Basic Knowledge of Radiation and Radioisotopes

(2019)

(Scientific Basis, Safe Handling of Radioisotopes and Radiation Protection)

Japan Radioisotope Association

Contents

Ⅰ. Introduction

1. The Role of Radiation Workers

The purpose of “the Act on the Regulation of Radioisotopes, etc.”, with relevant Cabinet order, Enforcement regulation and Notification etc. (hereinafter referred to as “the Acts and Regulations”), is not only to minimize the radiation exposure of individual workers and the public, but also to ensure the safety of people by preventing contaminations in both the workplace and the general environment. To satisfy this purpose, it goes without saying that facilities and equipments should be well maintained. But there are many areas where little can be achieved without the cooperation of the radiation workers themselves. That is to say, it is difficult to attain the purpose of the Act without appropriate handling of radiation and radioisotopes by radiation workers, no matter how much effort is put into maintaining facilities and equipments. Being aware of how to protect themselves, as well as the significance of their role in radiation protection management, each radiation worker must cooperate with others at his or her workplace.

1-1. What knowledge must radiation workers have?

In order to deal with radiation and radioactive materials safely at their workplace and to attain the goal of radiation protection, radiation workers must understand at least the following:

1) Basic provisions of the Act on the Regulation of Radioisotopes, etc.;
2) Basic physics of the radioactive materials that they handle;
3) Biological effects of radiation;
4) Techniques for preventing contamination;
5) Methods for radioactive waste management; and
6) How to deal with abnormal and emergency situations.

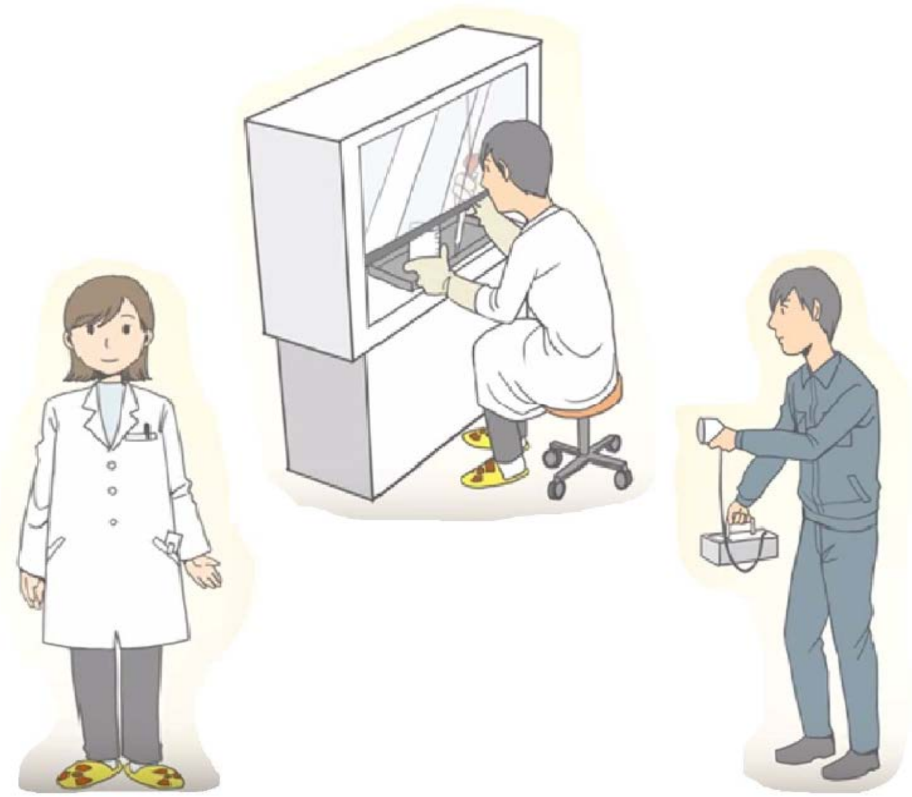

Fig. 1 What knowledge must radiation workers have?

Ⅱ. Scientific Basis

1. Structure of Atom

The structure of an atom is similar to that of the solar system.

All objects are composed of **atoms**. At the center of each atom is a nucleus with a positive electric charge, around which electrons with the negative charge are moving along fixed orbitals. These electrons are called **orbital electrons**. This structure can be compared to the solar system, where planets are orbiting around the sun.

Normally, the positive charge of the atomic nucleus is equal to the total negative charge of the orbital electrons, and the atom as a whole is electrically neutral. When external energy is applied to an atom, an orbital electron may be kicked out of its orbital, becoming a free electron no longer bound to the nucleus. The atom then remains as a positively charged **ion. This phenomenon is called ionization.**

Sometimes, the application of external energy may cause an orbital electron to move to an orbital further from the nucleus, leaving the nearer orbital position vacant. Such an atom is said to be **excited**.

The diameter of an atomic nucleus ranges from 10^{-15} to 10^{-14} m, with the orbitals of the electrons extending much further out. The size of the entire atom is of the order of 10^{-10} m. If, for example, the atomic nucleus is pictured as being the size of a tennis ball, then the orbital electrons would be as far as 5 kilometers away.

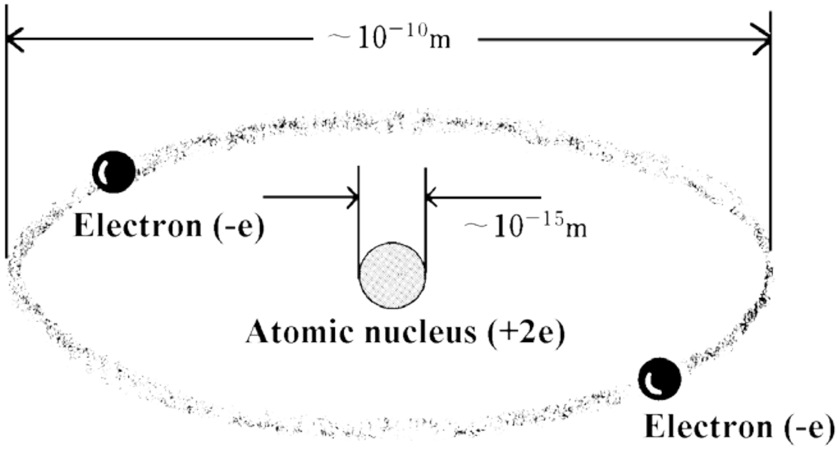

Fig. 2 Structure of a helium (He) atom: The charge (e) on each electron is called elementary electric charge. The helium nucleus has a positive charge twice that of the elementary electric charge, balancing the two orbital electrons.

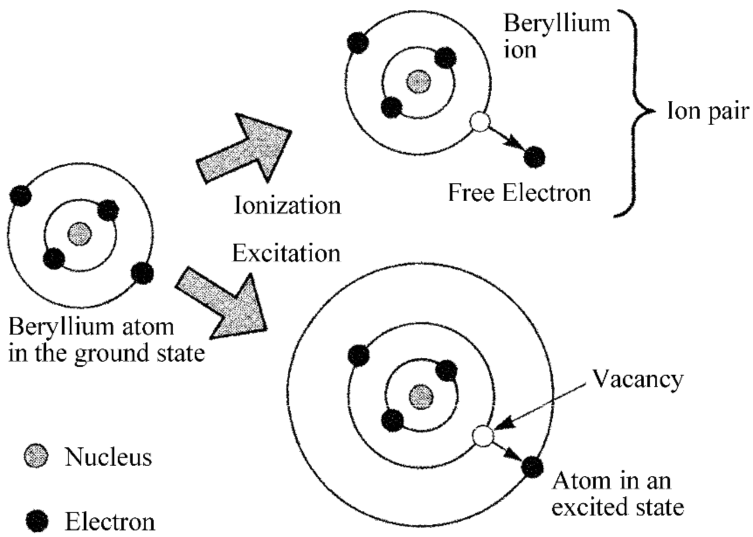

Fig. 3 Ionization and excitation of a beryllium atom

2. Structure of Atomic Nucleus

The atomic nucleus consists of two kinds of particles, protons and neutrons.

The atomic nucleus consists of protons, which are positively charged, and neutrons, which have no charge. The positive charge of a proton is equal, but opposite, to the negative charge of an electron. The mass of a proton is approximately 1,840 times that of an electron; the mass of a neutron is almost the same as, but slightly larger than, that of a proton. Thus, because an electron is so much lighter than either a proton or a neutron, the mass of an atom can be deemed to be essentially equal to the mass of its nucleus.

