JAEA-Review
2014-044

みんなで学ぼう　放射線の基礎
―中学生用放射線学習資料―

Let's Start Learning Radiation
―Supplementary Material on Radiation for Secondary School Students―

渡部 陽子　嶋田 麻由香　山下 清信
Yoko WATANABE, Mayuka SHIMADA and Kiyonobu YAMASHITA

原子力人材育成センター
Nuclear Human Resource Development Center

January 2015
Japan Atomic Energy Agency
日本原子力研究開発機構

JAEA-Review

独立行政法人日本原子力研究開発機構 研究連携成果展開部 研究成果管理課
〒319-1195 茨城県那珂郡東海村白方白根2 番地4
電話 029-282-6387, Fax 029-282-5920, E-mail:ird-support@jaea.go.jp

Institutional Repository Section,
Intellectual Resources Management and R&D Collaboration Department,
Japan Atomic Energy Agency.
2-4 Shirakata Shirane, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195 Japan
Tel +81-29-282-6387, Fax +81-29-282-5920, E-mail:ird-support@jaea.go.jp

みんなで学ぼう　放射線の基礎
―中学生用放射線学習資料―

日本原子力研究開発機構　原子力人材育成センター
渡部　陽子、嶋田　麻由香*、山下　清信

(2014 年 10 月 15 日　受理)

日本原子力研究開発機構では、文部科学省の委託事業を受託し、原子力発電の導入計画を進めているアジア諸国に対して人材育成を行っている。東京電力（株）福島第一原子力発電所事故以降、これらアジア諸国において放射線に関する正しい知識を普及することが重要と判断し、放射線基礎教育コースを立ち上げた。このコースで使用する教材として、文部科学省が発行した「中学生のための放射線副読本」及びその解説編を参考とし、英語版の放射線基礎学習資料を新たに作成した。海外の人々が学べる教材を提供することは、国際的な原子力の人材育成に大きく貢献するものである。今後、本資料は、国際原子力機関を通して、世界各国での放射線教育に使用される予定である。

原子力科学研究所：〒319-1195　茨城県那珂郡東海村白方白根 2-4
＊株式会社パソナ

JAEA-Review 2014-044

Let's Start Learning Radiation
—Supplementary Material on Radiation for Secondary School Students—

Yoko WATANABE, Mayuka SHIMADA* and Kiyonobu YAMASHITA

Nuclear Human Resource Development Center,
Japan Atomic Energy Agency
Tokai-mura, Naka-gun, Ibaraki-ken

(Received October 15, 2014)

The Japan Atomic Energy Agency has been organizing training programs for engineers in Asian countries introducing nuclear technology. In 2012, we launched a course 'Basic Radiation Knowledge for School Education' as we thought disseminating accurate knowledge on radiation to school students and public would also be important in those countries after Fukushima-Daiichi nuclear power station accident.

Ministry of Education, Culture, Sports, Science and Technology－Japan published supplemental learning material on radiation for secondary school students and teachers in Japanese in October 2011. Since the learning material is designed to give a clear explanation of radiation and covers various topics, we thought it would also be beneficial for young students in the world if a learning material in English was available.

Therefore, we made a new learning material in English using the topics covered in supplemental learning material on radiation in Japanese as a reference. This learning material has been favourably evaluated by the International Atomic Energy Agency (IAEA) and will be widely used as a practical educational tool in many countries around the world through the IAEA.

Keywords: Radiation Education, Basics of Radiation, Learning Material, Teacher Resources, Secondary School Student

＊Pasona Inc.

目　次

Contents

1. はじめに

独立行政法人日本原子力研究開発機構（以下、原子力機構）の原子力人材育成センター（以下、人材育成センター）では、1996 年度から文部科学省の委託事業「放射線利用技術等国際交流（講師育成）」（旧「国際原子力安全交流対策（講師育成）」）を受託し、原子力発電の導入計画が進められているアジア諸国に対して人材育成を行っている。これまで海外の原子力技術者（専門家）の人材育成を中心に行ってきたが、東京電力（株）福島第一原子力発電所での事故以降、アジア諸国でも一般の人々を対象とした放射線基礎教育が重要と認識されてきた。そのため、この委託事業の中で、一般の人々や公共教育にて放射線基礎知識の普及を行う人材を育成することを目的とした「放射線基礎教育コース（以下、コース）」を 2012 年に立ち上げた。人材育成センターでは、このセミナーで使用する教材選定の中で、文部科学省が 2011 年 10 月に発行した「中学生のための放射線副読本（生徒用）」[1]（以下、副読本）及びこの副読本の内容を分かり易く解説するための「中学生のための放射線副読本　解説編（教師用）」[2]（以下、解説編）に着目した。この副読本及び解説編は、放射線に関する幅広い話題を取り上げ、図や写真を豊富に使用し、放射線の基礎知識を分かりやすく解説しており、入門編としては適切な資料である。人材育成センターにおけるコースにおいて更に分かりやすい講義が行えること、また、海外の人々が学べる教材を提供し国際的な原子力の人材育成に貢献することを主旨とし、副読本及び解説編を参考として英語版の放射線基礎学習資料を新たに作成することにした。その後、文部科学省は、2013 年 12 月に副読本の改訂版を作成したが、旧版の方が放射線の基礎知識についての説明が多くなされていたため、旧版を参考とした。

2. 中学生用放射線基礎学習資料について

中学生用放射線学習資料（以下、中学生用学習資料）は、副読本[1]と同様に、スイセン中に含まれるカリウムから放出された放射線を撮影したイメージングプレートの画像やユリの中性子イメージングの画像から始まり、放射線の利用について視覚的に訴え、中学生が興味を持てるように構成した。

次に、自然界に存在する放射線について、人間が昔から宇宙や大地、空気中や食物に含まれている放射性物質と共存していることを説明した。続いて、放射線（能）の基礎について、原子は原子核と電子から成り立っていること、原子核は陽子と中性子で構成されていること等を図を用いて解説した。

放射線測定器については簡易放射線測定器だけでなく、実際に放射線業務従事者が使用するようなガイガーミュラーカウンタや NaI シンチレーション式サーベイメータ、個人線量計も紹介した。続いて、外部被ばく、内部被ばくの違いや、体内や身近な食物の中に含まれる放射性物質の量についても説明した。また、放射線から身を守るために、放射線防護の三原則（距離、遮へい、時間）についても説明した。

放射線の人体への影響については、国際放射線防護委員会（International Commission on Radiological Protection, ICRP）が勧告で述べている内容を解説し、また、自然放射線と人工

放射線はどちらでも、受ける放射線量が同じであれば人体への影響の度合いが同じであることも述べた。その他、放射線の医療・産業などでの利用や原子力施設周辺の環境モニタリングについて紹介し、非常時における防護や避難についても述べた。

中学生用学習資料を作成するにあたり、英語の表現を可能な範囲で簡単にし、海外の中学生が読みやすいように工夫した。しかし、専門的な単語が出てくるため、中学生には難しく感じられることが予想される。国内の学校関係者からも教材として使用したいとの希望があったことから、最後に英日専門用語対比表を添付した。

3. 教師用解説資料について

解説編[2)]では、基本的に副読本[1)]で紹介された内容について図や写真を用いて詳しく説明している。また、学習のポイントや指導上の留意点の記載もあり、教師がポイントを押さえて指導できるように構成している。教師用解説資料（以下、解説資料）も、これらを参考にして作成した。

解説資料においては、スイセン中の放射性カリウムの画像を撮影したイメージングプレートの装置を写真付で、また、中性子イメージングでは原理について解説した。それに加え、中学生用学習資料にはない大強度陽子加速器施設についても紹介した。

自然界に存在する放射線については、色々な場所における自然放射線レベルの違いについてグラフで示し、例えば、木造住宅と鉄筋コンクリート住宅での放射線量の違い等が比較できるようにした。放射線（能）の基礎については、原子核の大きさや放射性同位元素の種類、電子雲モデルまで学べるようにした。放射線量のような詳細な説明が必要な項目に関しては、ICRP の 2007 年勧告[3)]を引用して解説した。放射能の半減期については中学生用学習資料でも触れたが、解説資料では、物理学的半減期と生物学的半減期があることや、実効半減期の求め方など更に深い内容まで説明した。

放射線測定器については、簡易放射線測定器を使用した測定例の紹介や、霧箱の作成方法及び原理について説明した。霧箱は、目では見ることができない放射線の飛跡を見ることができる道具であり、人材育成センターでも基礎的な実習として取り入れている。外部被ばく、内部被ばくの項目においては、距離と放射線量の関係等の他、食品の暫定規制値についても説明し、ホールボディーカウンタについても紹介した。

放射線による人体への影響については、確定的影響や確率的影響についても詳細に説明した。また、参考データとして、一度に多量の放射線を受けた場合の影響についても図で示した。専門的な内容であるが、集団実効線量や、放射線のリスクとベネフィットについての ICRP の考え方についても解説した。その他、放射線と生活習慣によってがんになる相対リスクについて示したデータも掲載し、放射線を 100-200 mSv 受けるよりも肥満や喫煙の方が、はるかにがんリスクが高いこと等を示した。

放射線の医療や産業などでの利用や原子力施設周辺の環境モニタリングについても、中学生用学習資料で触れた事柄について、一つ一つ説明した。避難と退避の考え方や、避難勧告となる 20 ミリシーベルトの考え方等、東京電力（株）福島第一原子力発電所での事故を経験した

日本ならではの記事も紹介している。

解説資料は基本的に教師用に作成したものであるが、ICRP の勧告等は専門的な内容が多いため、可能な範囲で簡単な英語で表現した。

4. おわりに

我が国では、東京電力（株）福島第一原子力発電所事故以降、放射線基礎教育の重要性が再認識され、文部科学省が放射線副読本を小学生、中学生、高校生向けに発行した。放射線基礎教育は、個人の安全を確保するための知識と言うだけではなく、今後のエネルギー問題を考える上でも非常に重要である。これは、原子力発電を既に行っている国々だけでなく、これから導入を計画している国々にとっても同様に重要な課題であると考える。

本資料は、国際原子力機関（International Atomic Energy Agency, IAEA）からも、若い世代が原子力について興味を持つきっかけとなる有益な学習資料として高く評価されており、今後、人材育成センターで開催される国際セミナーで使用するだけでなく、世界各国での放射線教育に使用される予定である。

謝辞

原子力の平和利用を進める世界の若者にとって副読本が極めて良い資料と評価され、英語版放射線基礎学習資料を作成することを強く要望された IAEA 技術協力局 Jane Gerardo-Abaya 様、同原子力局 John de Grosbois 様及び同局久住涼子様に、深く感謝致します。

英語版放射線基礎学習資料の意義と重要性を示して頂いた IAEA 原子力安全・セキュリティー局出雲晃様及び東京大学環境安全本部飯本武志先生に深く感謝致します。

最後に、本資料の作成に対してご支援頂き、ご助言や励ましのお言葉を頂きました原子力人材育成センター長村上博幸氏及び国際原子力人材育成課長中村和幸氏に心より感謝致します。

参考文献

1) 放射線等に関する副読本作成委員会, 知ることからはじめよう放射線のいろいろ（中学校生徒用）, 文部科学省, 2011, 22 p. available from
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_04_1.pdf (accessed 2014.9.26)
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_05_1.pdf (accessed 2014.9.26)

2) 放射線等に関する副読本作成委員会, 知ることからはじめよう放射線のいろいろ（中学校教師用）, 文部科学省, 2011, 30 p. available from
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_06_1.pdf (accessed 2014.9.26)
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_07_1.pdf (accessed 2014.9.26)
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_08_1.pdf (accessed 2014.9.26)

3) ICRP: “The 2007 Recommendations of the International Commission on Radiological Protection”, ICRP Publ. 103, Ann ICRP 37(2-4), 2007.

付録 1

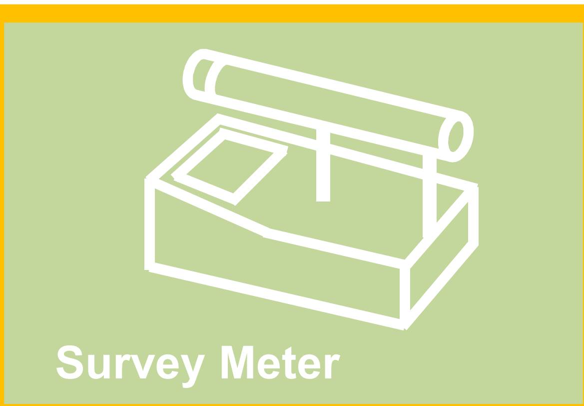
みんなで学ぼう　放射線の基礎

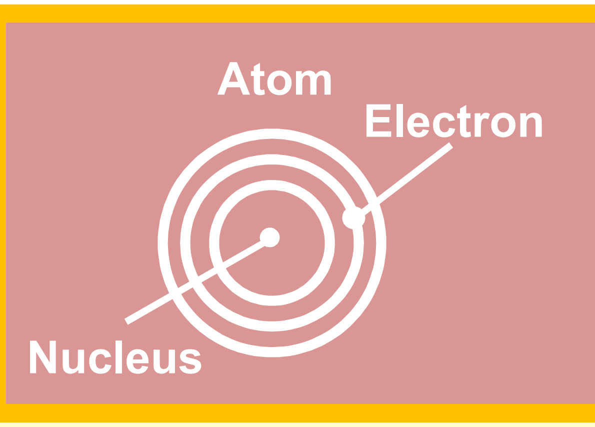
―中学校生徒用―

Appendix 1

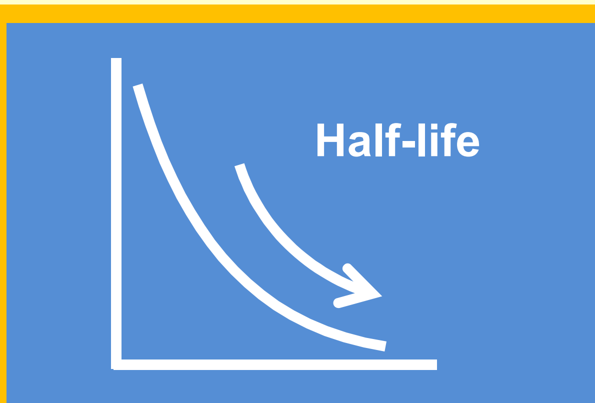
Let's Start Learning Radiation (Secondary School Students)

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.

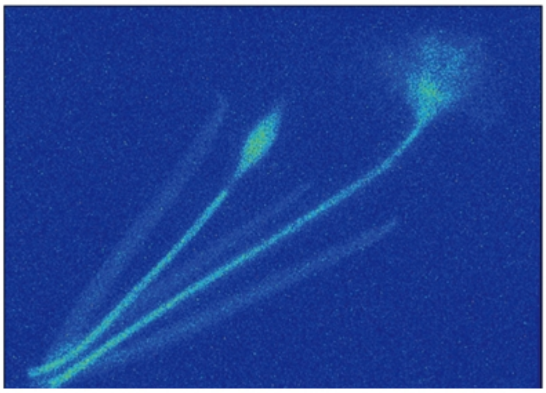
Therefore, we made a new learning material in English using the topics covered in supplemental learning material on radiation in Japanese as a reference. We also updated some data and considered the differences in cultural background to provide a better understanding of the content.

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.

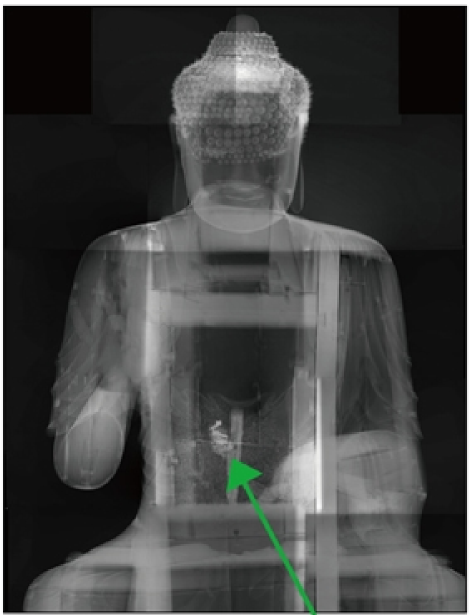
Neutron rays for Research on Liquid Flow

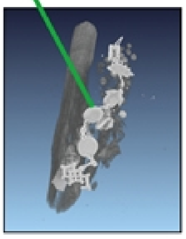
The picture on the right is made by exposing a lily to neutron rays. The white part shows the amount of water contained in the lily.

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.

4

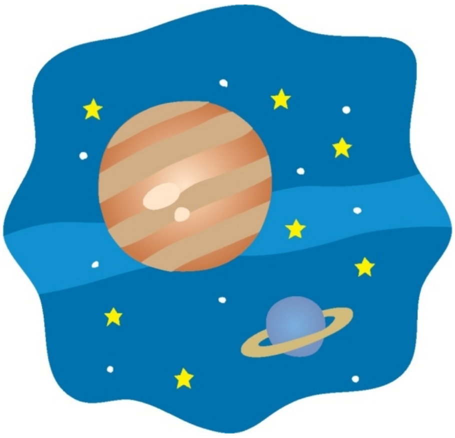
Radiation from the Natural World

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.

5

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.

