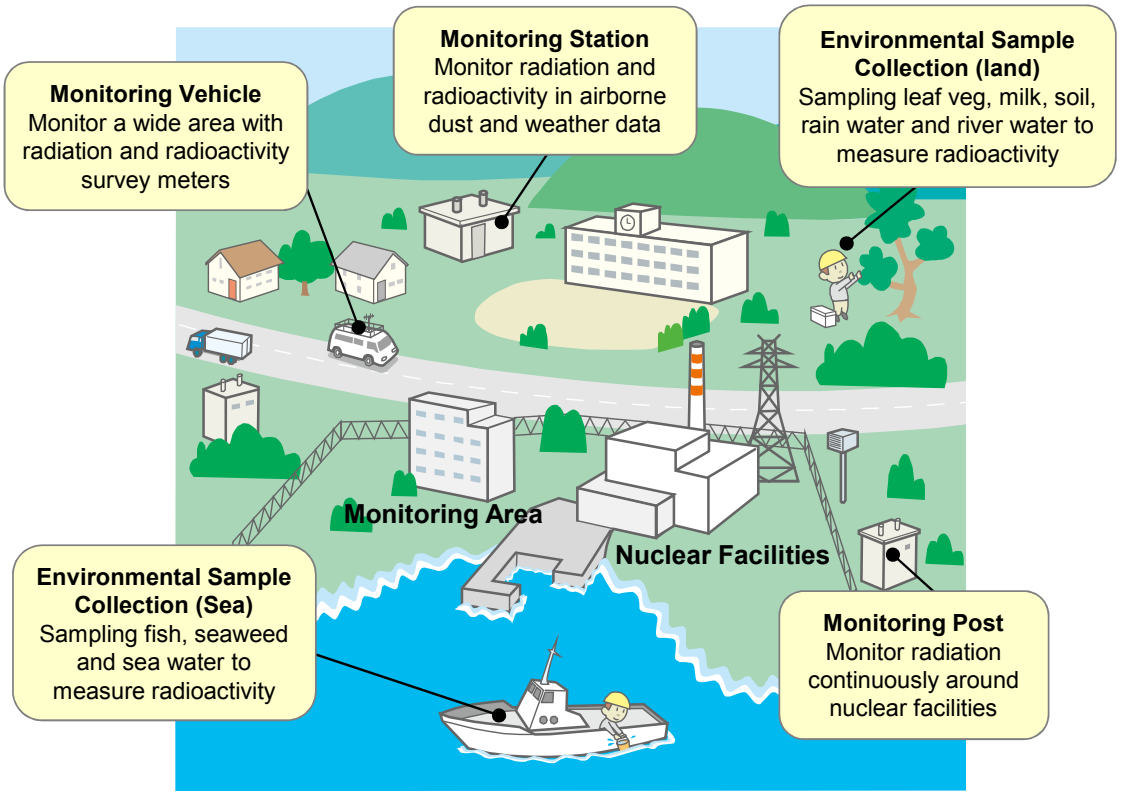
Monitoring posts and stations are located around the site of nuclear power stations and nuclear facilities in order to monitor radioactive materials released from the site to surroundings.

Using these monitoring facilities, the level of radiation in the environment is monitored, and its data and Information are open to the public and available through the website of nuclear operators and local governments.

Regular monitoring (measuring radioactivity) for marine sediment, soil, farm/marine products, and other samples is also conducted to check whether released radioactive materials have any effects on the environment.

Local governments in Japan examine the level of radiation and radioactivity by measuring radiation in the air and analysing radioactive materials in food, soil and water.

◆ Radiation monitoring around nuclear facilities




Monitoring Vehicle


Monitoring Post


Soil Sampling

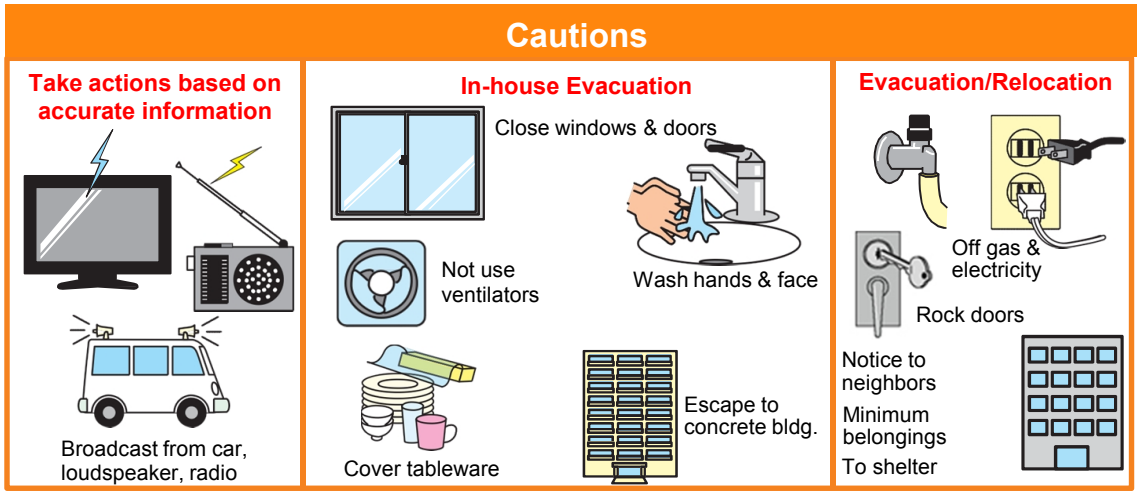
Protection from Radioactive Materials in Emergency

In case of accidents at nuclear power stations and nuclear facilities, radioactive materials might be carried by wind. However, you can avoid to contact radioactive materials with your skin by wearing a long sleeve shirt. Masks also prevent radioactive materials from entering your body. It is also important to stay inside the buildings, close all doors and windows, and switch off ventilators. If radioactive materials stick to your face and hands, these can be washed out. The amount of radioactive materials in the air decrease with time by falling to the ground so wearing masks may not be necessary later on.