The particles that make up the nucleus, i.e. the protons and neutrons, are called nucleons. Nucleons are held together by what is called the nuclear force, which overcomes the naturally repulsive tendency of the positively charged protons.

The number of protons in a nucleus is normally the same as the number of orbital electrons around the nucleus. The chemical nature of an atom is determined by the number of protons in its nucleus. This number is called the **atomic number**, and it defines a chemical element.

Atomic number = number of protons in an atomic nucleus
= number of orbital electrons in a neutral atom

Fig. 4 Just as a drop of water looks like a single structure but actually consists of a great number of molecules, the atomic nucleus is composed of individual protons and neutrons.

3. Isotopes

Isotopes are atomic brothers.

The type of an atomic nucleus is determined by the number of its protons and neutrons. When two atoms have the same number of protons but a different number of neutrons, they have different masses, but the same chemical nature. That is to say, they are the same element. These atoms are like brothers, and are called **isotopes**.

In order to distinguish among isotopes, the total number of protons and neutrons (called the **mass number**) is shown at the upper left of the element's symbol. The atomic mass is roughly expressed by the mass number.

Mass number = number of protons + number of neutrons

Hydrogen (H, atomic number 1) is an element with one proton, and exists in three isotopes: ^{1}H, ^{2}H and ^{3}H. ^{2}H is called deuterium (D), also known as heavy hydrogen, and ^{3}H is called tritium (T).

In elements having smaller atomic number, light elements, the number of neutrons is more or less equal to the number of protons, but, in elements having larger atomic number, heavy elements, the number of neutrons exceeds the number of protons. For example, the nucleus of ^{16}O consists of eight protons and eight neutrons, but the nucleus of ^{226}Ra (atomic number 88) has 88 protons and 138 neutrons.

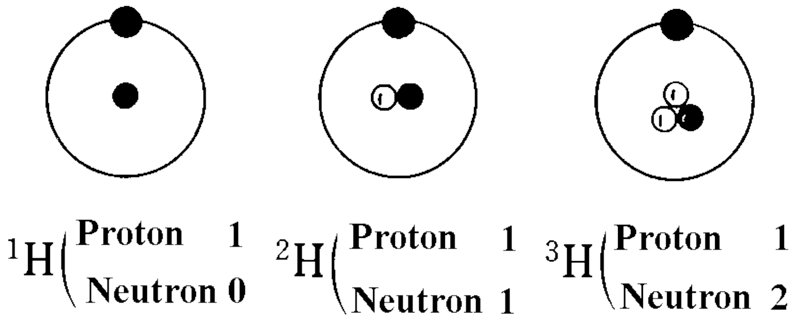

Fig. 5 Hydrogen isotopes: In all cases, the nucleus has one proton.

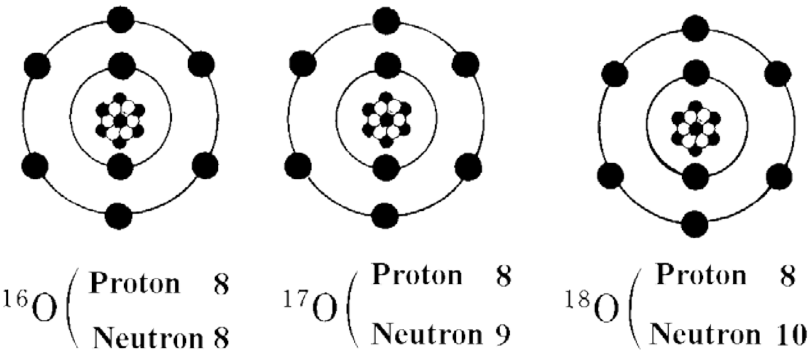

Fig. 6 Oxygen isotopes: In all cases, the nucleus has eight protons.

4. Radioisotopes and Radioactivity

Isotopes that spontaneously give off radiation and whose nuclei decay into other types of nuclei are called radioisotopes. Instead of the "radioisotope", the terms "radionuclide" or "radioactive nuclide" are often used.

Among isotopes, there are some in which the nucleus emits radiation and is converted into another type of nucleus spontaneously, i.e. without the application of any external condition, such as pressure, temperature, chemical treatment, etc. These are called **radioisotopes**. This property is called **radioactivity**, and the conversion of the nucleus is called radioactive **decay** or **disintegration**. Emitted radiation can be in the form of alpha rays, beta rays, gamma rays, or others. The nucleus before decay is called the **parent**, and the one after decay is called the **progeny** (or daughter).

Approximately 70 kinds of radioisotopes exist in nature. These include uranium, thorium, radium, and potassium(^{40}K). In addition, there are approximately 3,000 kinds of radioisotopes that have been created artificially using nuclear reactors or accelerators.

The term **"activity"** is used to describe the magnitude of radioactivity, the unit for which is the **becquerel (Bq)**, the number of decay events per second.

1 becquerel = 1 decay event per second

The old unit of activity **curie (Ci),** which was defined originally based on the activity of 1 gram of ^{226}Ra, is related to the becquerel as shown in the following equations:

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

$$1 \text{ Bq} = 0.2702\ldots \times 10^{-10} \text{ Ci} \approx 27 \text{ pCi}$$

5. Half-Life of a Radioisotope

A radioisotope has an inherent half-life.

Let us think of a group of atoms of a radioisotope. As the individual atoms decay (i.e., as their nuclei decay), they are converted into another type of atom. The time required for the number of atoms of the radioisotope to become half their original number, namely, for half of them to be converted into another type of atom, is called the **"half-life"**. The activity of a certain amount of the radioisotope is in proportion to the number of original atoms remaining.

Half-life is inherent to a radioisotope, and is not affected by external conditions, such as temperature or pressure. Half-lives vary among the kinds of radioisotopes, from more than several billion years to only a very small fraction of a second.

Fig. 7 shows the decrease in activity over time. Activity measured as 1MBq becomes 0.5 times of 1 MBq after one half-life; 0.25 times of 1 MBq after two half-lives; and 0.125 times of 1 MBq after three half-lives.

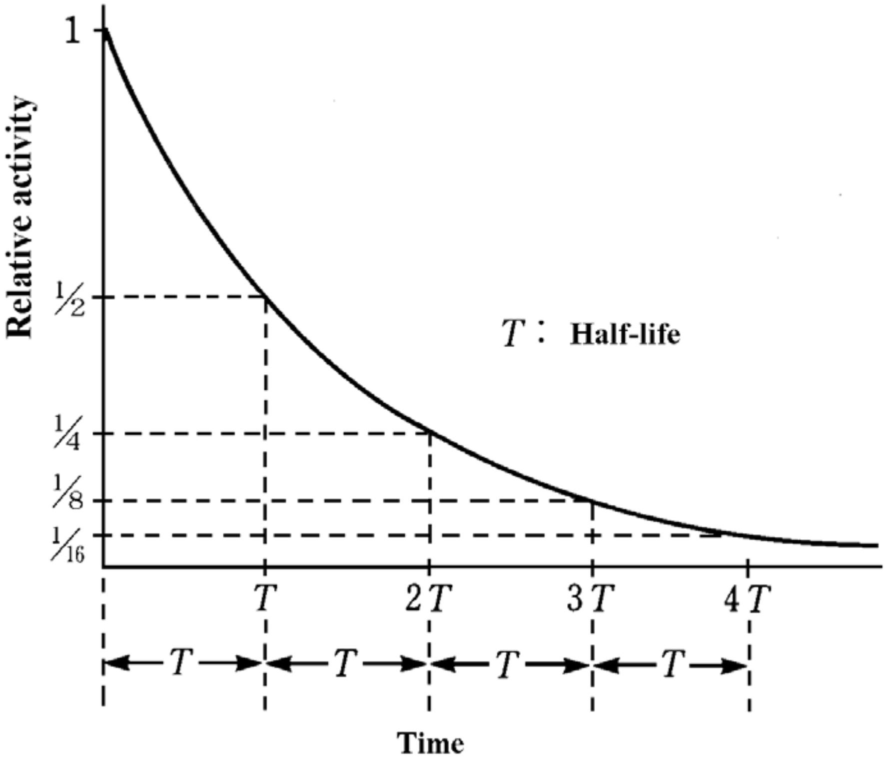

Fig. 7 Decrease in activity: Activity is reduced by half with the passage of each half-life (*T*).

6. Types of Radioactive Decay

6-1. Alpha rays are fast helium nuclei emitted from atomic nuclei.

In one type of radioactive decay, a set of two protons and two neutrons, i.e. a helium nucleus, is emitted at high speed from a heavy nucleus consisting of a large number of protons and neutrons, such as uranium or thorium. Such emissions are called alpha (α) rays, which are said to consist of alpha particles.