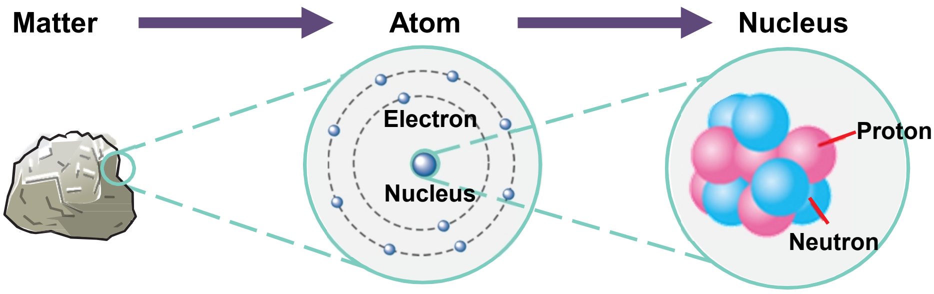
Approximately 110 types of elements* exist in the natural world, and everything such as the human body, food, air, water, clothes, desks, etc. is made up of atoms.

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

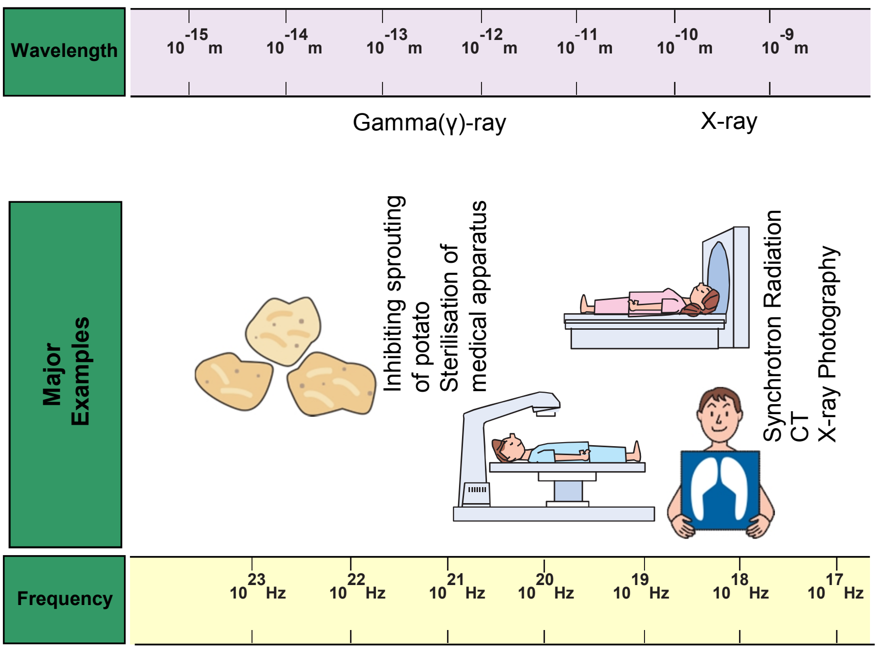
The atom is very small, only about 0.1 nanometer (1×10^{-10} m). The nucleus is much smaller, only about 2 femtometers (2×10^{-15} m).

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.

7

Radiation from Atoms

Some atoms emit radiation.

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

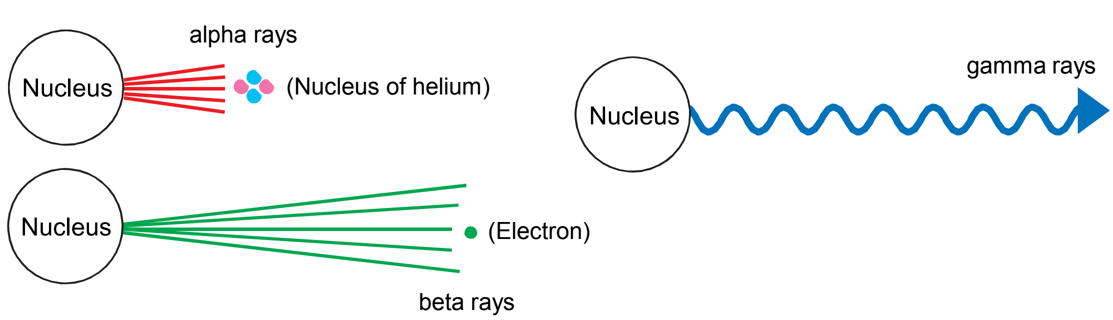
Radiation cannot be seen by the naked eye.

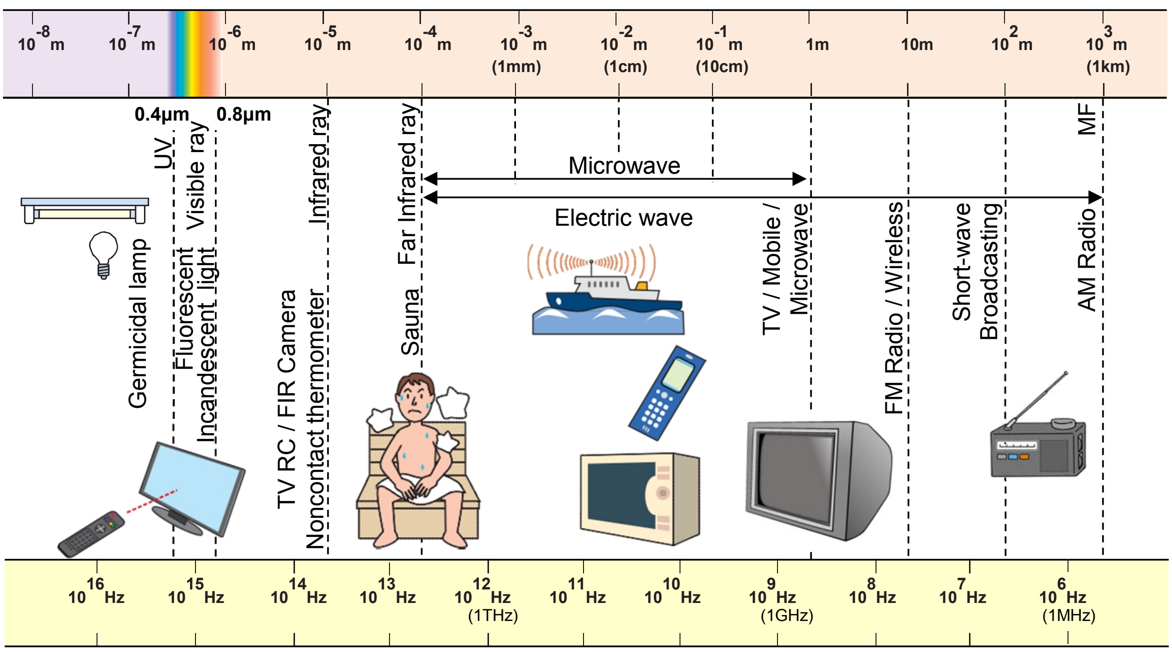
Radiation can pass through materials (penetrating properties) and can change the structure of atoms (ionisation).

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.

◆ **Small particles with high speed** ◆ **Travelling like a wave**





Source: Japan Atomic Energy Agency "what is radiation?"

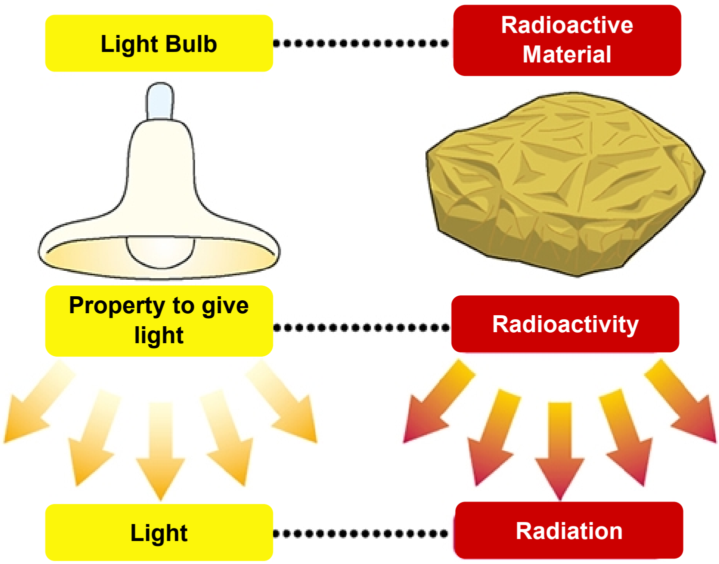
8

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.

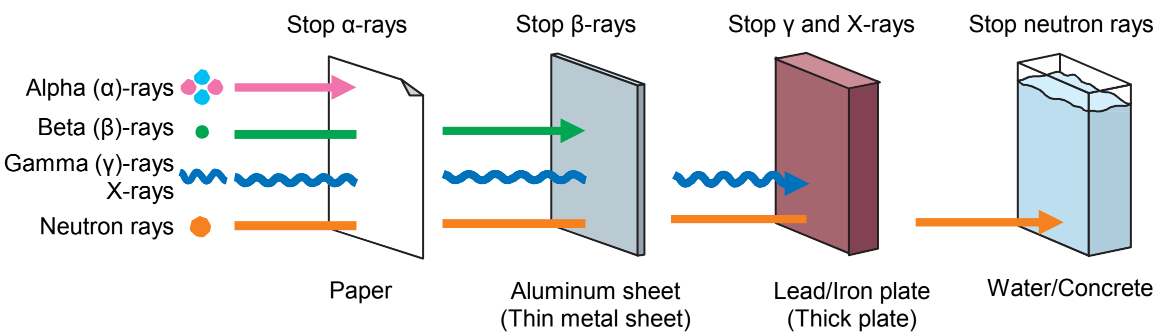


Penetrating Properties of Radiation

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.

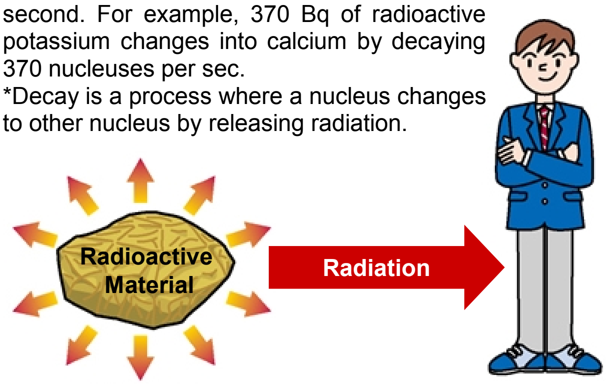
The power (intensity) that radioactive materials emit radiation is measured in a unit called "Becquerel (Bq)". The biological effects of radiation on the human body is measured in "Sievert (Sv)". The amount of radiation energy absorbed by materials and human tissues is measured in "Gray (Gy)".

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

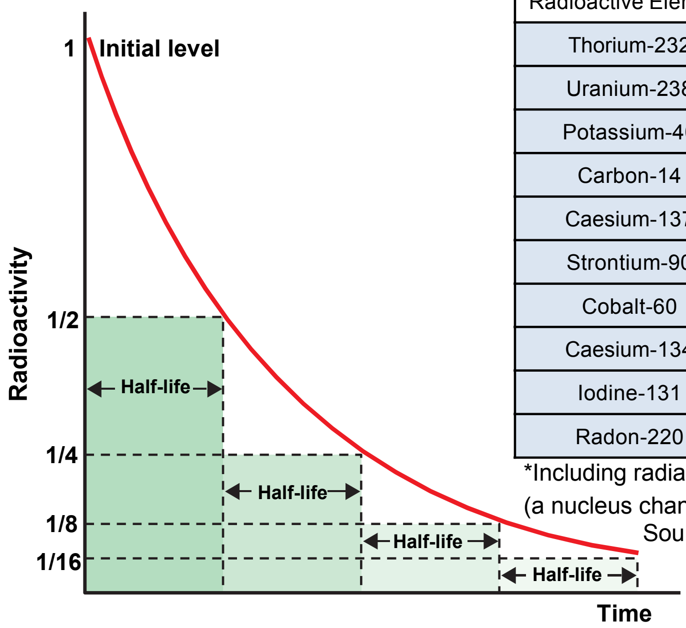
Using as an indicator for safety control of radiation

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)

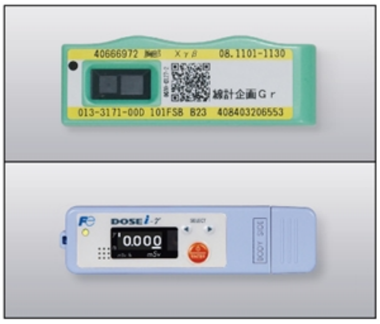
3) To check an individual radiation exposure

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

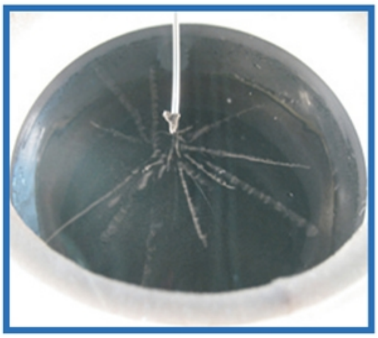
Measure the individual radiation dose. Also use to monitor the radiation levels. Unit: mSv/h
Note: Electric personal dosimeter may show an error value due to electric noise when placing next to a mobile phone.

◆ 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.

11

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

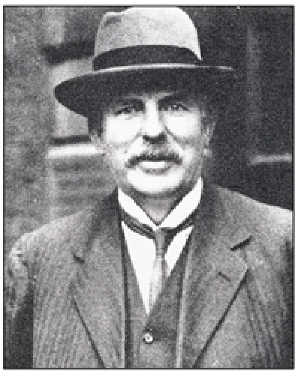
Becquerel put a cross shaped paperweight and uranium compound crystals on a photographic plate and left them in his desk drawer. He later found that the cross was projected to the photographic plate, and realised that the uranium released some form of radiation like X-rays.

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

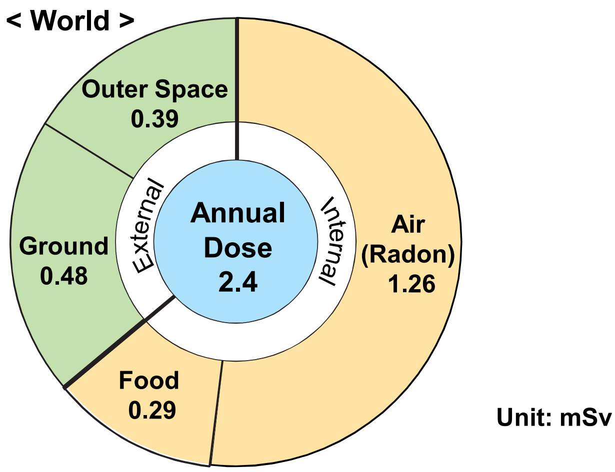
Exposure to radiation (to receive radiation) from radioactive materials that exists outside the body is called “external exposure”. On the other hand, exposure to radiation from radioactive materials that exist inside the body is called “internal exposure”.

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.

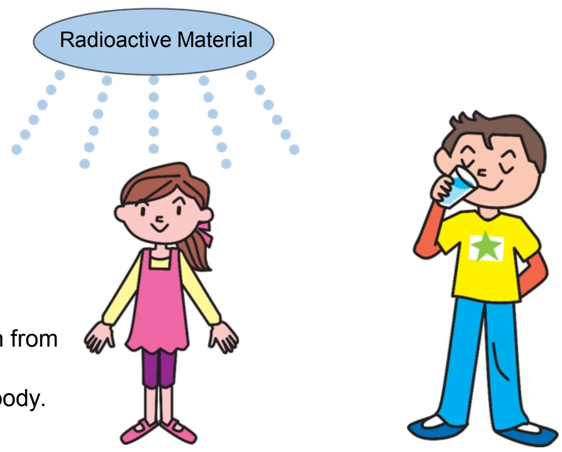
Radiation can pass through the body but does not remain inside, so the body or things will not become a source to release radiation. If you get contaminated with radioactive materials, these can be washed away by having a shower or washing clothes.

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.

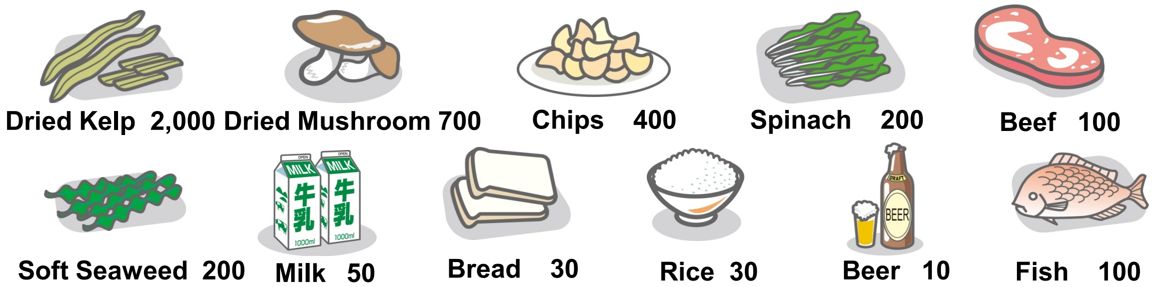
13

◆ 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)”

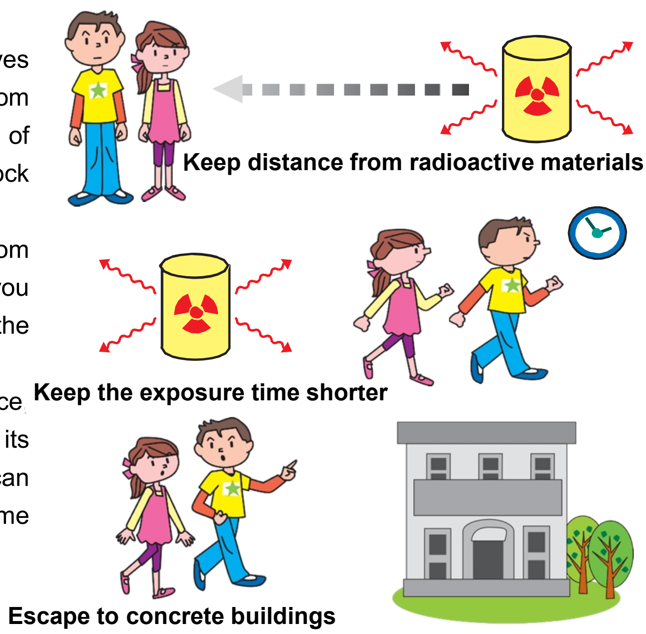
How to Protect from Radiation

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



(Higher shielding effects are expected than wooden buildings.)