Policy for Evacuation and In-house Evacuation

When an accident occurs at a nuclear facility and some radiation effects are expected in surrounding areas, evacuation and other orders will be given by national and local governments. In these cases, you should not be misled by wrong information and being panicked. It is also important to gain accurate information from teacher, TV and radio, and take actions calmly by following their instructions and orders.

The orders may change depending on the situation of the accident so you always need to pay attention to updated information.



Both evacuation and relocation are a method to protect yourself from radioactive materials. Evacuation is to stay in house or escape to a shelter. Relocation is to move from houses or shelters to other places.

POINT

Let's find out monitoring facilities of environmental radiation in your area and check monitoring data. Also think about a situation where you need to protect yourself from radioactive materials and how to do it.

Reference Site for Radiation

Radiation Effects on the Human Body

- **Japan Radiological Society (JRS)**
  http://www.radiology.jp/
- **Japanese Society of Radiation Safety Management**
  http://www.jrsm.jp/index.html
- **Japan Radiation Research Society**
  http://jrrs.kenkyuukai.jp/special/?id=5548
- **National Institute of Radiological Sciences "Radiation Q&A"**
  http://www.nirs.go.jp/

Radiation Effects on Food

- **Food Safety Commission of Japan**
  http://www.fsc.go.jp/
- **Ministry of Health, Labour and Welfare**
  http://www.mhlw.go.jp/
- **Ministry of Agriculture, Forestry and Fisheries**
  http://www.maff.go.jp/
- **Consumer Affairs Agency, Government Of Japan**
  http://www.caa.go.jp/

Environmental Radioactivity

- **Nuclear Regulation Authority**
  "Monitoring Information of Environmental Radioactivity Level"
  http://radioactivity.nsr.go.jp/ja/
- **Nuclear Regulation Authority**
  "Environmental Radioactivity and Radiation in Japan"
  http://www.kankyo-hoshano.go.jp/kl_db/servlet/com_s_index

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Learning Material in English

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Fuji Electric Co., Ltd. (p.11 X-Gamma Silicon Survey Meter)

English / Japanese Glossary of Technical Terms

Accumulated dose	積算線量
Alpha rays	アルファ線
Annual limited dose	年間線量限度
Anti-influenza agent	インフルエンザ治療薬
Archaeological research	考古学研究
Artificial blood vessel	人工血管
Asteroid	小惑星
Atom	原子
Atomic bomb	原爆
Basic radiation	放射線基礎
Beta rays	ベータ線
Biological effect	生物学的影響
Cardiac catheter	心臓カテーテル
Cataract	白内障
Cloud chamber	霧箱
Cloudiness of eye lens	眼水晶体の白濁
Computed Tomography (CT)	コンピュータ断層撮影
Contamination	汚染
Cosmic rays	宇宙線
Decay	(放射性物質の)崩壊
Decay product	崩壊生成物
Depression of blood forming	造血系の機能低下
Electric noise	電気的ノイズ
Electric wave	電波
Electrode	電極
Electromagnetic wave	電磁波
Electron	電子
Element	元素
Emergency preparedness	緊急時の心構え
Evacuation	避難
Evacuation order	避難指示
Exposure	被ばく
External exposure	外部被ばく
Far infrared ray	遠赤外線
Fluorescent incandescent light	蛍光灯
Femtometers	1/1000兆メートル
Fluorescent material	蛍光物質
Gamma rays	ガンマ線
Genetic effect	遺伝的影響
Germicidal lamp	殺菌灯
Granite	花こう岩
Half-life	半減期
Heavy ion radiotherapy	重粒子線治療
Hereditary effect	遺伝性影響
Human tissue	人体組織
Infrared ray	赤外線
Internal exposure	内部被ばく
Ionisation	電離作用
Isotope	同位元素
Local government	地方自治体
Magnetic force	磁力
Medical apparatus	医療機器
Microwave	マイクロ波
Mutant cells	変異細胞
Naked eye	肉眼
National government	国・中央政府
Natural radiation	自然放射線
Natural radioactivity	自然放射能
Neutron	中性子
Neutron rays	中性子線
Noble gas	希ガス
Non-natural radiation	人工放射線
Nuclear facility	原子力施設
Nuclear operator	原子力事業者
Nuclear science	原子力科学
Nucleus	原子核
Particle	粒子
Penetrating properties	透過作用
Personal dosimeter	個人線量計
Pest control	害虫駆除
Pitchblende	れきせいウラン鉱
Proton	陽子
Polonium	ポロニウム
Radiation	放射線
Radiation dose	放射線量
Radiation effect	放射線の影響
Radiation exposure	放射線被ばく
Radiation monitoring	放射線モニタリング
Radiation worker	放射線業務従事者
Radioactive material	放射性物質
Radioactivity	放射能
Radiocarbon dating	放射性炭素年代測定法
Relocation	退避
Selective breeding	品種改良
Shelter	避難所
Shielding	遮へい
Shielding effect	遮へい効果
Sterilisation	消毒
Sterility	不妊
Synchrotron radiation	放射光
Temporary hair loss	一時的脱毛
Three-dimension	三次元
Uranium compound	ウラン化合物
Uranium mineral	ウラン鉱物
Vacuum discharge	真空放電
Visible ray	可視光線
X-ray photography	エックス線撮影
X-rays	エックス線