After an alpha particle is emitted, there remains an atomic nucleus with two protons and two neutrons less than the original nucleus (see Fig. 8). This type of decay is called **alpha decay**.

6-2. Beta rays are fast electrons emitted from atomic nuclei.

In another type of radioactive decay, a neutron changes to a proton in the nucleus, and an electron is emitted. Such emissions are called beta (β) rays, which consist of beta particles. After a beta particle is emitted, there remains a nucleus with one proton more and one neutron less than the original nucleus (see Fig. 9). This type of decay is called **beta decay**.

The words "decay" and "disintegration" suggest that the atomic nucleus is destroyed or falls into pieces. Actually, the nucleus is merely converted into a different kind of nucleus.

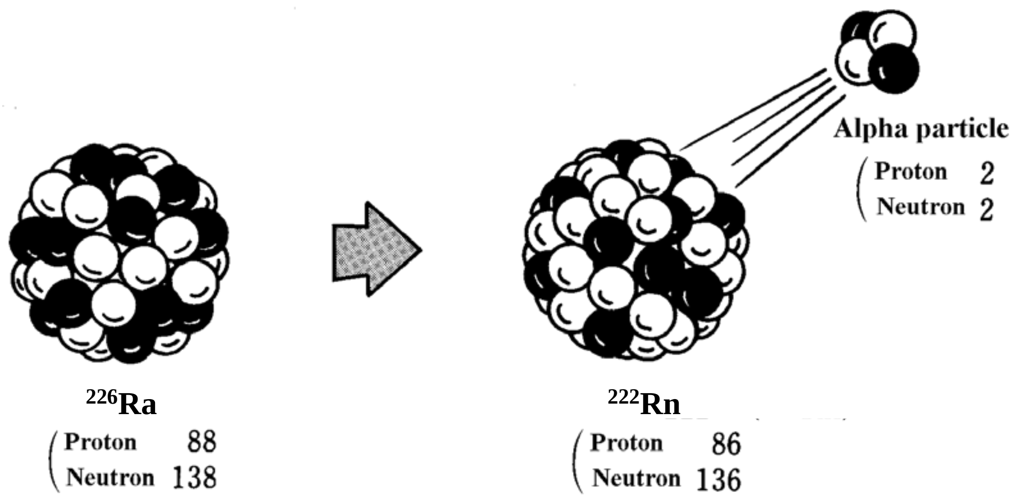

Fig. 8　Decay of ^{226}Ra(radium-226): ^{226}Ra(radium-226) becomes ^{222}Rn(radon-222) by emitting an alpha particle.

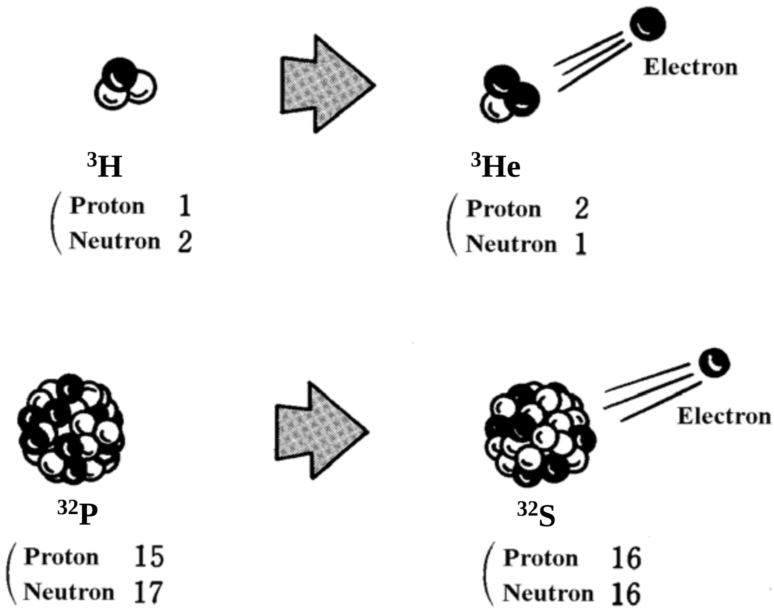

Fig. 9　Decay of ^{3}H (tritium) and ^{32}P (phosphorus-32): ^{3}H changes to ^{3}He (helium-3) by emitting a beta particle, and ^{32}P changes to ^{32}S (sulphur-32) by emitting a beta particle. In beta decay, one neutron in the nucleus changes into a proton and an electron, and the electron is emitted.

6-3. A positron sometimes emerges from a nucleus.

In another type of radioactive decay, a proton in the nucleus changes into a neutron and a positron (or a positive electron) is emitted. Positrons are described as beta-plus (β^+) rays, and this type of decay is called positron decay or β^+ decay* (see Fig. 10). Positrons have the same mass as electrons, and the same but opposite electric charge. After a positron is emitted, there remains a nucleus with one proton less and one neutron more than the original nucleus. Positrons are attracted easily to any available negative electron, whereupon the electron and the positron—being in fact the anti-particles of each other—annihilate. This annihilation process produces electromagnetic waves (two photons of 0.51 MeV each) emitted in opposite directions with energy equal to the mass of the electron pair (see Fig. 11). Such waves are called annihilation radiations.

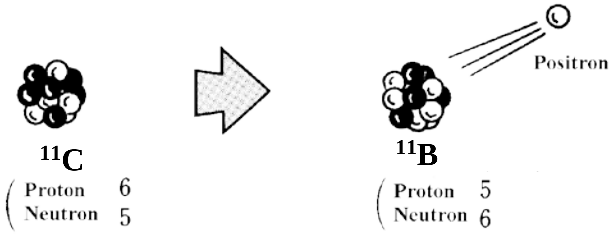

Fig. 10 Positron decay of ^{11}C (carbon-11): ^{11}C becomes ^{11}B(boron-11) by emitting a positron. In positron decay, one proton in the atomic nucleus changes into both a neutron and a positron.

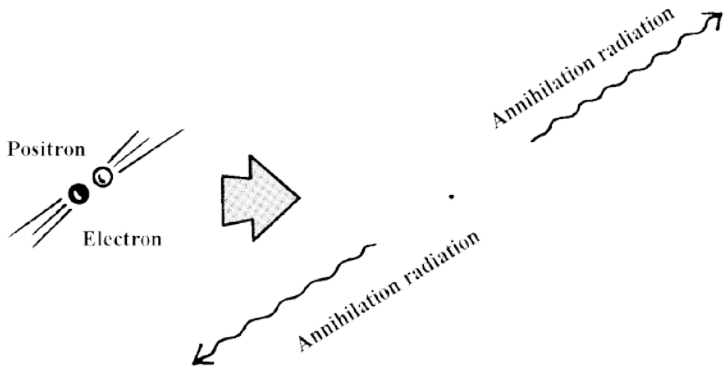

Fig. 11 Production of annihilation radiation: A positron and an electron meet and annihilate, and two waves (photons) of annihilation radiation are emitted 180 degrees apart.

* In contrast to β^+ decay, usual beta decay may be expressed as β^- decay, and, in contrast to β^+ rays, usual beta rays are described as β^- rays.

6-4.　An orbital electron is sometimes captured by a nucleus.

When a proton in the nucleus captures an orbital electron and changes into a neutron, this type of decay is called **orbital electron capture (EC).** After an EC decay, a nucleus is left which has one proton less and one neutron more than the original nucleus (see Fig. 12).

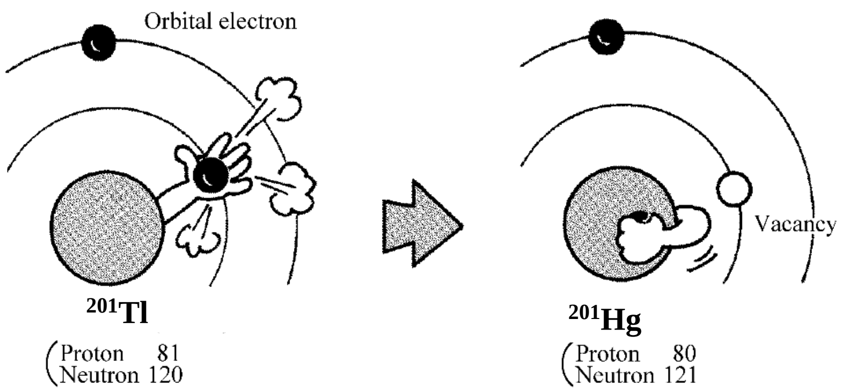

Fig. 12　Orbital electron capture in ^{201}Tl (thallium-201): A ^{201}Tl nucleus becomes a ^{201}Hg (mercury-201) nucleus after capturing one orbital electron. As this leaves a vacancy among the orbital electrons, emission of the characteristic X-rays of mercury follows. In orbital electron capture, one proton in the nucleus captures an orbital electron and changes to a neutron.