> ***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

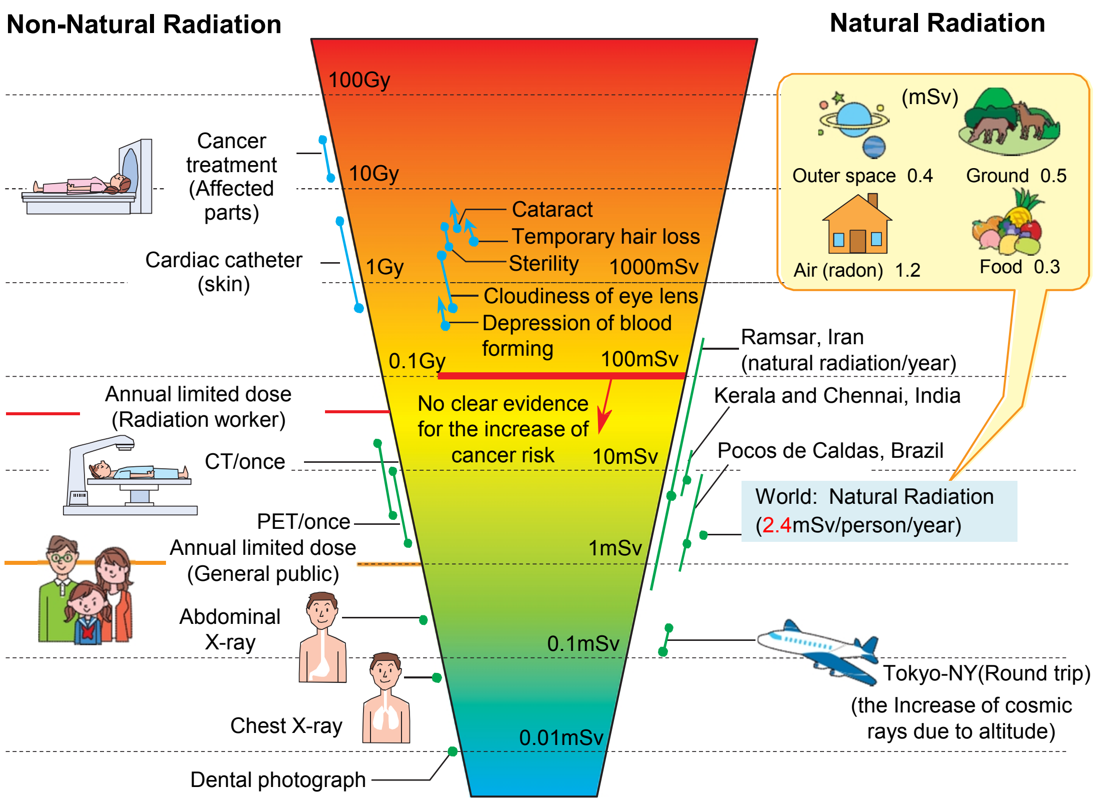
Relationship between Radiation Levels and Health

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

15

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

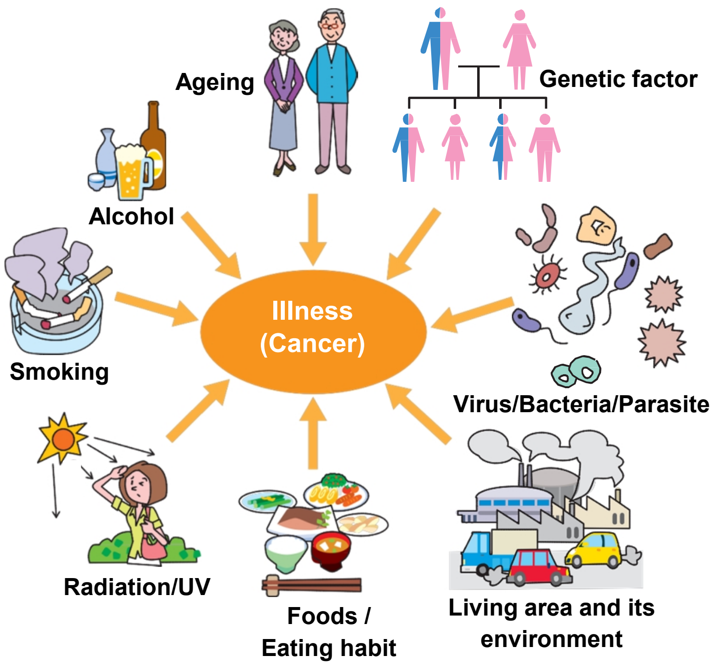
Our body is made up of living cells that can live with genetic information coding in DNA (deoxyribonucleic acid).

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.

16

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

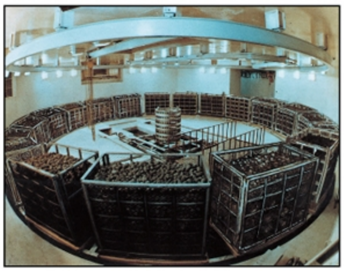
In Agriculture

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

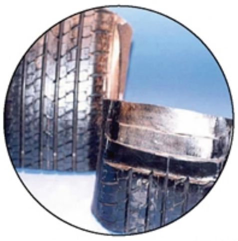
POINT
Radiation is used in various ways according to its features.

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

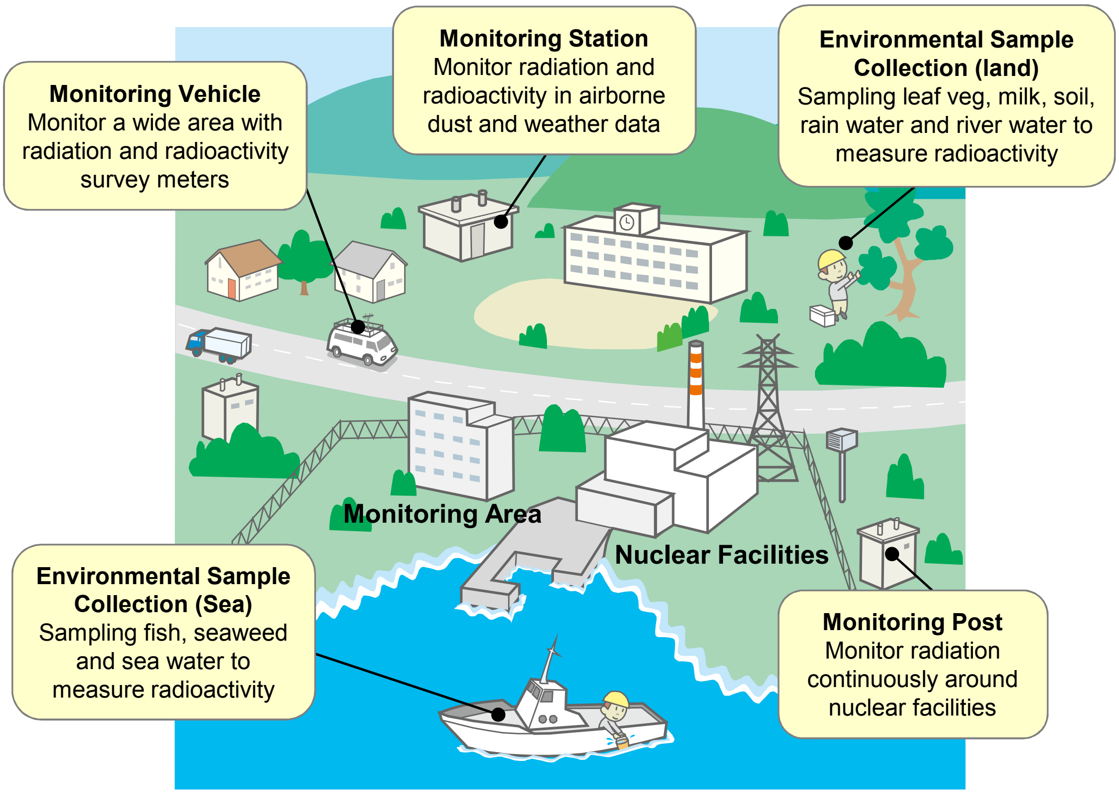
Monitoring posts and stations are located around the site of nuclear power stations and nuclear facilities in order to monitor radioactive materials released from the site to surroundings.

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

19

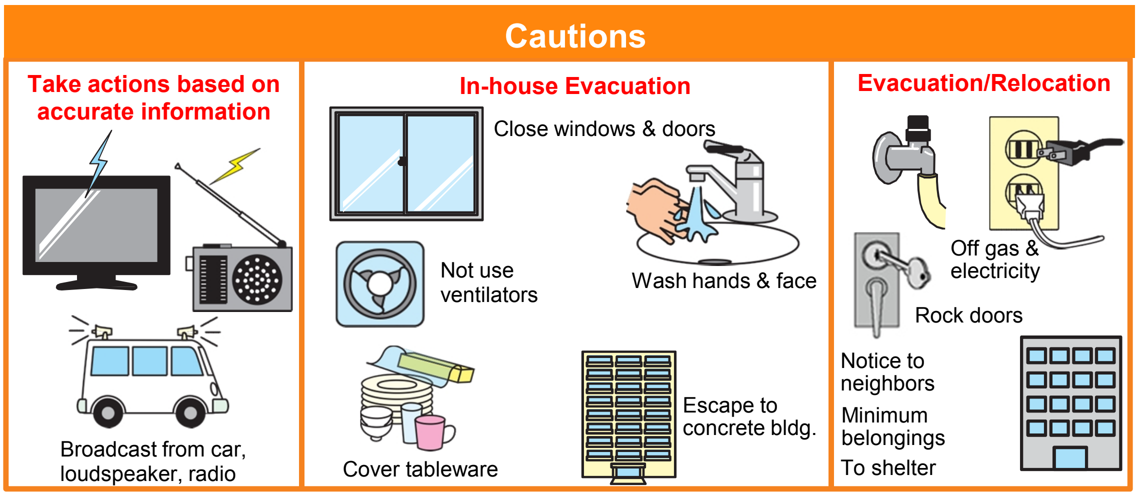
Protection from Radioactive Materials in Emergency

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

Learning Material in Japanese

Authors / Editors
Committee on Preparation of Supplementary Material in Radiation
Chairman: Takashi Nakamura

Editorial Supervision
Japan Radiological Society (JRS)
Japanese Society of Radiation Safety Management
The Japan Radiation Research Society
National Institute of Radiological Sciences

Photo Courtesy
Institute for Environmental Sciences / Kyushu National Museum / Kyoto University Hospital
Chiyoda Technol Corporation / Radiation Science Center / Tomoko Nakanishi
Japan Science Foundation / Nippon Nuclear Fuel Development Co., Ltd.
Japan Atomic Energy Relations Organization / Japan Chemical Analysis Center
Hitachi Aloka Medical, Ltd. / Fuji Electric Co., Ltd. / National Institute of Radiological Sciences
Yamagata Prefectural Center for Archaeological Research /
Institute of Physical and Chemical Research

Published by
Ministry of Education, Culture, Sports, Science and Technology
3-2-2 Kasumigaseki,
Chiyoda-ku,
Tokyo 100-8959,
JAPAN
In October 2011
Available at
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_04_1.pdf
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_05_1.pdf

Learning Material in English

Authors / Editors
Kiyonobu Yamashita
Yoko Watanabe
Mayuka Shimada

Nuclear Human Resource development Center
Japan Atomic Energy Agency
2-4 Shirakata-Shirane,
Tokai-mura,
Naka-gun,
Ibaraki 319-1195,
JAPAN
In December 2014

Photo Courtesy
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

付録 2

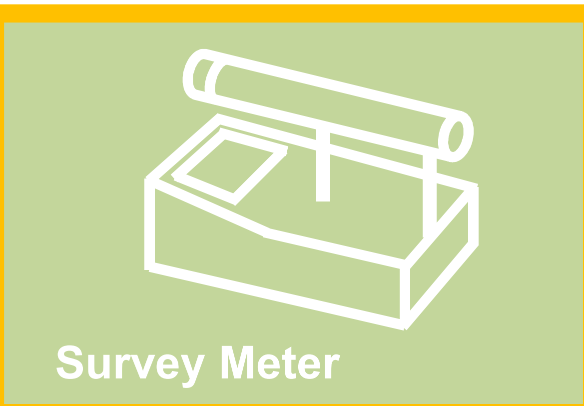
みんなで学ぼう　放射線の基礎

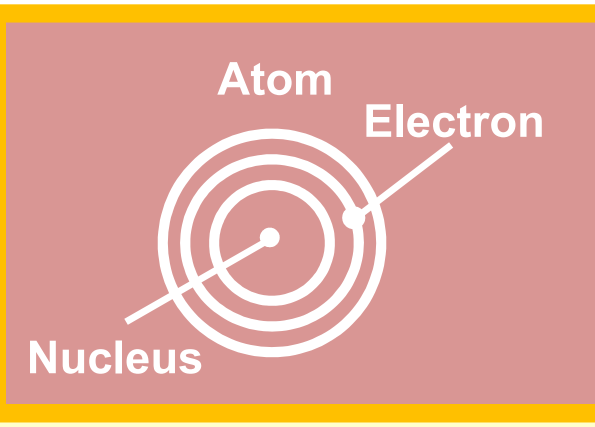
―中学校教師用―

Appendix 2

Let’s Start Learning Radiation (Secondary School Teacher)

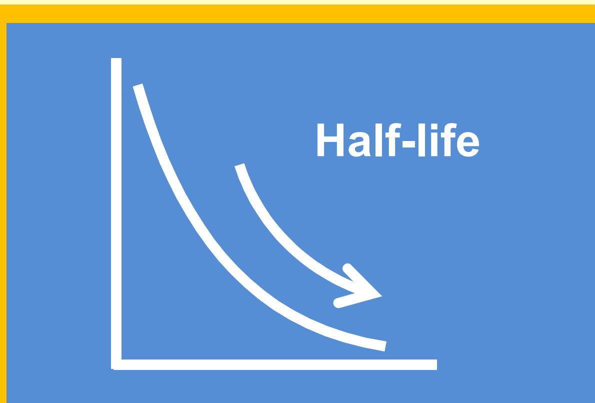
Supplementary Material on Radiation for Secondary School Students





Let's Start Learning Radiation

- Teaching Resources -



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.

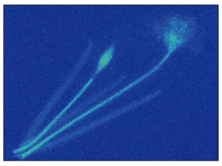
We hope this new material will offer the learning opportunities of radiation for young students in the world.

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

Contents

Mysterious World of Radiation

Mysterious World of Radiation



Radiation from Plants

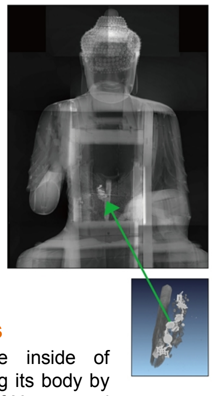
The figure on the left shows the natural radiation emitted from a narcissus.

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.



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.

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.

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.

3

4

Points for Learning

Students are going to learn;

- Radiation presents around us and is emitted from matter such as plants.
- Radiation is used for various areas of our life.

Points for Teaching

Students are able to understand;

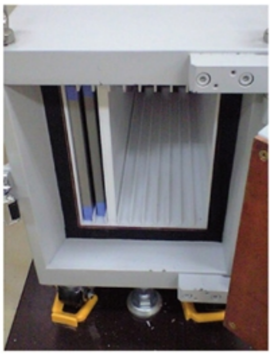
- Radiation exists around us and is emitted from matter such as plants.
- Practical uses of radiation for various areas of our life.

3

■ Imaging plate

Natural radiation emitted from plants can be seen as in the figure (student book, p.3) by using a special plate called an imaging plate. As the amount of radiation released from plants is very small, to obtain such picture, objects need to be shielded from the natural radiation by iron or lead, and are left for a few days to two months. The use of preservatives is recommended because the plants have to be left for a long period.

Plants emit beta rays or gamma rays because they contain an radioactive element, potassium-40, which occupies 0.012% of naturally occurring potassium. As you can see, the brighter part shows radiation where more potassium is contained.



Shielding box made by thick lead

■ Uses of neutron rays

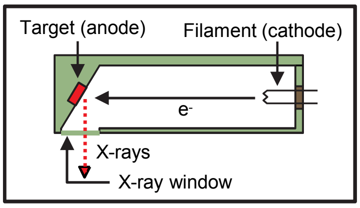
Since neutron rays have no electrical charge, they can easily penetrate substances. However, when the neutron interacts with lighter nuclei like hydrogen, it loses its energy more and slows down, so hydrogen-rich materials such as water can shield them effectively. Using these characteristics, living plants can be projected in photographic film as neutron rays cannot pass through water contained in the plants. Neutron radiography has been used for the study of plants, and its technique has been further improved. As a result, three dimensional (3D) images by CT (Computed Tomography) became available.

■ Radiation generator

Radiation is naturally emitted from radioactive materials, and can also be created artificially with special equipment.

1) X-ray generator

Giving a high voltage at both negative (cathode) and positive (anode) sides of the X-ray generator, high speed electrons are released from the filament. The released electrons hit the target of metal plate at the opposite side, where X-rays are generated. With the artificially created X-rays, the images of the inside of our body and materials can be obtained (e.g. chest and the statue of Buddha) .