6-5. Gamma rays are electromagnetic waves emitted from an excited nucleus, and are essentially the same as X-rays.

A nucleus after decay may often be unstable, i.e., the nucleus is in an excited state. It becomes stable by emitting its extra energy in the form of electromagnetic waves, usually within a very short period of time (see Fig. 13). In this case, the electromagnetic waves emitted from the nucleus are called gamma (γ) rays. Such emissions do not cause the nucleus to change further into another type, and, for this reason, the term 'gamma decay' is not used.

Gamma rays and X-rays are both electromagnetic waves and are distinguished not by their energy (wave length), but by their origins. High energy electromagnetic waves (photons) other than gamma rays are categorized to be X-rays.

Sometimes, instead of emitting a gamma ray, an excited nucleus transfers its extra energy to one of its orbital electrons, and that electron is emitted, i.e. knocked out of the atom. This phenomenon is called **"internal conversion",** and the emitted electron is called an **"internal conversion electron".**.

6-6. Gamma rays are sometimes emitted with delay.

Sometimes the excited nucleus is not extremely unstable but has a finite period of life. In such a case, the excited nucleus is said to be a **" nuclear isomer"**, and is designated by adding 'm' at the end of its mass number, e.g., ^{99m}**Tc**(technetium-99m). Nuclear isomers have their own half-lives. They become stable by emitting gamma rays in a process known as **"isomeric transition" (IT)**.

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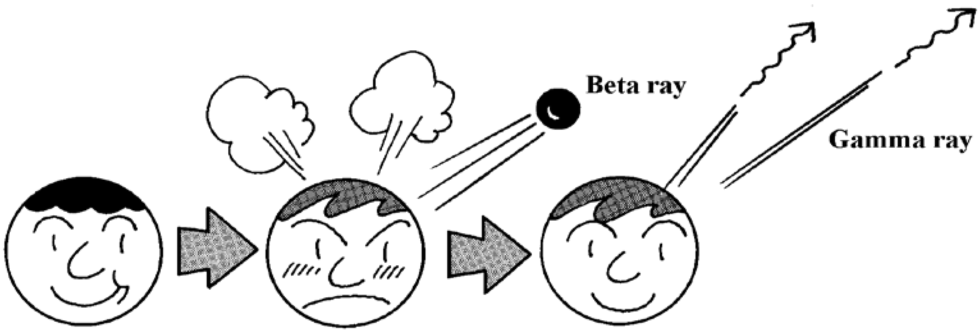
*Electromagnetic waves: X-rays/gamma rays are electromagnetic waves like radio waves, infrared rays, visible light and ultraviolet rays, but their wavelength is very short. Electromagnetic waves sometimes behave as particles. When electromagnetic waves are considered to be a stream of particles, the particles are called **photons**. The shorter the wavelengths are, the larger the photon energy is.



^{60}Co(cobalt-60)
Proton 27
Neutron 33

^{60}Ni(nickel-60)
Excited state
Proton 28
Neutron 32

^{60}Ni(nickel-60)
Ground state
Proton 28
Neutron 32

Fig. 13 Gamma ray emissions: Nuclei are left excited after decay, and become stable by emitting their extra energy as gamma rays.

6-7. Sources and action of neutrons with matter.

As we know, neutrons are generally produced by fission of heavy nuclei such as ^{235}U (uranium-235) irradiated with low-energy neutrons, a familiar process occurring in the nuclear reactor.

There exist, however, some radioisotopes whose nucleus splits automatically into two fragments and at the same time emits several high-energy neutrons. This process is called the **"spontaneous fission (SF)"**. The most widely used neutron source of such type is ^{252}Cf (californium-252).

Another type of neutron sources is those using nuclear reaction such as(α,n) reaction. The $^{241}Am/Be$ neutron source is an example.

The interaction of neutrons with other materials is very different from that of alpha and beta rays. Moreover, the action of neutrons varies greatly depending on their speed (kinetic energy). See Fig. 14.

Because the neutron has no electric charge, it can easily approach an atomic nucleus without electrically interacting with charged nuclei. Slow neutrons are readily absorbed by the nucleus. When a neutron is thus captured by a nucleus, the nucleus becomes an isotope of the same element with the mass number greater by 1. Such an isotope may often be radioactive. For example, stable ^{59}Co(cobalt-59) becomes radioactive ^{60}Co by capturing a neutron. Most radioisotopes are produced in nuclear reactors by using this process of **"neutron capture"**.

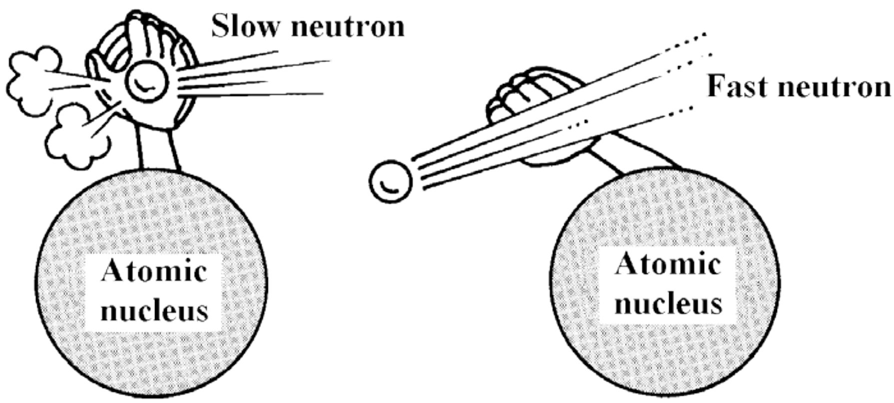


Fig. 14 Neutron capture by a nucleus: When a neutron is captured by an atomic nucleus, the nucleus becomes an isotope of the same element. Slow neutrons are captured more easily than fast neutrons.

Table 1 shows a comparison of the properties of alpha, beta, gamma (X−rays) and neutrons.

Table 1 Types of radiation and their properties

Properties	**Alpha rays**	**Beta rays**	**Gamma rays (X-rays)**	**Neutrons**
Nature	Helium nucleus	Electron Positron	Electromagnetic wave (photon)	Neutron
Mass	Large	Very small	None	Large
Electric charge	+ 2e	– 1e +1e	None	None
Penetration	Small	Medium	Large	Large
Photographic effect	Large	Medium	Small	Small
Fluorescence effect	Large	Medium	Small	Small
Ionization effect	Large	Medium	Small	Small

7. X-Rays

There are two types of X-rays: bremsstrahlung and characteristic X- rays.

X-rays are electromagnetic waves like visible light and radio waves. X-ray tubes are used to generate X-rays (see Fig.15). Electrons emitted from a heated filament in a vacuum are accelerated toward an anode by high voltage. When they strike the metal anode, X-rays are generated. This is because, as the electrons are passing by atomic nuclei of the atoms of the anode, the electric force between the nuclei and the electrons exerts a strong braking action on the electrons, and their kinetic energy is partially converted to X-rays (see Fig.16). X-rays generated in this way are called **bremsstrahlung** (a German term meaning braking radiation).

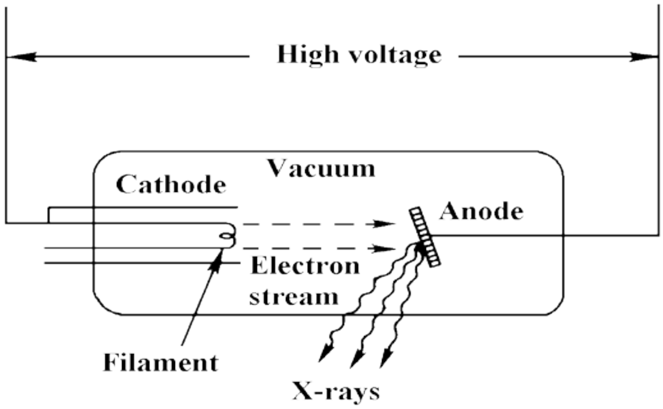


Fig. 15 X-ray tube:Fast electrons collide with the metal anode and generate X-rays.

Additionally, when fast electrons cause the atoms of the anode to become excited or ionized, and electrons from outer orbitals move to vacant inner orbitals, energy equal to the energy difference between the outer and the inner orbit is emitted as electromagnetic waves (see Fig.17). Such electromagnetic waves have energy specific to the kind of atom, and are called **"characteristic X-rays"** (see also Fig. 12). Instead of the emission of characteristic X-rays, sometimes one of the electrons in an outer orbit is given excitation energy and kicked out of the atom. This electron is called the **" Auger electron"** which is derived from French physicist Prof. Pierre Auger.

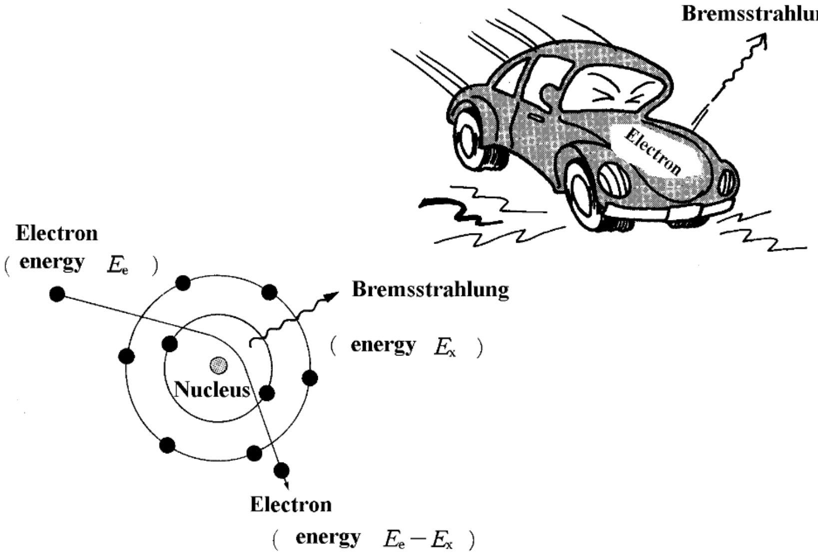


Fig. 16 Generation of bremsstrahlung: When moving electrons are braked, X-rays are generated.

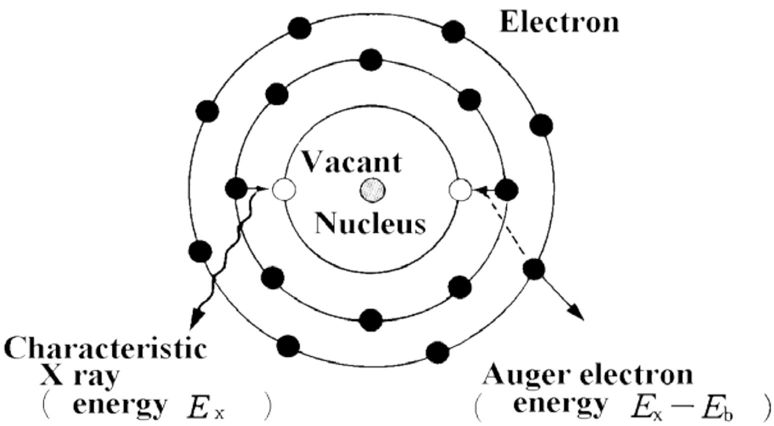


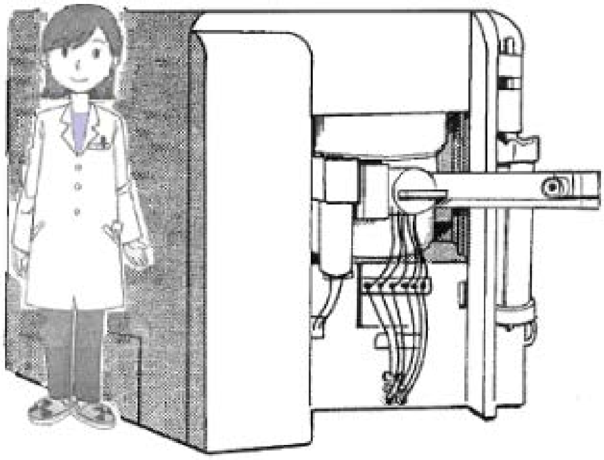
Fig. 17 Emission of characteristic X-rays or Auger electrons: When an electron in an outer orbit moves to a vacancy in an inner orbit, a characteristic X-ray or an Auger electron are emitted.

E_b: Energy necessary to release an orbital electron from the atom(binding energy of an orbital electron to the nucleus).

8. Accelerators

Accelerators are used to generate various kinds of radiation and to produce radioisotopes.

Because electrons and protons are electrically charged, they can be accelerated in a vacuum by application of electric force and given high kinetic energy. An accelerator is a device to produce fast streams of electrons, protons, or other charged particles. Various types of accelerators are used in academic studies, and for the production of high energy X-rays or radioisotopes for industrial and medical purposes. These accelerators are legally classified as radiation generating apparatuses.



9. Types of Radiation

There are many types of what we commonly call “radiation”.

As has been explained so far, radiation includes X-rays, alpha rays, beta-minus rays, beta-plus rays, gamma rays, neutrons, electrons, protons and cosmic rays. Major types of radiation can be classified by their characteristics as shown in the table below. Radiation that exists in the environment is called **“natural radiation”**. Radiation created artificially is called **“artificial radiation”**. **“Radioactivity”** and **“radiation”** are similar words and are often confused -- but the meanings are different. When a radioisotope is likened to an electric lamp, for example, radiation is the light emitted from the lamp, while radioactivity is the property of the lamp that emits light.

Radiation is the product of anything that is radioactive. It does not come only from radioisotopes, but also from accelerators and nuclear reactors, as well as cosmic rays.

Table 2 Major types of radiation

Radiation	Electromagnetic radiation (photons)	X-rays (Bremsstrahlung, characteristic X-rays, generated by phenomena occurring outside of nuclei)
		Gamma rays (generated by changes in the energy states of nuclei)
	Charged particles	Beta-minus rays (electrons emitted from nuclei)
		Beta-plus rays (positrons emitted from nuclei)
		Electrons (produced by accelerators)
		Alpha rays (helium nuclei emitted from nuclei)
		Protons (produced by accelerators)
		Deuterons (produced by accelerators)
		Various heavy ions and mesons (produced by accelerators)
	Uncharged particles	Neutrons (produced by reactors, accelerators and radioisotopes)

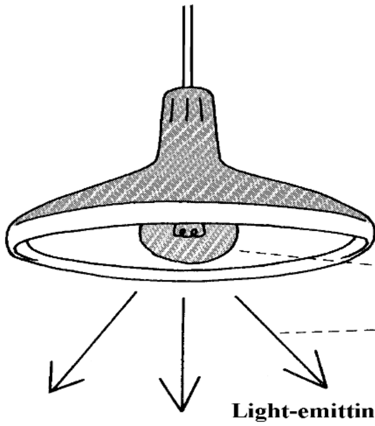


Fig. 19 Relationship among radioactivity, radiation and radioisotopes

10. Quantities and Units Related to Radiation

The basic unit of energy is the **joule (J)**; however, the usual measure of radiation energy is the **electron volt (eV)**. The kinetic energy gained by an electron when it is accelerated by a potential difference of 1 volt is defined as 1 eV. The relationship between the electron volt and the joule is,

$1\ \text{eV} = 1.6022\times10^{-19}\ \text{J}$

$1\ \text{eV}\times10^{3}$ and 10^{6} are called 1 keV and 1 MeV, respectively. For example, ^{60}Co emits gamma rays of 1.17 MeV and 1.33 MeV after emitting beta rays with a maximum energy of 0.32 MeV.

In assessing the effect of radiation on humans, three quantities: absorbed dose, equivalent dose and effective dose, are considered. The equivalent dose and the effective dose are used for the ICRP's system for radiation protection and called the **"protection quantities"**.

10-1. KERMA

The **KERMA** (Kinetic Energy Released in MAterial) is the given kinetic energy (J) per unit mass of the material (1kg) by the interaction between radiation and material. The KERMA is used for uncharged radiation or particles such as γ-, x-ray or neutron. The unit is the **gray (Gy)**. When the material is air, that is called "Air KERMA".

10-2. Absorbed dose

As a result of interaction between radiation and material (receptor), the energy absorbed per unit mass of the material is called the **absorbed dose**. The absorbed dose is a fundamental dosimetric quantity, and can be considered regardless of the kind of radiation or the kind of material. The unit for absorbed dose is the **gray (Gy)**. An absorbed dose of one gray means that one joule of energy is absorbed per one kilogram of the material.