X-ray CT is a combination of an X-ray generator and computer technology. It can produce sliced images of the human body by computer processing of X-ray data that are taken from various angles of our body. Recent advances in this technology enable CT scan to produce 3D images, which contribute to the accurate diagnosis of illnesses.

By using the properties of radiation, an accelerator can also generate X-rays. When charged particles such as electrons are bent by the magnetic force, X-rays are emitted.

2) Neutron generator

There are three ways to generate neutrons; the uses of nuclear reactors, accelerators and radioactive materials.

Nuclear reactor: 2 or 3 neutrons are generated by each nuclear fission when a neutron collides with uranum-235 inside the reactor.

Accelerator: when accelerated particles collide with a target, neutrons are generated.

Radioactive material: neutrons are generated by bombarding beryllium with alpha rays emitted from americium-241.

■ Radiation and the mystery of the universe

X-ray astronomy satellite "Suzaku" (graphic image)

There are various types of radiation; alpha rays, beta rays, gamma rays, proton beam, neutrino, etc., and these are generated from a nucleus. Different types of radiation have been applied to advanced research in the world.

"Suzaku" is an astronomy satellite to observe X-rays. As Suzaku can observe a wide range of wavelength of X-rays, it is used to study the structure and evolution of the universe and black holes.

Neutrino observation is also carried out at Japan Proton Accelerator Research Complex (J-PARC) located in Tokai, Ibaraki prefecture, Japan. At J-PARC, neutrino is generated and sent to a detector called Super-Kamiokande in Gifu prefecture (approx. 295km away).

Moreover, to identify the appearance of the universe becomes possible by observing weak radiation from outer space that could not be done with the existing telescope.

4

Radiation from the Natural World

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 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 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.

From Foods

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.

POINT

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

5 6

Points for Learning

Students are going to learn;

- Radiation presents since the birth of the earth and the universe, and rocks and soil contain radioactive materials.
- The level of natural radiation differs depending on regions and places.
- Radioactive materials are also contained in food and water.

Points for Teaching

Students are able to understand;

- Cosmic rays have been falling to the earth since the birth of the earth. (around 4.6 billion years ago).
- Radioactive materials are contained in natural resources, such as uranium and thorium in the ground, radon in the air, and potassium in food.

5

■ Natural radiation

We generally receive radiation from outer space, the ground, air and food. The average annual dose from the natural radiation in the world is about 2.4mSv. (see p.22)

1) From outer space

The radiation dose from outer space increases with height, as fewer materials present in the air to block radiation. Radiation from outer space (cosmic rays) forms radioactive elements in the atmosphere. For example, when cosmic rays collide with an atom in the air, neutron rays are generated. The neutron rays interact with atmospheric nitrogen and release protons, and the nitrogen becomes an radioisotope, carbon-14. Carbon-14 is used to determine the age of organic materials. Victor Francis Hess is the first person to discover cosmic rays in 1912 during the measurement of radiation on the balloon flight. For his discovery, he was later received the Nobel Prize in Physics.

2) From the ground

Radioactive elements have existed since the birth of the earth which is about 4.6 billion years ago. These elements decrease with time according to the law of half-life. However, some radioactive elements have longer half-lives, such as thorium and uranium, remain in the ground for a long time, so we receive radiation from the ground. There are regional differences in radiation dose from natural resources due to the concentration of radioactive materials in the ground of each area. For example, the annual dose from natural radiation at Kerala, India is 10mSv due to a large amount of minerals (monazites) that contains a radioactive element called thorium. Also Pocos de Caldas (Brazil), Ramsar (Iran), and Yangjiang (China) have relatively higher natural radiation levels.

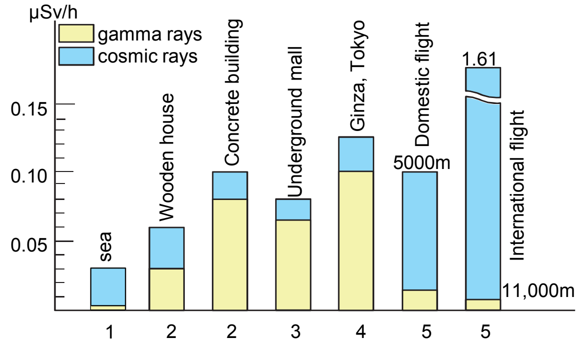
In Japan, the annual natural radiation is higher in the Kansai region than the Kanto region because more granite (a relatively large amount of radioactive materials is contained) is found in the Kansai.

3) From air

Radon is a noble gas, which is released from a small amount of radium in rocks, and emits alpha rays. Radon is emitted from the ground, stone-made houses and concrete walls. Therefore, the level of radon inside houses made of stone is relatively higher than other types of houses.

4) From food

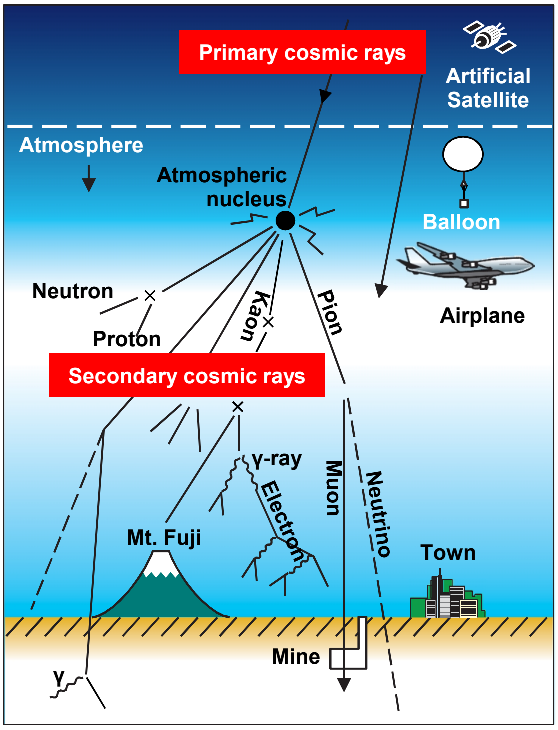
The three main nutrients for plants are nitrogen, phosphorus, and potassium. The 0.012% of potassium-40 (K-40) is contained in naturally occurring potassium, and its half-life is 1.28 billion years. K-40 emits beta rays and gamma rays. The amount of radioisotope is very small yet, carbon-14 and other radioisotopes are contained in food.



Note: 1000 μSv is 1mSv, i.e. 1 μSv/h is 8.76 mSv/ year.
Source: Radiation Science Center, High Energy Accelerator Research Organization "Handbook for radiation in daily life" (2005).

1. The level of gamma rays is low on the sea, as less radioactive materials are contained in sea water. Also water can shield gamma rays from the sea bottom.
2. Wooden houses have the lower level of gamma rays than concrete buildings but less shielding cosmic rays.
3. Usually cosmic rays cannot reach underground but surrounding walls emit gamma rays.
4. Granite is commonly used for pavements in Ginza, Tokyo, and there are many concrete buildings. The level of gamma rays from granite and concrete is higher than cosmic rays.
5. The cosmic doses increase with altitude as less shielding effects in higher places.

Cosmic rays from the galaxy and the sun are falling to the earth. These radiations are charged particles with high energy, and collide with atoms and break them. These atoms further interact with other atoms and release different types of radiation like a shower.



What is Radiation

What is Radiation

Atoms and Nucleus

All matter is formed by atoms.

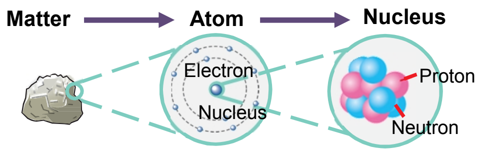
Approximately 110 types of elements* exist in the natural world, and everything such as the human body, food, air, water, clothes, desks, etc. is made up of atoms.

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.



Radiation from Atoms

Some atoms emit radiation.

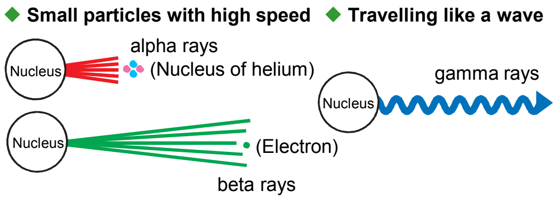
Radiation can be a particle or a wave with high energy.

Radiation cannot be seen by the naked eye.

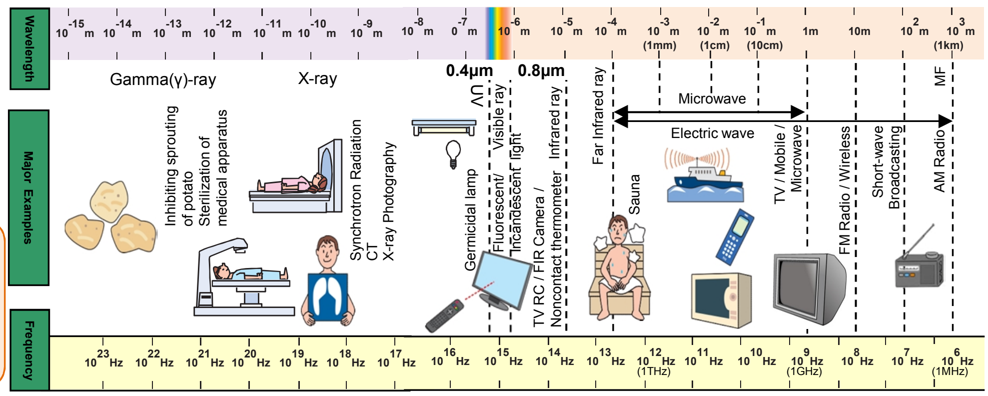
Radiation can pass through materials (penetrating properties) and can change the structure of atoms (ionisation).

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.



◆The group of electromagnetic wave



POINT
Let's find out which materials are radioactive.

Source: Japan Atomic Energy Agency "what is radiation?"

7 8

Points for Learning

Students are going to learn;

- Radiation is emitted from a nucleus.
- Radiation has the particle and wave characteristics.
- Atoms emit radiation.

Points for Teaching

Students are able to understand;

- Radiation is a "particle ray" (α-rays, β-rays) or a "wave"(γ-rays), and both are emitted from a nucleus.
- Types and characteristics of radiation.

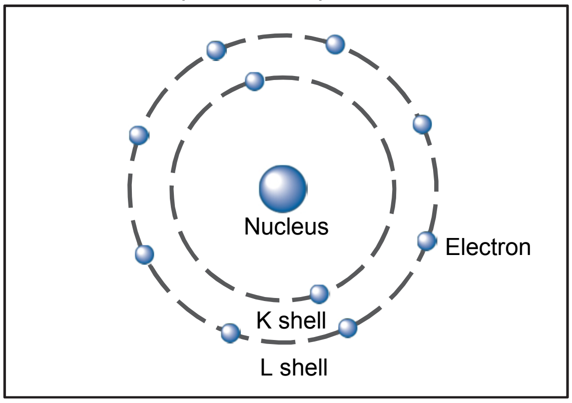
7

■ Shape and size of atoms

All matter is formed by a large number of atoms. The size of atoms is depending on its type, but usually is about 0.1 nanometer. For example, 1 cubic centimeter (cm^3) of gold bar (mass is 19.3g) is made of 6×10^{22} (one trillion times of 60 billion) of gold's atoms. The diameter of gold's atom is 0.32 nanometer so you can imagine how small one atom is.

An atom consists of much smaller elements called "nucleus" and "electron". A nucleus is 10,000 times smaller than the atom and has a positive charge. An electron is negatively charged and a lighter particle with 9.1×10^{-28}gram in mass. The number of electrons, which moves around the nucleus, is equal to a valence of the nucleus.

◆ Atom model (Shell model)

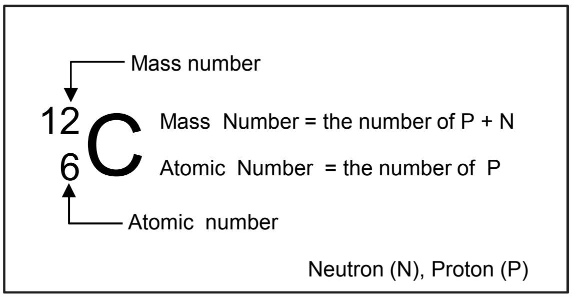


■ Nucleus, atomic number, mass number

A nucleus contains positively charged protons and uncharged neutrons, and both have approximately the same mass which is about 1,840 times greater than the mass of an electron.

A nucleon is a collective term for the components of a nucleus, namely protons and neutrons.

The number of protons is equivalent to the atomic number, and the total number of both protons and neutrons is called the mass number. A nucleus has the same number of protons but a different mass number (i.e. a different number of neutrons), are known as isotopes.



■ Types of radiation

Radiation can be divided into "particle rays" as particles and "waves" as the same as radio waves and light. Particle rays are further divided into charged particle rays and uncharged neutron rays.

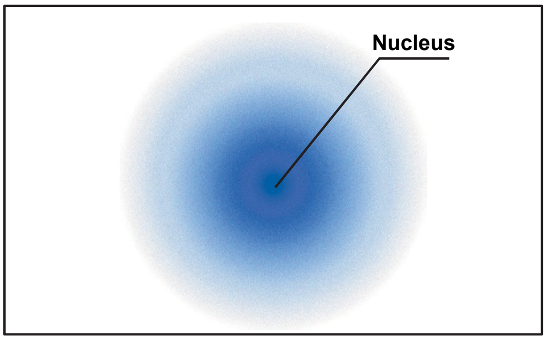
Charged particle rays include alpha rays, beta rays, and positively changed carbon and proton for medical applications, as well as elementary particles like muon. Middle waves (radio waves), microwaves, visible rays, X-rays, and gamma rays are considered as waves. Alpha rays, beta rays and gamma rays are the main types of radiation being emitted by the decay process of a nucleus. Alpha rays are the nucleus of helium (2 protons and 2 neutrons), and beta rays are the flow of electrons.

◆ Examples of radioactive elements (radioisotope)

Tritium (hydrogen-3)	Strontium-90
Carbon-40	Iodine-129
Sodium -24	Iodine-131
Phosphorus-32	Caesium-137
Potassuim-40	Gold-198
Calcium-45	Radium-226
Iron-59	Thorium-232
Cobalt-60	Uranium-238

Reference [Electron cloud model]

We cannot detect the exact location of electrons and its speed. The electron cloud model can show their probable location. The darker colour in blue shows places where electrons are more likely to be present.



■ Relationship between wavelength and frequency

The wavelength λ meter (m) can be calculated by this equation. λ (m) = 300 (Mm/s) / f (MHz)

Where,

Transmitting speed of wave : 300,000 kilometer per second (km/sec) (=about 300Mm/s)

Frequency : f MHz

The wavelength and frequency in the figure (student book, p.8) can be calculated by the equation.

*mega (M) is 10^6.

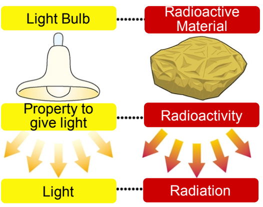
Basic Knowledge of Radiation

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.

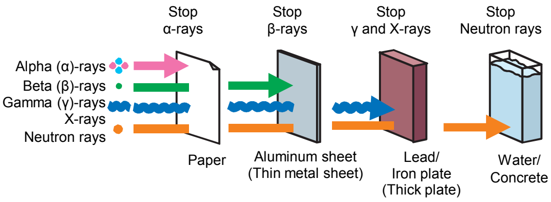


Penetrating properties of Radiation

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.

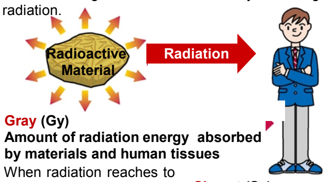
9

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)
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)
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.

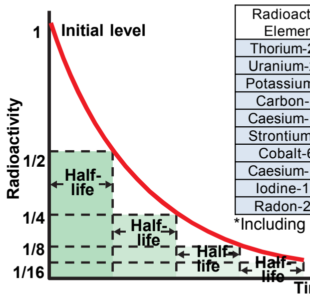
Sievert (Sv)
Biological effect of radiation on the human body
Using as an indicator for safety control of radiation

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	14.1billion yrs
Uranium-238	α, β, γ	4.5 billion yrs
Potassium-40	β, γ	1.3 billion yrs
Carbon-14	β	5,730 yrs
Caesium-137	β, γ	30 yrs
Strontium-90	β	28.7 yrs
Cobalt-60	β, γ	5.3 yrs
Caesium-134	β, γ	2.1 yrs
Iodine-131	β, γ	8 days
Radon-220	α, γ	55.6 sec

*Including radiation from decay products (a nucleus change to other nucleus by releasing radiation)

Source: Japan Radioisotope Association “Radioisotope Pocket Data book 10th ed.”

10

Points for Learning

Students are going to learn;

- “Radioactive material”, “Radioactivity” and “Radiation”
- Radiation can penetrate materials, and there are different shielding methods depending on their types.
- Three units are used in radiation.
- Radioactive materials decrease with time, and their decrease patterns differ by radioactive elements contained in materials.

Points for Teaching

Students are able to understand;

- Differences between “Radioactive material”, “Radioactivity” and “Radiation”.
- Radiation can penetrate materials, and there are different shielding methods depending on radiation types.
- Differences between “Becquerel”, “Sievert”, and “Gray”
- Radioactive materials decrease with time, and their decrease patterns differ by radioactive elements contained in materials.