When using the absorbed dose, it should be mentioned what the absorber is, because in a radiation field the absorbed dose will vary depending on the absorber. For radiation protection purposes, air, water, and soft tissue are usually regarded as the absorber.

10-3. Equivalent dose

When the human body is exposed to radiation, the degree of biological effects will differ depending on the type and energy of the radiation, even in cases where the absorbed dose is the same. This is because the damage to DNA due to the energy deposited by radiation is more difficult to repair as the density of energy deposition becomes greater.

The concept of equivalent dose was created as a common index for calculations of risk to the human body from radiation under different conditions. This concept of equivalent dose is used only in the context of radiation protection calculations.

The relationship between equivalent dose and absorbed dose in a particular tissue or organ is described by the following formula:

Equivalent dose in Sv = Absorbed dose in Gy ×
radiation weighting factor (w_R)

The **radiation weighting factor** assumes that the degree of biological effect differs depending on the ionization density (**linear energy transfer, LET**) of radiation and determined by the ICRP based upon theoretical and experimental data and considering practical applications. Radiation weighting factors of 1 for beta rays (electrons) and gamma rays (X-rays), and 20 for alpha rays are currently used. For neutrons the value varies with their energy ranging 2.5 to about 20.

When the gray is used as the unit for absorbed dose, the unit for equivalent dose is the sievert (Sv). The millisievert (mSv, 10^{-3} Sv) and the microsievert (μSv, 10^{-6} Sv) are also used.

10-4. Tissue equivalent dose and effective dose

Equivalent dose for a particular tissue or organ T is called **tissue equivalent dose** H_T. When the human body is exposed to radiation, how the effects (in this case, incidence of fatal cancer or severe genetic diseases) appear depends on tissue or organ. In order to assess the total of such effects on various tissues and organs throughout the body, **effective dose** is used. To get the effective dose, tissue equivalent doses are multiplied by tissue weighting factors and then summed up for each exposed tissue and organ throughout the body. Tissue weighting factors (Table 9) are estimated from clinical data, followup studies of Atomic bomb survivors, and studies with experimental animals. The unit of effective dose is also Sv (See also Ⅳ 7 and 8).

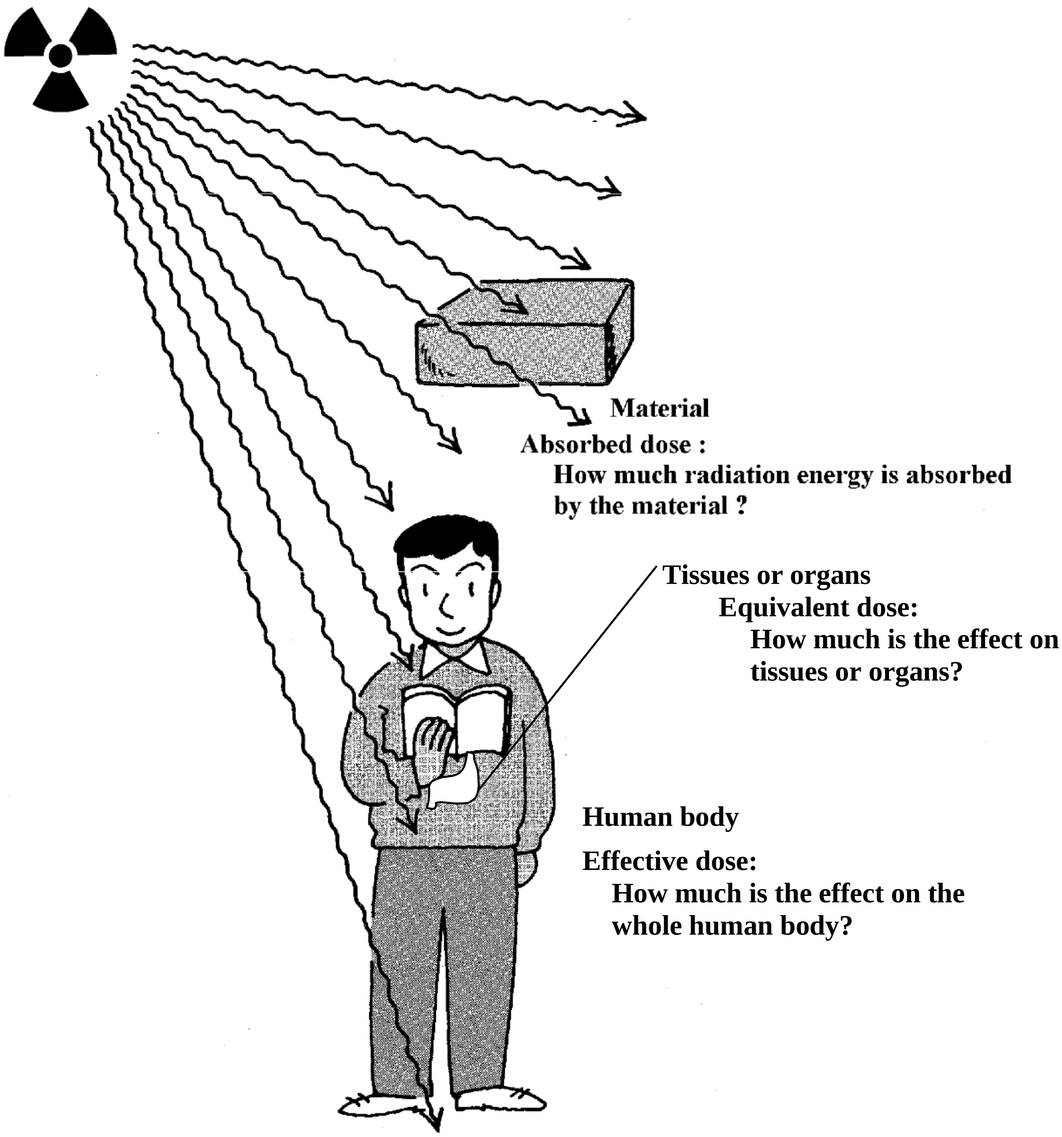


Fig. 20 Absorbed dose, equivalent dose and effective dose: The absorbed dose is a measure of how much energy is absorbed in material, regardless of the type of radiation or material; the equivalent dose is a measure of biological effects of radiation on tissues or organs in the human body. The effective dose is a measure of total effects on the whole body. The tissue equivalent dose and the effective dose are used solely in the context of radiation protection calculations.

10-5. Operational dose quantities and units

The tissue equivalent dose and the effective dose are almost impossible to be measured because it would require dosimeters inside of the body. Therefore, in practice, **operational dose quantities** are defined as substitutes for them for external irradiation. These operational dose quantities were provided by the International Commission on Radiation Units and Measurements (ICRU).

For the measurements of effective dose rate in a workplace, dose rate meters calibrated with the **ambient dose equivalent** (designated as **1 cm dose equivalent** in Japanese regulations) are used which is defined by the dose at a point of 1 cm depth in a sphere of 30 cm diameter made of tissue equivalent material (ICRU sphere).

For the measurements of skin equivalent dose in a workplace, dose rate meters calibrated with the **directional dose equivalent** (designated as **70µm dose equivalent**) are used.

For the measurement of personal dose, personal dosimeters calibrated with the **personal dose equivalent** are used.

The units of these dose equivalents are also Sv.

Table 3 Quantities and units related to radiation

Item	Unit	Symbol	Definition	Remarks
KERMA	gray	Gy	Kinetic Energy Released in MAterial. Used for uncharged particles such as γ, x ray or neutron.1 Gy corresponds to one joule per kilogram of material.	SI unit J/kg
absorbed dose	gray	Gy	1 Gy corresponds to absorbed energy of one joule per kilogram of material	SI unit: J/kg
equivalent dose	sievert	Sv	Absorbed dose (Gy) × radiation weighting factor	SI unit: J/kg
effective dose	sievert	Sv	∑(Equivalent dose for a tissue × tissue weighting factor)	SI unit: J/kg
activity	becquerel	Bq	One decay event per second	SI unit: s^{-1}
radiation energy	electron volt	eV	Kinetic energy gained by an electron when it is accelerated by a potential of one volt	SI unit: J

III. Safe Handling

1. Who is the Radiation Protection Staff?

Those who support the practice of radiation protection at a facility are called the **radiation protection staff**. This is not a legally defined occupation, but no facility can be operated without someone who actually supports radiation workers to practice the radiation protection. The number and positions of radiation protection staff will differ according to the size and nature of the facility. The scope of work of radiation protection staff ranges from controlling the access of radiation workers to environmental monitoring, and to personal exposure control.