9

■ Radioactive material, radioactivity, and radiation

Matter emitting radiation is called radioactive materials, and the power of emitting radiation is radioactivity. Uranium, thorium, potassium, and carbon are examples of natural radioactive materials. Conversely, radiation can be produced artificially from radiation generators (accelerator, etc.) or fission products by nuclear fission, and these radioactive materials are cobalt, iodine, caesium, technetium, etc.

■ Penetrating power of radiation

Penetrating properties of radiation differ depending on its types. Alpha-ray is a helium nucleus, which can travel only for a few centimeters (cm), and can be stopped by a piece of paper. While alpha rays are traveling, they interact with other particles in the air and gradually lose its energy and stop, finally become an atom of helium.

Alpha rays emitted from radioisotopes cannot penetrate the skin surface so biological effects on the human body hardly occur. However, if alpha emitters enter inside the body by breathing or ingesting, living cells and tissues could get damage.

Beta rays can be blocked by a thin metal sheet like aluminium. Gamma rays can pass through a paper and an aluminium plate, and can be stopped by lead or thick iron plate. Neutron rays can be stopped by water or concrete. Therefore, radiation levels can be reduced by choosing a right shielding material according to radiation types.

■ Units of radiation

Becquerel (Bq), Sievert (Sv), and Gray (Gy) are units to express the intensity of radioactivity or the amount of radiation.

1. Becquerel

The count of nuclear decay per second indicates as Becquerel (Bq) (count/second). The amount of radioactive materials contained in matter is given in Bq/kg. This unit was named after Henri Becquerel who discovered radiation.

2. Sievert

The degree of radiation effects on the human body indicates as Sievert (Sv). Since each radiation has the different forms of energy, its biological effects on living tissues and organs also differ. Therefore, these differences are adjusted in measurement using modifying factors, and two types of dose quantity (effective dose and equivalent dose) are used for radiation protection. (see the reference on the right)

3. Gray

The amount of radiation energy absorbed by matter or human tissues indicates as Gray (Gy). 1 Gy is equal to the dose that 1 joule of energy per 1 kilogram is absorbed (J/kg). This unit is more often used for the evaluation of radiation effects on cancer treatment and sterilisation rather than direct radiation effects on the body.

Reference [Radiation Doses (Gray and Sievert)]

Gray is a "physical quantity" defined as the energy absorbed per unit mass and is used to consider deterministic effects*1. Sievert*2 is used as an index*3 for radiation protection to consider radiation-related cancer. Effective dose is only applied to stochastic effects*4 such as cancer and hereditary effects and cannot apply to deterministic effects.

*1Deterministic effects: effects certainly occur when doses exceed the certain level. The severity increases with doses. Major symptoms are the decrease of lymphocytes, vomiting, hair loss, and cataract.

*2Refer to effective dose here, but sievert is used also for other quantities (e.g. equivalent dose and 1 centimetre dose equivalent).

*3Calculating based on gray with weighing factors to take account of differences in radiation sensitivities of each organ and tissue.

*4Stochastic effects: increase the occurrence rate with doses, and major symptoms are cancer, leukaemia.

Note1: there are two quantities to express biological effects on the human body; effective dose and equivalent dose (unit is sievert for both doses). The equivalent dose is quantity to express radiation effects on tissues or organs considering different effects by radiation types. The effective dose is quantity doses that calculate by adding the different radiation effects on each organ and tissue to the equivalent doses of organs and tissues.

Equivalent dose = Absorbed dose x Radiation weighting factor

Effective dose = (Equivalent dose of organ/tissue 1 x Radiation weighting factor of organ/tissue 1) + - - + (Equivalent dose of organ/tissue N x Radiation weighting factor of organ/tissue N)

Note2: 1 centimetre dose equivalent: as the effective dose is immeasurable by devices, the measurable quantity dose is introduced. It is designed to keep the effective dose is always within the safety levels in case of any types of radiation exposure. Under the Japanese law, 1 centimetre dose equivalent is considered as the effective dose.

◆ **Radiation weighting factors**

Type of radiation	W_R
Photons (gamma rays, X-rays)	1
Electrons (beta rays)	1
Protons	2
Alpha particles, fission fragments , heavy nuclei	20
Neutron rays	2.5 ~ 20

◆ **Tissue weighting factors**

Organ/Tissue	W_T	Organ/Tissue	W_T
Bone marrow	0.12	Oesophagus	0.04
Colon	0.12	Thyroid	0.04
Lung	0.12	Salivary glands	0.01
Stomach	0.12	Skin	0.01
Breast	0.12	Bone surfaces	0.01
Gonads	0.08	Brain	0.01
Bladder	0.04	Remainder organs / tissues	0.12
Liver	0.04		

Source: ICRP Publication 103 (2007)

Basic Knowledge of Radiation

■ Radioactivity and half-life

Radioactive materials emit radiation with fixed energy.

The time that the amount of radioactivity to be halved by releasing radiation is called physical half-life.

For example, the physical half-life of caesium-137 is 30 years, so its radioactivity is reduced by half of its initial value in 30 years. Caesium decays and becomes barium by releasing energy of 0.514 MeV of beta rays and 0.66 MeV of gamma rays.

In contrast, the time that radioactive materials taken into the body to be halved by metabolism and excretion is called biological half-life.

Taking both biological half-life (Tb) and physical half-life(Tp) into account, the actual time that radioactive material in the body to be halved is known as effective half-life (Te), which can be obtain by the following formula. For example, the physical half-life of iodine-131 is 8 days, and shortly after 70% of them are removed in urine to outside the body. The remained 30% are accumulated in thyroid, and its biological half-life is 80 days. Thus, the effective half-life of iodine-131 is around 7 days. The physical half-life of caesium-137 is 30 years, and its biological half-life is 100 days (distributed in muscles of the whole body). The effective half-life is also 100 days. Strontium is distributed complicatedly in the whole body (70%), and most of them are removed to outside the body in 100 days. About 30% remains in bones, and their biological half-life is very long. (ICRP Publication 67, 1993)

The biological half-life is applied to adults. As infants and children have a faster metabolic process, their biological half-life becomes shorter than adults.

Having the same radiation dose, the impact of health effects is the same either from the natural radiation or non-natural radiation.

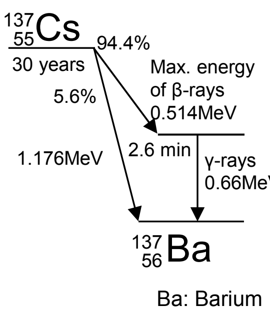
*MeV

M: 10^6

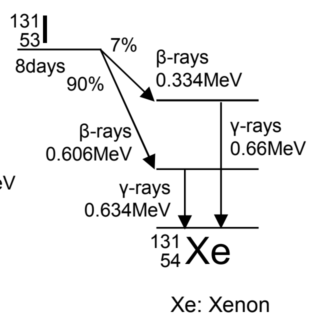
eV: the amount of energy that single electron gains by accelerating in electrical potential difference of 1 V.

$$\frac{1}{T_e} = \frac{1}{T_p} + \frac{1}{T_b}$$

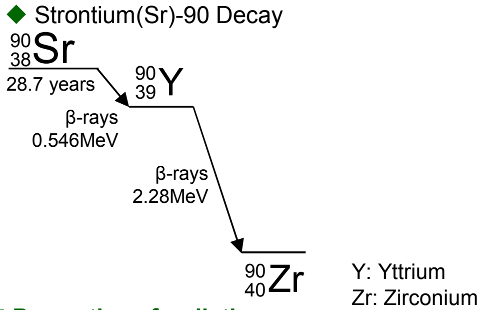
◆ Caesium (Cs)-137 Decay



◆ Iodine (I)-131 Decay



◆ Strontium(Sr)-90 Decay



■ Properties of radiation

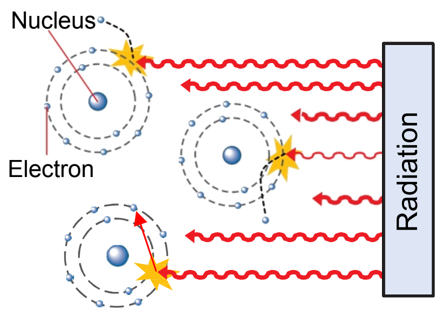
Radiation has various characteristics. The interaction of radiation with matter is used as practical applications in medicine, industry and agriculture.

1. Ionisation and excitation

When radiation passes through atoms, electrons are removed. The process is called ionisation. Remained atoms become positively charged atoms (ion). Whereas, when radiation interacts with atoms, electrons transfer to outside the orbit. The process is called excitation.

The structure of atoms can be changed by using these properties. For example, the material strength of high polymers like plastics can be enhanced by irradiation, which leads to the change of bonding of atoms. As agricultural applications, radiation is used for selective breeding by speeding up of naturally occurring mutation processes.

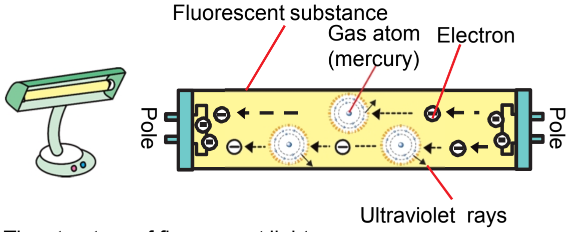
The GM counter or the ionisation chamber are radiation detectors which use ionisation in a tube filled by air or inert gas (helium, argon or neon). When a negative and positive high voltage is applied in the tube, an ionised electric charge is created. The charge is counted as a signal.



2. Fluorescent properties

When excited electrons return to the original orbit, an extra energy is released as X-rays. These X-rays interact with matter and release light during the interaction. This process is the fluorescent properties of radiation, and these materials are called fluorescent substances. Uranium ore emits fluorescent when ultraviolet rays are exposed.

Scintillation-type survey meter makes use of the fluorescent properties. Exposing to radiation, a crystal material inside the survey meter emits light which is counted as a signal.

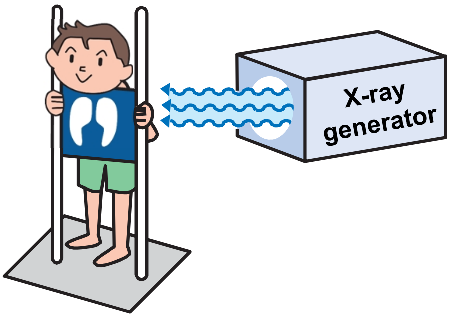


The structure of fluorescent light

Giving electric power to poles on both sides of the tube, electrons flow between them. When electrons hit mercury, producing ultraviolet rays, which light fluorescent substances.

3. Penetrating properties

The ability that radiation can pass through matter is called penetrating properties. X-rays can show the inside of our body using a different penetrability of radiation between calcium and water, as heavy atoms absorb more X-rays. The penetrability is also applied to measure the thickness of liquid, iron plate and paper.



Reference [Carbon dating using half-life]

A characteristic property of half-life has been used for a better understanding of our history. The age of earthenware can be estimated by measuring carbon deposits on plants that are attached to the earthenware.

A radioactive carbon-14, which has a half-life of 5,730 years, is made from cosmic rays and nitrogen atoms in the atmosphere. Most carbon dioxide consists of one carbon-12 atom that does not emit radiation, and two oxygen atoms. However some carbon dioxide consists of carbon-14.

Plants absorb carbon dioxide, as well as carbon-14 from air by photosynthesis. Animals take in carbon-14 by eating these plants. When plants and animals die, they cannot take new carbon-14 anymore. For that reason, by measuring the amount of carbon-14 in organic materials, the age of historic remains can be estimated

Reference

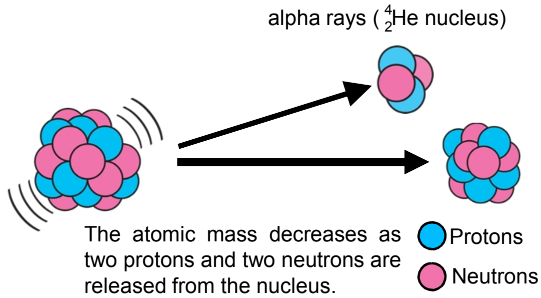
[Alpha, beta decay and gamma rays emission]

Alpha decay

Two protons and two neutrons are emitted together from a nucleus as a particle that is called an alpha particle. The particle has the same component of helium's nucleus, and is a positive particle.

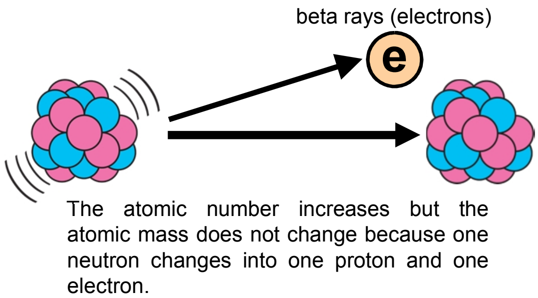
As alpha rays are heavy particles among radiation, they can be stopped in shorter distance where they lose the energy through ionisation and excitation in the air.

A decay by releasing alpha rays is known as alpha decay. Alpha rays are emitted from heavier nuclei such as uranium and radium.



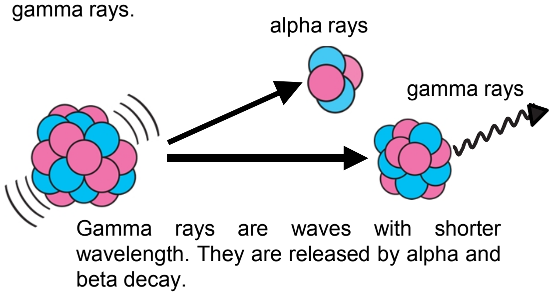
Beta decay

When one of neutrons in a nucleus changes into a proton, a fast electron is released. The released electron is beta ray. A decay by releasing beta rays is known as beta decay. Negative electrons emitted from the nucleus can be stopped by losing their energy by Ionisation and excitation like alpha rays.



Release of gamma rays

After a nucleus releases alpha rays and beta rays, the nucleus becomes unstable (excited state), and the unstable nucleus releases energy to outside to become stable. The released energy is gamma rays. The nucleus itself is unchanged, even after releasing gamma rays.



Radiation Measurement Devices

Radiation Measurement Devices History of Radiation & Radioactivity

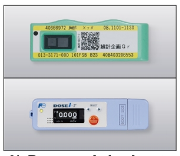
We cannot feel radiation with our five senses (sight, hearing, smell, taste and touch), but we can detect radiation with appropriate equipment.

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



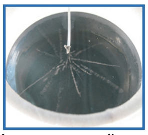
3) Personal dosimeter
Measure the individual radiation dose. Also use to monitor the radiation levels. Unit: mSv/h
Note: Electric personal dosimeter may show an error value due to electric noise when placing next to a mobile phone.

◆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.

11

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.

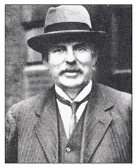
Discovery of Radioactivity In 1896
Henri Becquerel

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".

12

Points for Learning

Students are going to learn;

- There are various types of radiation measurement devices, and we can measure invisible radiation by using them.
- The presence of radiation around us through experiments such as "cloud chamber" and "simplified radiation survey meter".

Points for Teaching

Students are able to understand;

- There are various types of radiation measurement devices for different purposes.
- The presence of radiation around us through experiments such as "cloud chamber" and "simplified radiation survey meter".
- Studies on radiation have been conducted by many researchers to find out radiation types and its properties that are used for many applications and measurement devices.

13

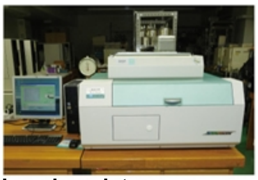
■ Various types of measurement equipment

Radiation measurement equipment is mainly categorised into three types.

1) To detect the presence of radioactive materials (use for surface contamination)
2) To measure air radiation doses
3) To measure individual radiation doses

1) Geiger-Müller counter (GM tube) counts the number of radiation by giving high voltage in a tube. (Use of radiation ionising properties)
2) Scintillation-type survey meter measures the energy and dose of gamma rays using radiation fluorescent properties in crystal. The crystal is made by sodium iodine or caesium iodine.
3) Personal dosimeter is a small wearable device to measure radiation doses from the outside of the body. Examples are silicon semiconductor dosimeter, Optically Stimulated Luminescence Dosimeter (OSL), Thermoluminescent Dosimeter (TLD), fluoroglass dosimeter, etc.

It is important to choose the right equipment as radiation has different characteristics.

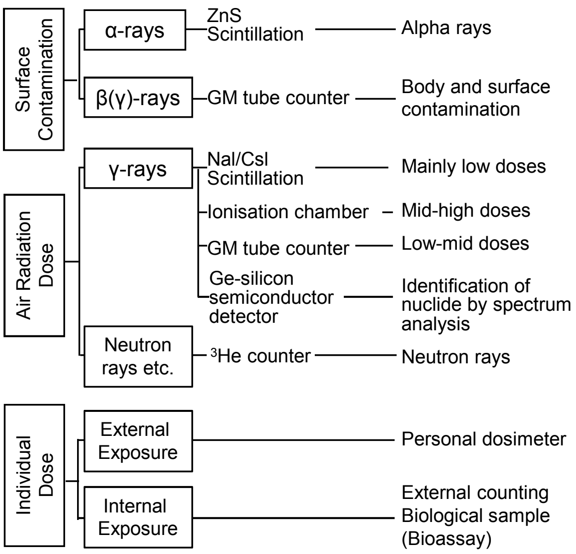


Imaging plate
To measure and study the 2D distribution and local distribution of radioactivity in materials.

ion chamber survey meter
To measure radiation doses.

Semiconductor
To measure the energy distribution of radiation. To determine radioactive nuclide.

◆ Classification of radiation measurement



■ To measure radiation

Radiation can be detected and measured by different kinds of equipment according to radiation types. Getting closer to a radiation source, a measurement device shows higher measurement values. When measuring air doses, generally the device set at 1m or 50cm from the ground where no buildings are around.

When detecting radiation sources, keep the distance or cover a measurement device to avoid contamination.

When measuring personal doses (radiation workers), wear the dosimeter on chest or abdomen (women with possible pregnancy).

Before using measurement equipment, reading its instructions is necessary as measureable radiation, energy range and accuracy differ by each device.

■ Use of a simplified radiation measuring device

For educational purposes, simplified radiation measurement devices are used at primary and secondary schools in Japan.

By using the device, students are able to experience the presence of radiation.

[Examples of radioactive materials surrounding us]

1. Granite (thorium, uranium, potassuim-40, etc)
2. Salt (potassium-40)
3. Sinter (thorium, uranium)
4. Potassium fertilizer (potassium-40)
5. Bottom ship paint (thorium-232)
6. Mantle: a wick of lantern (thorium-232)
7. Potassium chloride (potassium-40)

[Examples of measurement place]

Inside: buildings made of wood, concrete, stone, brick, etc.

Outside: private garden, street, farm field, temple, park, etc.

Other: stone retailer, tunnel, cave, pond, lake, sea, mountain, higher places and the ground at the beginning of raining and snowing.

[note]

1. Taking a record of places where you measure radiation such as building materials, types of soil and rocks, the ground and surroundings
2. Measurement devices may show an error value due to electric noise when it places next to electric devices.

14

Radiation Measurement Devices

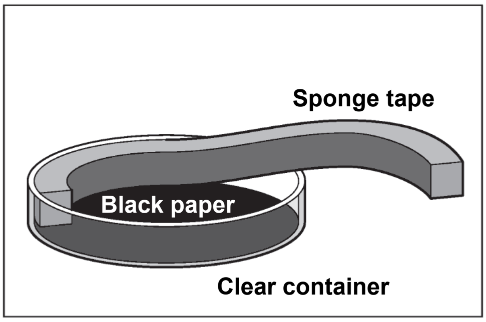
■Observation of radiation track

Radiation tracks become visible with a simple device, known as a cloud chamber. The following instructions show the track of alpha rays.

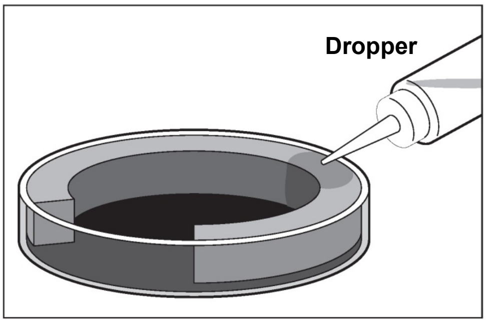
1. Items:

Clear container, black paper, ethanol, dropper, sponge tape, pocket torch, foamed styrol, dry ice, radiation source. If the radiation source is not available, dusts can be used as an alternative because dusts contain decay products of radon (to suck dusts for 30 minutes using a nozzle of vacuum cleaner covered by soft paper).

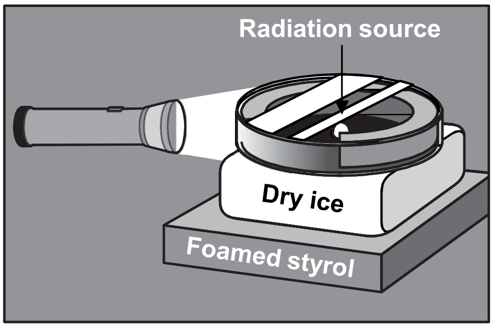
2. To set a sheet of black paper at the bottom of a clear container, and attach a sponge tape inside.



3. The sponge tape is socked with ethanol in dropper.



4. To set a radiation source in the centre of container and close the container with a lid, and then place the container on dry ice.
5. To observe radiation by lighting the side of container with a pocket torch in the dark room.

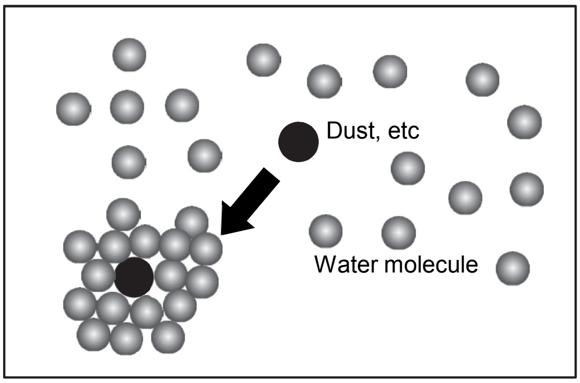


*Do not touch the dry ice directly with your hands
*Do not use ethanol close to flammable.

■ Principle of a vapor trail

The track of radiation, which you can observe in the cloud chamber, is similar to a vapor trail of an airplane. The temperature at an altitude of 10,000m is – 40 °C as the temperature decreases by 0.6 °C every 100m rise from the ground.

When the airplane passes through a supersaturated state that is created by sudden temperature gradient, the vapor trail generates as water drops or ice particles (ice crystal) attach to dusts in waste gas from the airplane.



When dusts are floating in the air, water attaches to them.

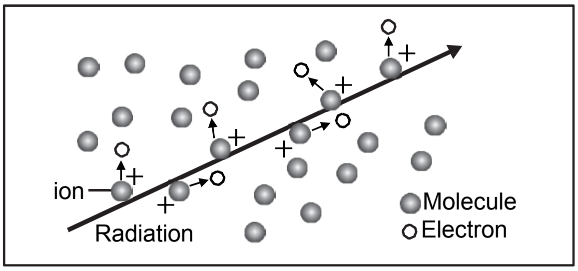
■ Mechanism to observe a track

Fog is made of small water drops that surround dusts. When vapour in the air is cooled down in a short time, an unstable state (supersaturation state) is created where the vapour concentration reaches the limit (higher than the saturation vapour pressure).

Under the supersaturation state, fog is easily generated. In order to create the supersaturation state easily in the cloud chamber, alcohol vapour (ethanol) is used instead of water vapour. The supersaturation state can be generated in the container by making the temperature differences between the room temperature and dry ice. Alpha rays emitted from the radiation source in the container take a straight line in the air and loses all its energy in a few cm.

Meanwhile many positive and negative ions are produced along the path of the α-ray track.

Visible straight lines (radiation track) will appear because the supersaturated alcohol vapour is condensed, and formed alcohol fog.



Electron and ion are removed as pair by radiation.

15

History of Radiation & Radioactivity

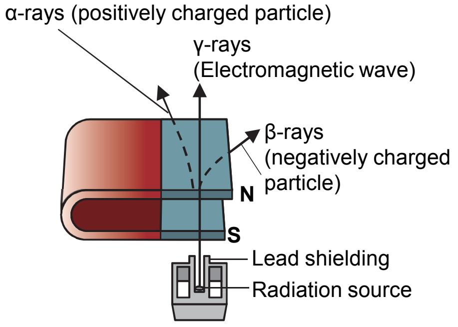
■ History of the discovery of radiation

A German physicist, Wilhelm Conrad Röntgen, was on experiment using a glass tube with electrode like a fluorescence tube. In 1895, he realised that although the glass tube was covered by a black paper, light was emitted from a fluorescent screen. He named the unknown light released from the tube as X-ray. Later experiment confirmed that bone fractures can be seen by exposing a photographic plate to X-rays.

In 1896, the next year of the discovery of X-rays, a French physicist, Henri Becquerel, found some form of radiation like X-rays that were emitted from uranium. One day, he placed a paperweight and a uranium compound on a photographic plate and left them in his desk drawer. When the photographic plate was developed, the shape of paperweight appeared.

Mr. and Mrs. Curie was trying to extract elements which emit a similar ray to X-rays. In 1898, they succeeded to extract radioactive elements with strong radiation, polonium and radium, from uranium mineral. Marie Currie named the properties of radioactive elements (i.e. releasing radiation) as “Radioactivity”.

A British physicist, Ernest Rutherford, found radiation emitted from radium that was curving in two directions by the magnetic force. He called them alpha rays and beta rays. He later discovered another radiation that was not curved by the magnet, and named it gamma rays.



Year	History in Radiation	History in World
1895	Röntgen discovered X-rays	
1896	Becquerel discovered mysterious rays from uranium	The first modern Olympic Games in Athens J. J. Thomson discovered electrons
1898	Mr. & Mrs. Curie discovered polonium and radium	
1899	Rutherford discovered alpha and beta rays	
1900	Villard discovered gamma rays	
1901		First Nobel Prizes Awarded

16

Effects of Radiation

Effects of Radiation

Internal Exposure and External Exposure

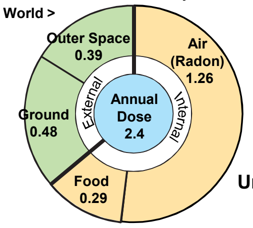
Exposure to radiation (to receive radiation) from radioactive materials that exists outside the body is called "external exposure". On the other hand, exposure to radiation from radioactive materials that exist inside the body is called "internal exposure".

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 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"

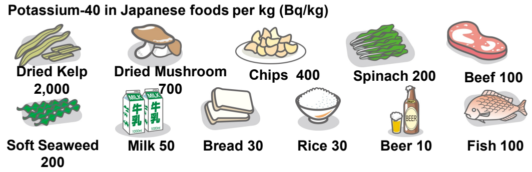
13

◆ **Natural radioactivity in human body and foods**

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)"

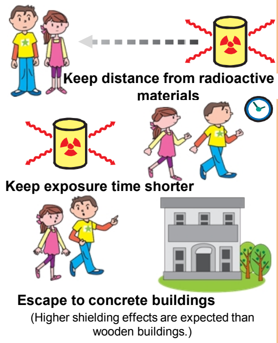
How to Protect from Radiation

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.

14

Points for Learning

Students are going to learn;

- The human body has the ability to repair damaged DNA.
- The difference between internal exposure and external exposure.
- Radioactive materials are contained in various foods.
- How to protect ourselves from radiation.

Points for Teaching

Students are able to understand;

- The human body has the ability to repair damaged DNA, but various factors may damage DNA, which leads to the development of cancer.
- The difference between internal exposure and external exposure.
- How to protect ourselves from radiation.

17

■ Internal exposure and external exposure

The body is exposed to radiation is called exposure, and exposure from radioactive materials existing outside the body is external exposure. Exposure from radioactive materials existing inside the body is internal exposure. Examples of external exposure are the natural radiation from outer space (cosmic rays) and non-natural radiation such as a X-ray at hospitals.

Internal exposure is caused by the intake of radioactive materials in the air, food and water to the body through breathing and eating.

■ How to protect from radiation

Radiation dose depends greatly on the distance from radioactive materials. As you are farther away from radiation sources, you receive less radiation dose.

For example, if a radiation source exists as a relatively small spot compared with the human body, and the distance becomes twice, the radiation dose will be a quarter of its original value. However, if radiation wieldy spreads to surroundings, even radiation effects decrease by the distance, the relationship of inversely proportional to the square of the distance becomes weaker. In either case, the radiation dose can be reduced by shortening the exposure time and using shielding materials.

(see p.27 “Protective methods of external exposure”)

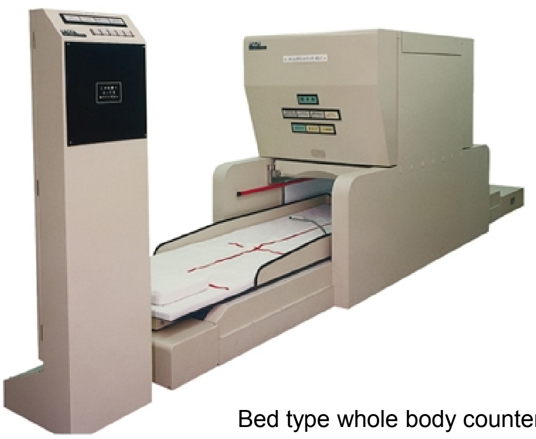
■ To measure internal exposure

Internal exposure can be assessed by measuring the amount of radioactive materials inside the body.

Whole Body Counter (WBC) is a device installed several detectors or mobile detectors to measure the amount of radioactive materials contained in the whole human body. As WBC uses materials (e.g. iron) that can shield the natural radiation from the outside, it can analyse an energy spectrum* of gamma rays emitting from the body, and measure the amount of radioactive materials by each type.

The amount of radioactive materials in the body can also be measured from urine and exhalation.

*Energy spectrum: the energy of light, gamma rays, X-rays, etc. corresponds to its frequency .



Bed type whole body counter

■ Provisional regulation for food and water

In Japan, the Nuclear Safety Committee* established the guidelines on food and water intake regulations, based on recommendations by ICRP (50mSv/year in thyroid, 5mSv/year in the whole body). Ministry of Health, Labour and Welfare of Japan sets “Provisional regulatory limits for radioactivity in food” based on these limited values.

Provisional regulatory limits are assumed to set that there is no health effects even all food and water is taken everyday for a year, and are set conservatively to consider safety.

The provisional limits apply in case of emergency and will revise within achievable ranges, as the health effects from exposure should be kept as low as possible and also radiation exposure risks and health risks resulting from a lack of vegetable intake should be considered.

*After the Tokyo Electric Power Company (TEPCO) Fukushima daiichi NPS accident, the function of the Nuclear Safety Commission was integrated into the new regulation body, named the Nuclear Safety Authority.

■ Radiation in our daily life

We are exposed to radiation everyday from the natural world such as the universe, the ground, food, and others.

The Individual annual radiation dose from the natural resources is about 2.4mSv in the world average (see p.6 “Natural radiation”).

On the other hand, we are also exposed to artificially created radiation.

Artificial radiation is widely used in medicine, industry and agriculture.

18

Effects of Radiation

Effects of Radiation

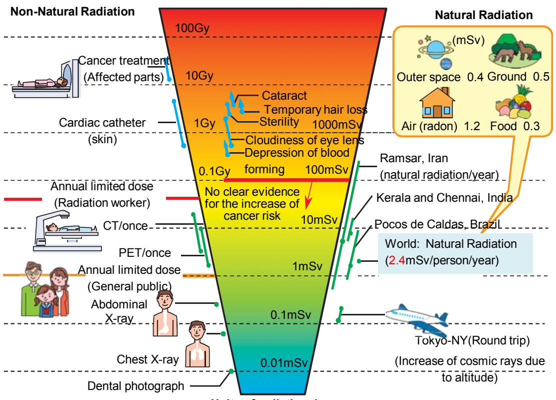
Relationship between Radiation Levels and Health

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

15

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, which means 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

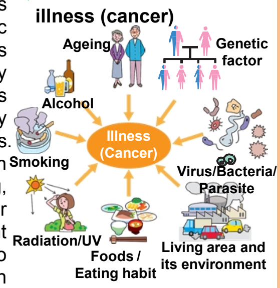
Our body is made up of living cells that can live with genetic information coding in DNA (deoxyribonucleic acid).

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.

16

Points for Learning

Students are going to learn;

- Risk factors for cancer in our life.
- The relationship between dose levels and health effects.
- Examples of radiation exposures around us.
- The importance of reducing radiation doses in terms of protection.

Points for Teaching

Students are able to understand;

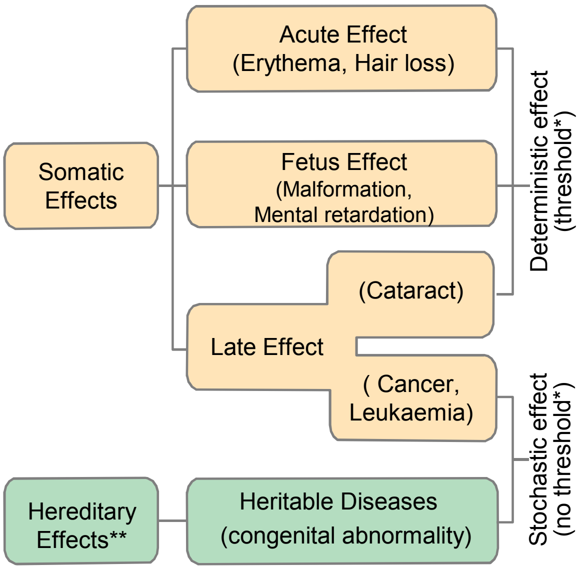
- There is no clear evidence for the linkage between low doses (below 100 mSv) and illnesses.
- There are many different risk factors for cancer.

19

■ Radiation effects on the human body

The health effects of radiation on the human body have been studied by research data gained from the follow-up survey of Nagasaki and Hiroshima atomic bomb survivors, also results from exclusive radiation exposure in medical doctors and scientists.

There are two types of health effects of radiation on humans. Somatic effects appear directly on person who are exposed to radiation, and the effects are further divided to acute effect, fetus effect, and late effect. Hereditary effects appear on offsprings of exposed person. Hereditary effects have been studied, and the actual appearance of the effects on humans has not been reported yet.



*Threshold: the border value of some effects to occur.
**Hereditary effects : effects will be transmitted to one's children and is distinguished from genetic effects (as genetic effects includes its effects on cells).

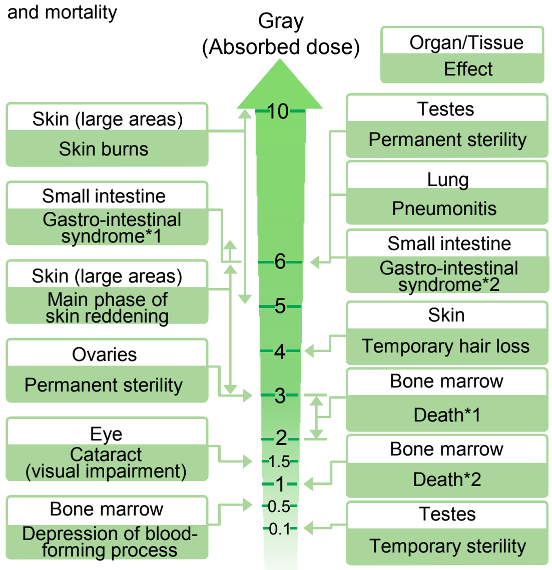
Biological effects of radiation on the human body differ according to radiation types and its dose level, and various symptoms appear at the high radiation dose. Exposing to the same radiation dose, exposure at once has more impact on the body than exposure over time. This is because the human body has the recovery function.