1-1. Responsibilities of radiation protection staffs and their relationships with radiation workers

The position within the organization, scope of work, and responsibilities of a radiation protection staff member will differ according to the facility, and be defined in the Radiation Hazards Prevention Program of the facility (see Chapter VI).

There may be a misunderstanding among radiation workers that the work of radiation control can be left in the hands of the radiation protection staff. In reality, actual radiation control cannot be done only by radiation protection supervisors (see Chapter V 7) and radiation protection staff, but requires the active participation of the radiation workers themselves.

1-2. Keeping close contact with radiation protection staff

Because the radiation protection staffs at each facility are most knowledgeable about radiation control at that location, radiation workers should feel free to talk to him or her even about routine operations. Of course, whenever anything abnormal occurs ― particularly any kind of accident ― radiation workers must contact anyone of the radiation protection staff members promptly, and follow his or her instructions.

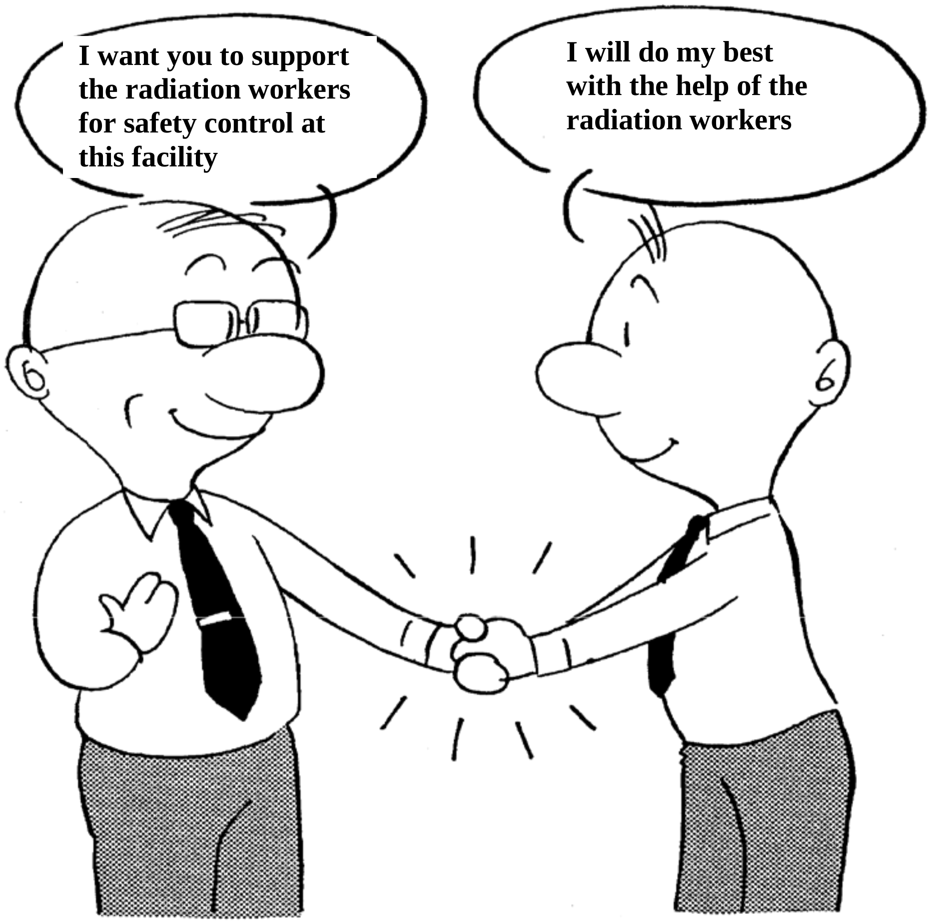


Fig. 21 Radiation protection staff

2. Protection Against External Exposure

Measures for protection against external exposure should focus on the three principles: shielding, distance and time.

2-1. Shielding

Dose rate in any workplace should be reduced by shielding radiation sources with lead, iron or concrete for gamma rays, and plastics or water for neutrons. Specific measures will vary according to the type and energy of radiation. Shielding can generally be done more easily and more economically as dose to the radiation source as possible.

2-2. Distance

It is important to work as far as possible from the radiation source. If the radiation source is a point source, such as a gamma ray source, the dose rate is in inverse proportion to the square of the distance. For example, if the dose rate at a point one meter from the point source of gamma ray is 100 mSv/h, it will be one fourth, or 25 mSv/h, at a point two meters away, and only one hundredth, or 1 mSv/h, at a point ten meters away. The exposure can be substantially reduced by using remote handling equipment such as tongs.

2-3. Time

By shortening exposure time, the exposure can be reduced. Radiation workers should review operational procedures in advance, and work efficiently. Time reduction, however, should be looked to only after the best measures for shielding and distance have been taken.

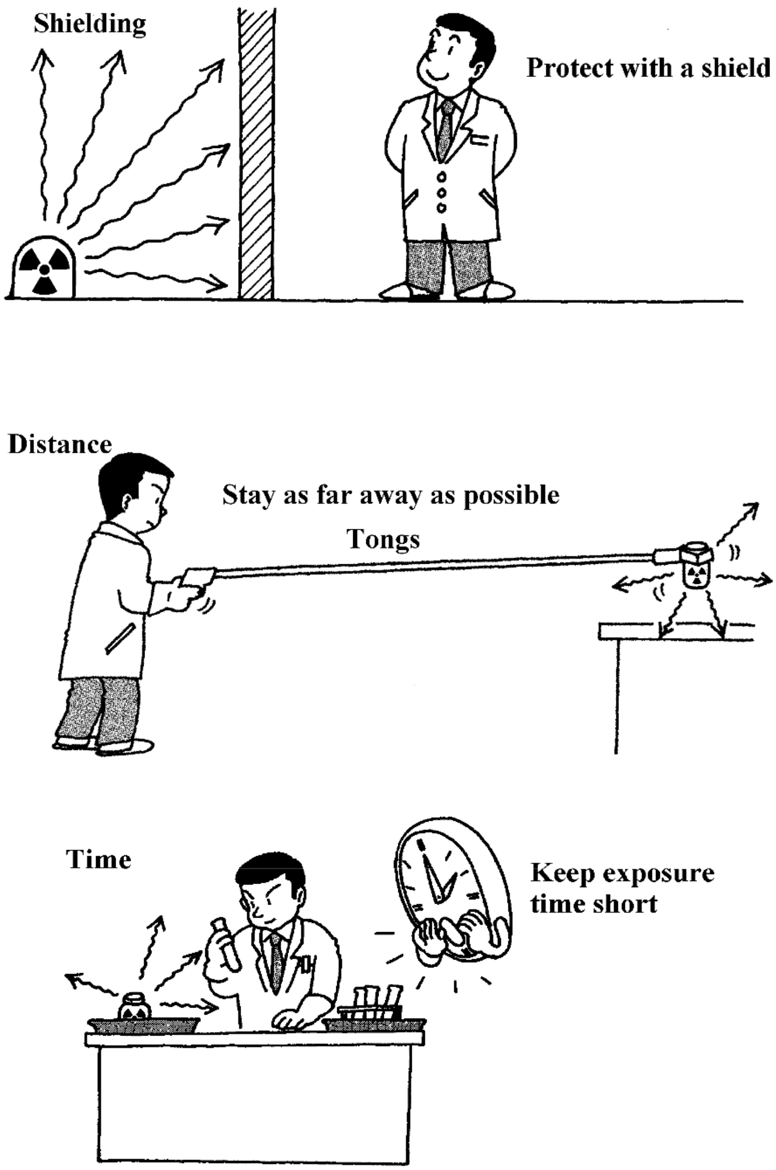


Fig. 22 Three principles for protection against external exposure: Those who handle radiation must always keep in mind the three principles of shielding, distance and time.

3. Protection Against Internal Exposure

Protection against internal exposure can be attained by faithfully observing all rules and guidelines for operations with unsealed radioisotopes.

Radioisotopes can enter the body through the following three intake routes:

(1) through the respiratory system;
(2) through the digestive system; and
(3) through the skin, especially a wound.