There is no clear evidence for the increase of cancer death at the low radiation dose (below 100mSv at once). When radiation types and levels are the same, the effects of radiation is the same regardless radiation sources either from the natural or non-natural radiation.

Reference [effects of high doses at once]
Regarding acute effects caused by the high level of γ-ray and X-ray exposures to the whole body at once, researches have revealed what kinds of health effects will arise by the different radiation doses.

◆ Radiation effects on the human body

Projected threshold estimation for 1% incidences of morbidity and mortality

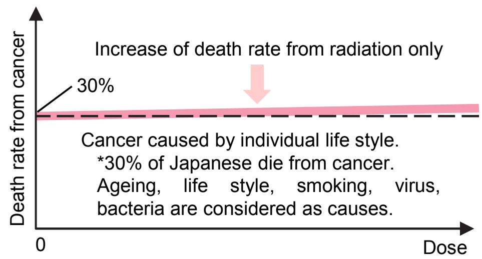


*1 with good medical care
*2 without medical care

Source: ICRP Publication 103, 2007

Reference [effects with threshold and without threshold]
"Threshold" is the minimum dose to appear radiation-related damage on the human body. For example, a person whose radiation dose is above 250mGy (threshold), the decrease of white blood cells occurs, but below the level (threshold), the symptom does not appear. Definite effects will appear above the threshold, are known as deterministic effects (effects with threshold).
On the other hand, stochastic effects (effects without threshold) are assumed that radiation-related damage on the human body will occur without threshold. For example, radiation-induced cancer has no threshold, and its cancer risks increase with exposed doses.
Three major causes of death in Japan are cancer, stroke, and heart disease, which occupy 60% of the total death. Especially, cancer is the most common cause of death and the number of death has been increasing.
Carcinogens are well-known risk factors for healthy cells turning into cancer cells. Eating habits, aging, smoking, and air pollution are linked to creating carcinogens. Radiation can be one of these risks to induce cancer. Therefore, cancer can be developed by many factors and it is difficult to determine whether cancer is being caused by radiation or not.

◆ Increase of radiation-related cancer and leukaemia



Source: National Institute of Radiological Sciences

20

Effects of Radiation

Reference [Cancer and ICRP Recommendations]
Radiation exposure may arise some health effects on the human body. As long-term effects, cancer risks may increase in a few years to a few decades with higher radiation doses.
The International Commission on Radiological Protection (ICRP) recommends that radioactive protection should be conducted with conservative consideration of a proportional relation between the death rate from cancer and the low level of doses*. Even cancer risks will be halved at the low dose rate up to 100mSv for a single dose (exposure at once) or an accumulated annual dose, compared with the high dose rate at once like atomic bomb exposure.
The ICRP estimates that if 1,000 people were exposed to 100mSv of radiation (accumulated dose), about 5 people would die from cancer.
In fact, 30% of Japanese die from cancer during their lifetimes, which means 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.

* Although the relationship between exposure at lower doses and biological effects is unclear, the ICRP recommends that radiation doses should be kept as low as possible, as we should take the proportional relationship between doses and health effects into consideration.

■ Collective effective dose

Collective effective dose indicates dose quantities in a group that is the sum of all individual effective doses from an exposed group. In the case of several groups, the whole collective effective dose is calculated by the sum of each group's collective effective doses in unit of man sievert. This indication is used to assess whether the optimisation of radiation protection is carried out by groups or not. It is also used to indicate the scale of radiation accident. However, It is not appropriate to use for the estimation of group risks by summing up a large number of individuals with very low doses.

The ICRP stated as "Collective effective dose is an instrument for optimisation, for comparing radiological technologies and protection procedures. Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. This is because the assumptions implicit in the calculation of collective effective dose (e.g., when applying the LNT model) conceal large biological and statistical uncertainties. Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided. Such computations based on collective effective dose were never intended, are biologically and statistically very uncertain, presuppose a number of caveats that tend not to be repeated when estimates are quoted out of context, and are an incorrect use of this protection quantity." (ICRP Recommendations 2007)

■ Benefits and Risks

There are both positive and negative aspects in our life. A positive aspect is known as benefits and a negative aspect as risks. Risks indicate the probability of unexpected hazards that happen sometimes in the future. When the actual impact of hazards differ from the expected one, risks sometimes define by the combination of the impact of hazards and its incidence rate.

Greater benefits with smaller risks will be a perfect or an ideal situation, but if willing to obtain benefits, risks are unavoidable and can never be removed completely. In other words, getting only benefits without any risks is impossible.

In the case of radiation uses, there are both benefits and risks. The onset of radiation-related cancer by exposing to a large amount of radiation is considered as risks. On the other hand, we receive benefits from radiation such as medical check with a X-ray and CT scan, the diagnosis of the early stage of cancer, and cancer treatment.

■ Benefits and Risks of radiation

Radiation is widely used in our life, but we need to consider both benefits and risks of radiation.

The ICRP has established the following principle for dose limits that can reasonably be restricted.

1. Justification: the weight of benefits from radiation exposure is always greater than risks from it.
2. Optimisation: the radiation doses should be kept as low as reasonably achievable, taking economic and societal factors into account.
3. Dose Limits: the planned exposure situations should not exceed recommended doses by ICRP, excepting doses from the natural sources and medical exposure.

Reference: [The role of ICRP]
In 1928, the International X-ray and Radium Protection Committee was established as an international body aimed at preventing radiological effects. The International Commission on Radiological Protection (ICRP) was funded in 1950 to carry the mission of radiation protection and to develop the international system of radiological protection. The ICRP plays a wide range of roles in radiological protection from basic researches to the establishment of guidelines for dose limits. Most of countries in the world respect the ICRP guidelines and recommendations.
The ICRP recommends that dose limits should be kept to protect people from radiation health effects in terms of both deterministic effects and stochastic effects.

Reference [various causes of cancer]
When human genes get damage by some causes, and the damage exceeds the certain level, cancer cells may develop. Chemicals, medicines, virus, radiation, and UV-rays are known as risk factors for cancer.
Tar in cigarettes is one of well known carcinogens linked with our life style, also many carcinogens are contained in natural foods.

Reference
[Relative risks of cancer by radiation and lifestyle]
The table below is the survey result published by National Cancer Center in Japan. The table indicates that how many times cancer risks increase (relative risk) by comparing between a target group and a control group (e.g. smokers and non-smokers).

Risk factor	Cancer Risk
Radiation exposure: 1000 ~ 2000mSv	**1.8 times**
Smoking Drinking (540cc of Japanese sake /day)	**1.6 times**
Underweight	**1.29 times**
Overweight	**1.22 times**
Radiation exposure: 200 ~ 500mSv	**1.19 times**
Lack of exercise	**1.15 ~ 1.19 times**
High salt intake	**1.11 ~ 1.15 times**
Radiation exposure :100 ~ 200mSv	**1.08 times**
Poor diet (a lack of vegetables)	**1.06 times**

- Data for radiation exposure was analysed from the survey on acute radiation exposure from Hiroshima and Nagasaki atomic bomb (solid cancer), not from the survey on long-term effects of exposure.
- Other data is from National Cancer Center.
- Target: Japanese aged between 40-69
- Lack of exercise: low levels of physical activity
- Poor diet: Very little vegetable consumption

Source: National Cancer Center

■ Uses of non-natural radiation

We can artificially create radiation, which is applied to various fields as practical purposes in our life. (see p.23)

When we use radiation, benefits from radiation should always be greater than risks arising from its uses.

1. Radiation exposure from medicine

In medical applications, radiation is used for a diagnosis of chest, bone and stomach, also for cancer treatment. Benefits of radiation for cancer treatment is that cancer cells can be reduced without surgical operations, and the better quality of life is expected after the treatment.

In Japan, radiation doses from medical exposure take up 60% of the total individual annual doses from the natural and non-natural radiation.

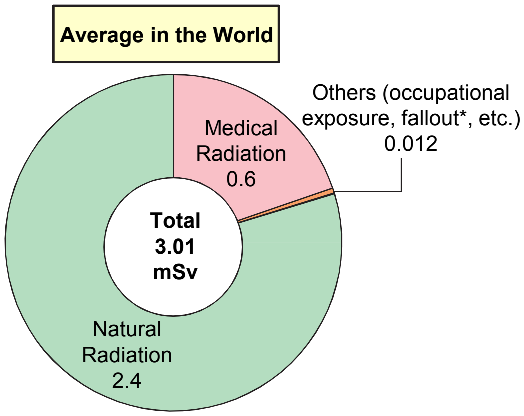
2. Radiation exposure from nuclear facility

Nuclear power plants (NPPs), nuclear fuel manufacturing plants, nuclear research reactors, etc. are considered as nuclear facilities. NPPs generate electricity like thermal and hydroelectric power plants.

Facilities handling radioactive materials always monitor radiation doses at surrounding areas.

Under the law, the dose limit sets at less than 1mSv per year. NPPs and nuclear fuel facilities set the target does limit in order to reduce radiation levels in surrounds as low as possible.

◆ Individual annual dose from natural and non-radiation sources



*Fallout: Radioactive fallout from nuclear weapons tests

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

Uses of Radiation in Our Life and Industry

Uses of Radiation in Our Life and Industry

Property of Radiation

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 knives and syringes, 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 iron radiotherapy

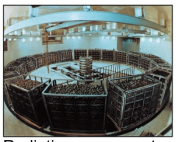
In Agriculture

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.

17

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

Advance 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

18

Points for Learning

Students are going to learn;

- Radiation is used in many fields such as medicine, industry and agriculture.

Points for Teaching

Students are able to understand;

- Radiation is widely used in fields such as medicine, industry and agriculture according to their properties of radiation.

23

■ In medicine

< Sterilisation >

Medical apparatus such as surgical knives and syringes needs to be sterilised to kill all bacteria and germs before use. The radiation sterilisation is an effective method for materials which are not suitable for the boiling sterilisation and the chemical sterilisation, since material deterioration and chemical contamination hardly occur by the radiation sterilisation. In addition, it can be done from the outside as radiation can penetrate packaged materials. Therefore, this method is widely applied to medical apparatus, including disposable syringes, disposable blood collecting devices, blood infusion tools, medical adhesives, plastic sutures, etc.

< Diagnosis >

An X-ray and CT scan are common diagnostic equipment at hospitals to examine internal organs such as chest and stomach. In nuclear medicine, a small amount of compound made of radioisotopes with short half-lives are used as a diagnostic tracer. The radioactive tracer is given to a patient to find problems inside the body by scanning radiation emitted from the tracer.

< Treatment >

Radiation therapy is one of alternatives to surgery in cancer treatment by which cancer cells can be selectively destroyed. There are two types of treatment methods; 1) irradiating target areas from the outside, and 2) planting radioactive materials in target parts. To compare with surgery and medication, radiation therapy can retain affected organs and has fewer side effects.

■ In agriculture

<Food Irradiation>

We cannot eat sprouted potatoes. However, sprouting in potatoes can be inhibited by exposing to gamma rays from Cobalto-60, and irradiated potatoes can storage for a long period.

In Japan, food irradiation is allowed for only potato sprout inhibition, but it is applied to various foods in the world such as fresh vegetables (potato, onion, etc.), fruits (mango, papaya, etc.), fresh meats, and seasonings (spice, herb, etc.).

< Selective breeding >

Selective breeding is a method in which mutations are created artificially by irradiation, and new types of breeds can be developed. Examples are pears with disease resistance and rice with cold resistance. In Japan, during 1950s, a gamma irradiation room was built at research institutes, and experiment on radiation breeding has started.

In 1960, Institute of Radiation Breeding with a large outside gamma field was established (National Institute of Agrobiological Sciences) in Hitachi-omiya, Ibaraki prefecture. Since then, developing new types of breeds has further progressed in Japan.


Gamma Field

< Pest control >

Agricultural industry makes use of radiation for pest control as alternative to pesticides.

One of pest control methods using radiation is the sterile insect technique (SIT). This technique is used to suppress the number of harmful insects by releasing sterilised male insects. When more infertile male insects are released to the wild, successful natural reproduction becomes less. As a result, the total population gradually decreases, and finally they will become extinct.

In Japan, a sterilisation facility for melon flies was established in 1972 at Okinawa prefectural agricultural experiment station (pest control technology center) in order to control the number of melon flies which were giving serious damage to vegetables such as bitter gourd and cucumber. In 1993, these flies were successfully eradicated in Okinawa and Amami Islands, Kagoshima. However, melon flies still enter these areas from the outside, so that this eradication project is carried out every year.

Currently, SIT is conducted for one of the fly family in Japan with international cooperation, but this technique is not effective to all harmful insects.

24

Uses of Radiation in Our Life and Industry

■ In industry

< New materials >

Material features such as strength and heat resistance can be enhanced by using the ionising properties of radiation, and the enhanced materials are widely used in industry (e.g. dashboards, sheets, and tires for vehicles)

Moreover, various additional functions can be added to materials, which are used for a cleaner filter and a button cell battery.

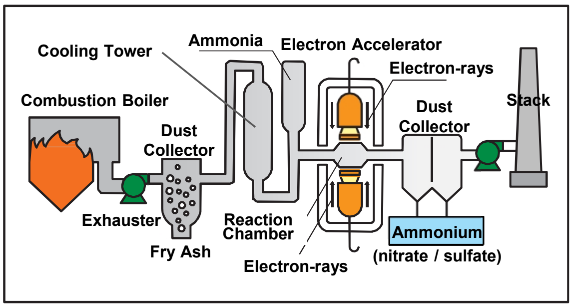
< Environmental conservation >

A large amount of acidic gas such as nitrogen oxides (NOx) and sulfur oxides (SOx) produced at thermal power plants is one of main causes for acid rain, which has been an important environmental issue.

The Japan Atomic Energy Agency (JAEA) developed an effective removal method of air pollutants (NOx and SOx) using electron beams that are produced from a small sized accelerator.

This system has been used at thermal power plants in many places such as China and Poland. A pilot facility also has been running at the thermal power plant in Maritsa East, Bulgaria.

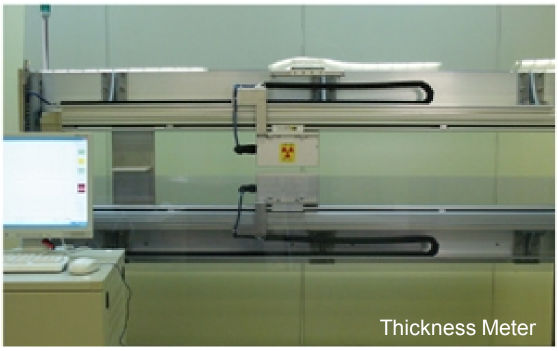
Thermal power station in Hangzhou (China)



The removal system of air pollutants developed by JAEA.

< Thickness meter >

Thickness meter is used to measure an accurate thickness of industrial materials such as paper, plastic wrap and aluminum foil that must be uniform in thickness. This meter uses the penetrating properties of radiation.



Thickness Meter

< Non Destructive Testing (NDT) >

NDT is an analysis technique to detect failures and cracks inside materials (e.g. equipment, buildings, metal welding, fine Industrial and art objects, etc.) without causing damage to objects. This method uses X-rays and gamma rays as the same mechanism as an X-ray at hospitals. Luggage screening at airports also use NDT techniques.

■ In natural science and humanity

< Radiocarbon dating >

The age of earthenware at historical sites can be determined by measuring carbon deposits (ash and burnt deposits) left on the surface of the earthenware.

Carbon-14 is a radioisotope of carbon, which is formed in the atmosphere, and emits radiation. When cosmic rays reach the atmosphere of the earth, they produce neutron rays. Generated neutron rays are absorbed by nitrogen in the air and become a radioactive carbon. The concentration of radioactive carbon and non-radioactive carbon is constant in the air. After living organisms die, they cannot take carbon and only the amount of carbon-14 in the organism decreases with time according to its half-life (about 5,730years). Therefore, by measuring the ratio of carbon-14 and non-radioactive carbon, the approximate age of earthenware can be estimated.

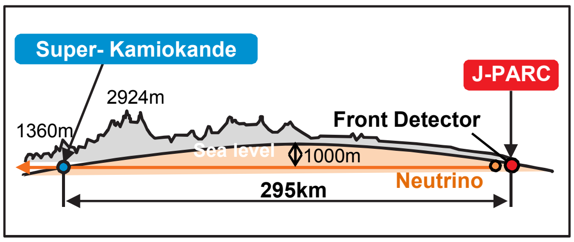
■In advanced science technology

SPring-8 is a large synchrotron radiation research facility located in Hyogo prefecture, Japan, where material analysis, such as the time variation in the structure of materials and chemical reactions, can be performed at the ultrastructural level (molecular and atomic levels) by producing a strong electromagnetic wave called synchrotron radiation. X-rays and UV-rays contained in synchrotron radiation are applied to nanotechnology, biotechnology, and medical and industrial fields.

25

Major research achievements at SPring-8:
The asteroid particles were analysed at SPring-8. These were brought back from a small asteroid by an unmanned spacecraft called "Hayabusa". Moreover, the high performance of exhaust gas purification catalyst for automobile and anti-influenza agents are developed at SPring-8.

Japan Proton Accelerator Research Complex (J-PARC) in Ibaraki prefecture, Japan, is a cutting-edge research facility for particle physics and material science. Neutron, pion, kaon and neutrino beams are produced at J-PARC by collisions between accelerated protons and a target nucleus.
A sign of neutrino phenomenon was discovered for the first time in the world. Neutrino generated at J-PARC was detected at Super-Kamiokande in Gifu prefecture (approx. 295km away).



Reference [Radiation-related professions]
- **Medical radiology technician / doctor**
  To diagnose illness using a X-ray, CT, PET.
  To conduct cancer treatment by gamma rays and heavy iron rays.
- **Researcher**
  To research basic physics, new materials, medicines, and the universe at nuclear facilities (e.g. research reactor, accelerator, etc.).
- **Radiation protection supervisor**
  To supervise radiation safety at university, hospital, research institute, and company.
- **NDT engineer**
  To examine materials by ultrasound, radiation, and magnetic force.
  To conduct non-destructive testing and analyse using X-rays and gamma rays.
- **Engineer for environmental survey**
  To monitor radioactive materials in the environment.
- **Engineer for radiation measurement devices**
  To develop and manufacture radiation measurement devises.

Radiation Control and Protection

Radiation Control and Protection

Monitoring in Normal Situation

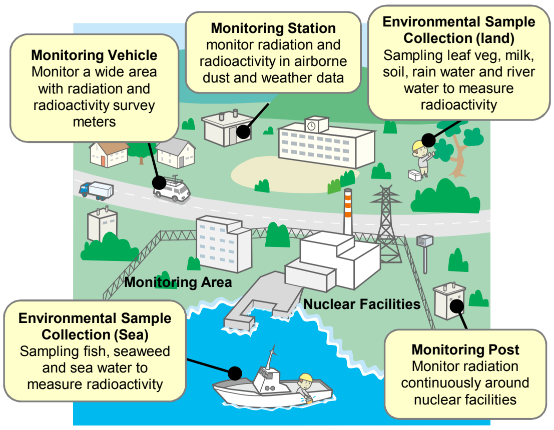
Monitoring posts and stations are located around the site of nuclear power stations and nuclear facilities in order to monitor radioactive materials released from the site to surroundings.

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

19

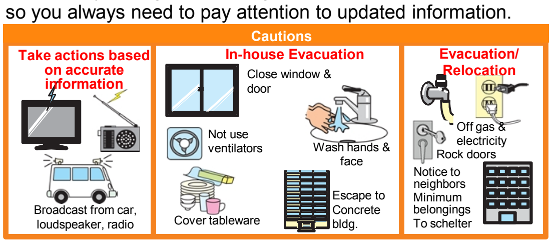
Protection from Radioactive Materials in Emergency

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 case, 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 house or shelter 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.

20

Points for Learning

Students are going to learn;

- Radiation is monitored by different methods in normal situation.
- In case of emergency, orders and instructions may change depending on accident conditions.

Points for Teaching

Students are able to understand;

- In case of emergency, orders and instructions may change depending on accident conditions.

27

■ Control of radioactive materials

Under the laws and regulations, users must obtain licenses or be authorised prior to the use of certain radioactive materials. In addition, providing "(radiation) controlled area" is required in radiation handling facilities. Controlled area is an access-restricted area excepting radiation workers.

■ Protection methods for external exposure

There are three principles for radiation protection; time, shielding and distance. "Time" is to reduce radiation doses by shortening exposure time of radiation workers. "Shielding" is to reduce doses by using appropriate materials to shield radiation as each radiation has a different penetrating property. "Distance" is to reduce the air dose rate by keeping the distance from radiation sources.

These principles can be applied to the general public in case of a nuclear accident. Exposure can be reduced by shortening exposure time and escaping to concrete buildings (a higher shielding effect is expected than wooden buildings).

Moreover, as you go further away from the radiation source, your radiation dose will decrease. For example, if radioactive materials present as a point source, and the distance from the source becomes twice, radiation doses will be a quarter. However, when radioactive materials spread over a large area, the intensity of radiation may not be inversely proportional to the square of the distance.

■ Principles for evacuation and relocation

"Evacuation" and "relocation" are effective ways to protect ourselves from external exposure (radiation received from the outside of the body). In order to prevent internal exposure, it is important not to take radioactive materials into the body through inhalation and ingestion. Therefore, in the case of emergency, you should stay inside buildings (close all windows), also not take foods and water restricted by national and local governments. After the TEPCO Fukushima Daiichi NPS accident, the relocation was ordered for residents whose accumulated doses might be exceeded 20mSv within a year.

*the ICRP and the IAEA set the reference levels for radiation protection at emergency situations between 20~100mSv/year.

■Criteria of the reference level (20mSv) for evacuation

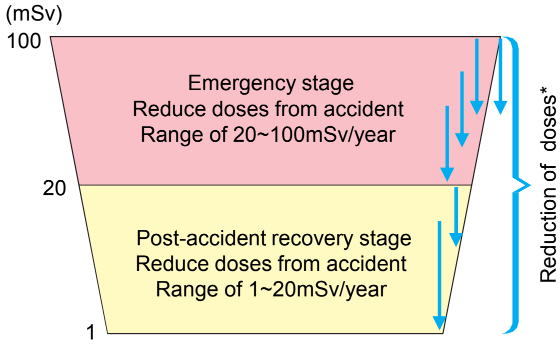
The ICRP set the reference levels for radiation dose in emergency situations between 20mSv to 100mSv with considering the balance of health risks resulting from radiation exposure and the restriction of contaminated foods.

Just after the TEPCO Fukushima daiichi NPS accident, the lowest dose of ICRP reference levels (20mSv) was applied as the emergency does limit in Japan.

The basic policy for radiation protection had made based on the ICRP recommendations and advice from the Nuclear Safety Commission of Japan (NSC).

1. Emergency stage: exposures should not exceed 20~100mSv. At this stage, efforts should be made to reduce doses by evacuating to safer places and monitoring radioactivity in food and water.
2. Post-accident recovery stage: the annual doses should not exceed 1~20mSv. At this stage, efforts should be made to reduce doses by decontaminating the ground around schools and residential areas, and controlling the intake and distribution of contaminated foods (exceeding the regulation values of radioactivity).

◆ ICRP recommendations



*To reduce radiation doses by various protective measures** such as evacuation, the control of food distribution, and environmental restoration.

**Just after the TEPCO Fukushima daiichi NPS accident, the Japanese government issued the evacuation order to residents who were living within 20km from the site, as well as the planned evacuation order to individuals whose accumulated doses would be more likely to exceed 20mSv within a year. Since the accident, these orders have been modified or lifted according to the radiation levels in each area. The food distribution has been controlled by national and local governments since the accident, including the restriction of intake and distribution of foods that contain the exceeded level of radioactive materials. Environment restoration such as soil decontamination has been conducted, and the government has taken further measures for affected areas in order for evacuees to return their homes as early as possible.

■ Radiation dose limits

In Japan, the national regulations for radiation exposures are established based on the ICRP recommendations. The dose limits are set by each nuclear facility (NPP, hospital, factory, etc.) to achieve that public exposures do not exceed 1mSv in a year. The limits apply to authorised conditions in which safety design and protection planning are properly conducted by nuclear facilities in order to monitor the radiation level at its site boundary. Therefore, it does not indicate the critical line between safe and dangerous.

Emergency exposure situations (exposure from unexpected events e.g. nuclear accidents) differ from planned exposure situations (exposure from regulated radiation sources) because planned protective measures cannot be taken in the case of emergency.

Therefore, the annual dose limit (1mSv) is not applied to emergency exposure situations. The reference levels are used instead in emergency and post-accident recovery stages. The reference level is the limiting value by which radiation protection such as evacuation or decontamination must be taken to reduce radiation doses. However, the ICRP states that protective actions should be taken without excessive manpower or costs, and economic and social factors should be considered to keep the reference levels as low as reasonably achievable.

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

Learning Material in Japanese

Authors / Editors
Committee on Preparation of Supplementary Material in Radiation
Chairman: Takashi Nakamura

Editorial Supervision
Japan Radiological Society (JRS)
Japanese Society of Radiation Safety Management
The Japan Radiation Research Society
National Institute of Radiological Sciences

Photo Courtesy
Institute for Environmental Sciences / Kyushu National Museum / Kyoto University Hospital
Chiyoda Technol Corporation / Radiation Science Center / Tomoko Nakanishi
Japan Science Foundation / Nippon Nuclear Fuel Development Co., Ltd.
Japan Atomic Energy Relations Organization / Japan Chemical Analysis Center
Hitachi Aloka Medical, Ltd. / Fuji Electric Co., Ltd. / National Institute of Radiological Sciences
Yamagata Prefectural Center for Archaeological Research /
Institute of Physical and Chemical Research

Published by
Ministry of Education, Culture, Sports, Science and Technology
3-2-2 Kasumigaseki,
Chiyoda-ku,
Tokyo 100-8959,
JAPAN
In October 2011
Available at
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_04_1.pdf
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2011/11/04/1313005_05_1.pdf

Learning Material in English

Authors / Editors
Kiyonobu Yamashita
Yoko Watanabe
Mayuka Shimada

Nuclear Human Resource development Center
Japan Atomic Energy Agency
2-4 Shirakata-Shirane,
Tokai-mura,
Naka-gun,
Ibaraki 319-1195,
JAPAN
In December 2014

Photo Courtesy
Fuji Electric Co., Ltd. (p.13 X-Gamma Silicon Survey Meter)

31

English / Japanese Glossary of Technical Terms

Accumulated dose	積算線量
Absorbed dose	吸収線量
Accelerator	粒子加速器
Acute Effect	急性障害
Alpha rays	アルファ線
Americium	アメリシウム
Annual limited dose	年間線量限度
Anti-influenza agent	抗インフルエンザ薬
Archaeological research	考古学研究
Argon	アルゴン
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
Beryllium	ベリリウム
Beta rays	ベータ線
Biological effect	生物学的影響
Biological half-life	生物学的半減期
Caesium	セシウム
Carcinogen	発がん性物質
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
Cobalt	コバルト
Collective effective dose	集団実効線量
Computer Tomography	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
Deterministic effect	確定的影響
Effective half-life	実効半減期
Electric noise	電気的ノイズ
Electric wave	電波
Electrical potential	電位
Electrode	電極
Electromagnetic wave	電磁波
Electron	電子
Element	元素
Emergency preparedness	緊急時対応
Equivalent dose	等価線量
Erythema	紅斑
Evacuation	避難
Evacuation order	避難指示
Excitation	励起作用
Excretion	排泄
Exposure	被ばく
External exposure	外部被ばく
Far infrared ray	遠赤外線
Fetus Effect	胎児発生の障害
Fission fragments	核分裂片
Fluorescent incandescent light	蛍光灯
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
Hydrogen	水素
Inert gas	不活性ガス
Infrared ray	赤外線
Internal exposure	内部被ばく
Iodine	ヨウ素
Ionisation	電離作用
Irradiation	照射
Isotope	同位元素
Kaon	カオン
Late effect	晩発障害
Leukaemia	白血病
Local government	地方自治体
Lymphocytes	リンパ球
Magnetic force	磁力
Malformation	形態異常
Medical apparatus	医療機器
Mental retardation	精神遅滞
Metabolism	代謝
Microwave	マイクロ波
Molecule	分子
Monazite	モナザイト
Morbidity	罹患率
Mortality	死亡率
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
Neon	ネオン
Neutrino	ニュートリノ
Neutron	中性子
Neutron rays	中性子線

Nitrogen	窒素
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 reactor	原子炉
Nuclear science	原子力科学
Nucleon	核子
Nucleus	原子核
Particle	粒子
Penetrating property	透過作用
Personal dosimeter	個人線量計
Pest control	害虫駆除
Phosphorus	リン
Photosynthesis	光合成
Physical half-life	物理学的半減期
Pion	パイオン
Pitchblende	れきせいウラン鉱
Polonium	ポロニウム
Potassium	カリウム
Potassium chloride	塩化カリウム
Potassium fertilizer	カリ肥料
Proton	陽子
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 weighting factor	放射線加重係数
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
Radioisotope	放射線同位元素
Radium	ラジウム
Radon	ラドン
Relocation	退避
Selective breeding	品種改良
Shelter	避難所
Shielding	遮へい
Shielding effect	遮へい効果
Sinter	湯の花
Sodium	ナトリウム
Somatic effect	身体的影響
Sterilisation	滅菌
Sterility	不妊
Stochastic effect	確率的影響
Strontium	ストロンチウム
Supersaturation state	過飽和状態
Synchrotron radiation	放射光
Technetium	テクニチウム
Temporary hair loss	一時的脱毛
Thorium	トリウム
Three-dimension	三次元
Tritium	トリチウム
Ultraviolet rays	紫外線
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

This is a blank page.

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度，質量密度	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
量濃度 (a)，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率 (b)	（数字の） 1	1
比透磁率 (b)	（数字の） 1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン(b)	rad	1 (b)	m/m
立体角	ステラジアン(b)	sr(c)	1 (b)	$m^{2/}m^2$
周波数	ヘルツ (d)	Hz		s^{-1}
力	ニュートン	N		$m\ kg\ s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N m	$m^2\ kg\ s^{-2}$
仕事率，工率，放射束	ワット	W	J/s	$m^2\ kg\ s^{-3}$
電荷，電気量	クーロン	C		s A
電位差（電圧），起電力	ボルト	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
電気抵抗	オーム	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
磁束	ウエーバ	Wb	Vs	$m^2\ kg\ s^{-2}\ A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
セルシウス温度	セルシウス度(e)	℃		K
光束	ルーメン	lm	cd sr(c)	cd
照度	ルクス	lx	lm/m^2	$m^{-2}\ cd$
放射性核種の放射能 (f)	ベクレル (d)	Bq		s^{-1}
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	$m^2\ s^{-2}$
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト (g)	Sv	J/kg	$m^2\ s^{-2}$
酸素活性	カタール	kat		$s^{-1}\ mol$

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で”radioactivity”と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	$m^{-1}\ kg\ s^{-1}$
力のモーメント	ニュートンメートル	N m	$m^2\ kg\ s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg\ s^{-2}$
角速度	ラジアン毎秒	rad/s	$m\ m^{-1}\ s^{-1}=s^{-1}$
角加速度	ラジアン毎秒毎秒	rad/s^2	$m\ m^{-1}\ s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg\ s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2\ kg\ s^{-2}\ K^{-1}$
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	$m^2\ s^{-2}\ K^{-1}$
比エネルギー	ジュール毎キログラム	J/kg	$m^2\ s^{-2}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	$m\ kg\ s^{-3}\ K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1}\ kg\ s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m\ kg\ s^{-3}\ A^{-1}$
電荷密度	クーロン毎立方メートル	C/m^3	$m^{-3}\ sA$
表面電荷	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
電束密度，電気変位	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
誘電率	ファラド毎メートル	F/m	$m^{-3}\ kg^{-1}\ s^4\ A^2$
透磁率	ヘンリー毎メートル	H/m	$m\ kg\ s^{-2}\ A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2\ kg\ s^{-2}\ mol^{-1}$
モルエントロピー, モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	$m^2\ kg\ s^{-2}\ K^{-1}\ mol^{-1}$
照射線量（Ｘ線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1}\ sA$
吸収線量率	グレイ毎秒	Gy/s	$m^2\ s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4\ m^{-2}\ kg\ s^{-3}=m^2\ kg\ s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2\ sr)$	$m^2\ m^{-2}\ kg\ s^{-3}=kg\ s^{-3}$
酵素活性濃度	カタール毎立方メートル	kat/m^3	$m^{-3}\ s^{-1}\ mol$

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	µ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^9	ギガ	G	10^{-12}	ピコ	p
10^6	メガ	M	10^{-15}	フェムト	f
10^3	キロ	k	10^{-18}	アト	a
10^2	ヘクト	h	10^{-21}	ゼプト	z
10^1	デカ	da	10^{-24}	ヨクト	y

表６．SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	$1ha=1hm^2=10^4m^2$
リットル	L，l	$1L=11=1dm^3=10^3cm^3=10^{-3}m^3$
トン	t	$1t=10^3$ kg

表７．SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	$1eV=1.602\ 176\ 53(14)\times10^{-19}J$
ダルトン	Da	$1Da=1.660\ 538\ 86(28)\times10^{-27}kg$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$1ua=1.495\ 978\ 706\ 91(6)\times10^{11}m$

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	$1\ bar=0.1MPa=100kPa=10^5Pa$
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	$1\ Å=0.1nm=100pm=10^{-10}m$
海里	M	1 M=1852m
バーン	b	$1\ b=100fm^2=(10^{-12}cm)2=10^{-28}m^2$
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\ s\ cm^{-2}=0.1Pa\ s$
ストークス	St	$1\ St=1cm^2\ s^{-1}=10^{-4}m^2\ s^{-1}$
スチルブ	sb	$1\ sb=1cd\ cm^{-2}=10^4cd\ m^{-2}$
フォト	ph	$1\ ph=1cd\ sr\ cm^{-2}\ 10^4lx$
ガル	Gal	$1\ Gal=1cm\ s^{-2}=10^{-2}ms^{-2}$
マクスウェル	Mx	$1\ Mx=1G\ cm^2=10^{-8}Wb$
ガウス	G	$1\ G=1Mx\ cm^{-2}=10^{-4}T$
エルステッド (c)	Oe	$1\ Oe \triangleq (10^3/4\pi)A\ m^{-1}$

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R=2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
ガンマ	γ	1 γ =1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	µ	$1\ \mu=1\mu m=10^{-6}m$

（第8版，2006年改訂）