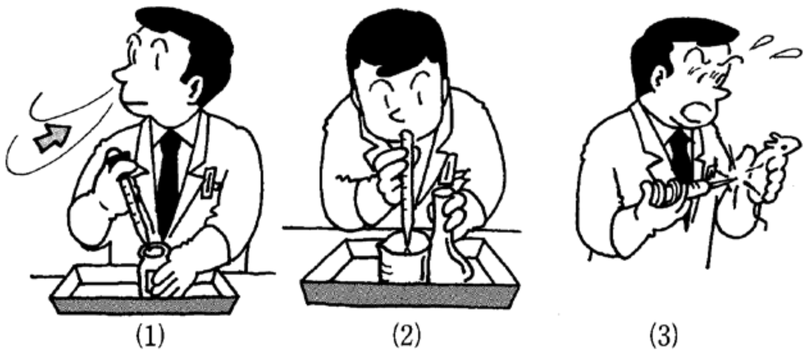


Fig. 23 Intake routes of radioisotopes into the Body

Generally, intake through the respiratory system—inhalation—is the most significant. In order to prevent radioisotopes from entering the body, it is important to keep equipment and the workplace orderly, to work efficiently, and to faithfully observe all rules for operation.

In a facility where radioisotopes are handled, it is necessary to put on special working clothes. When leaving a controlled area, those clothes should be removed, hands should be well washed, and contamination on the hands, feet and clothes should be checked for by using a body surface monitor (a Hand-foot- clothes monitor). Whenever anything is brought out of the controlled area, it should be checked for radioactive contamination with appropriate measuring equipment. Continuous care must be taken in regard to radioactive air contamination and surface contamination on floors, tables, etc., in the working environment.

When working in an area of possible air contamination, workers need to wear a protective mask to avoid inhalation of radioactive aerosol.

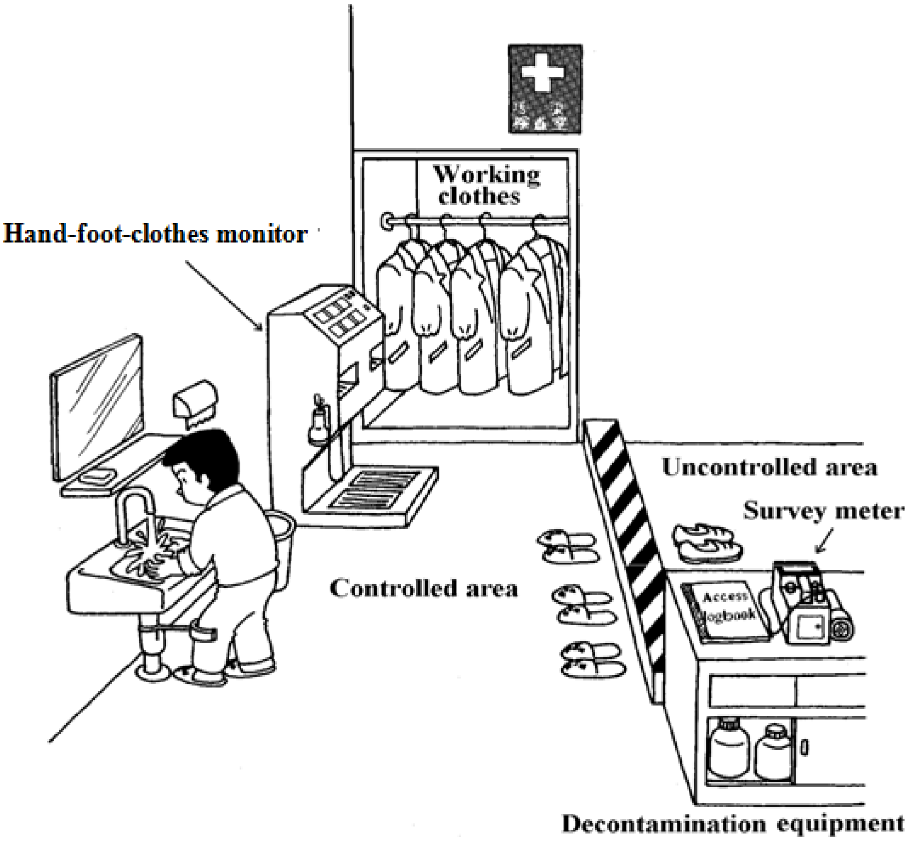


Fig. 24 In order to prevent radioactive contamination when handling unsealed radioisotopes, special working clothes, slippers and rubber gloves should be worn. When leaving the controlled area, working clothes should be removed, hands washed well, and contamination checked for by a body surface monitor.

When airborne dust, gas or vapor can be produced, unsealed radioisotopes should be handled under a hood (see Fig. 25). It is sometimes necessary to handle them in a fully airtight space, such as a glove box (see Fig. 26).

Eating, drinking, smoking and wearing make-up must not be done in a workroom where isotopes are handled. Nothing should be sucked through a pipette by mouth.

In order to prevent radioisotopes from adhering to the body, special clothes, a cap, footwear and rubber gloves should be worn. If circumstances so require, a respirator or, sometimes, an airline suit should be worn.

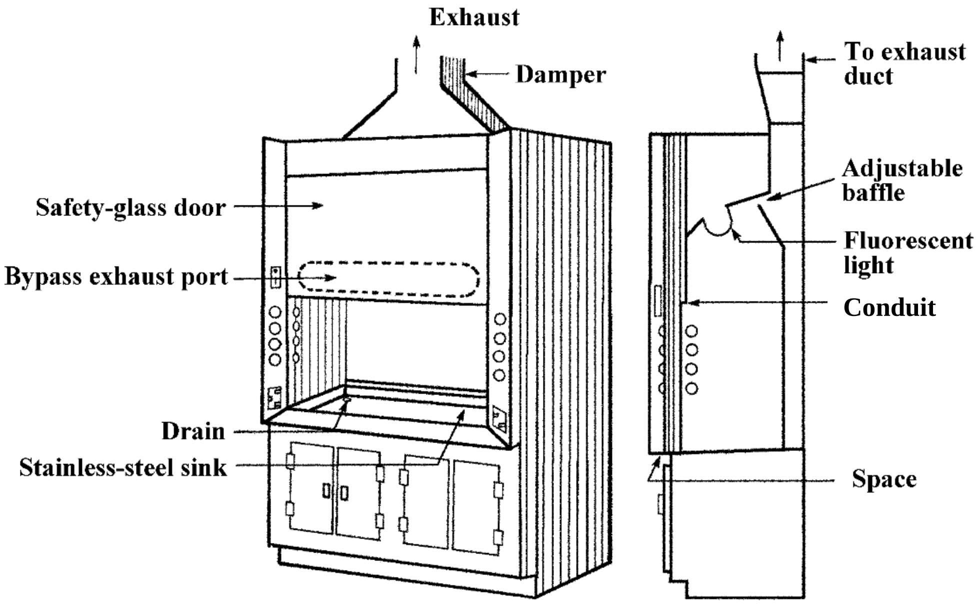


Fig. 25 Oak-Ridge-type hood

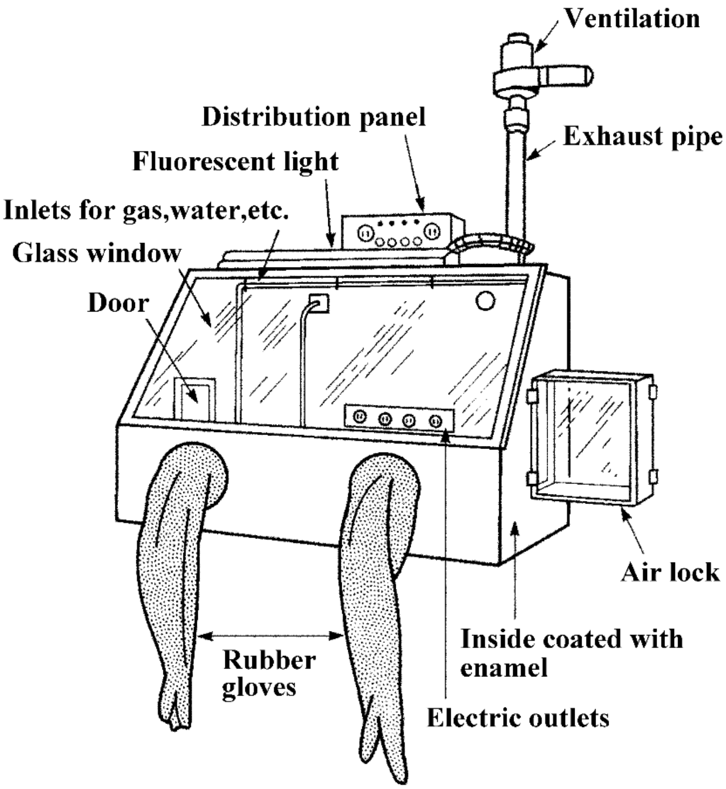


Fig. 26 Glove box

4. Attitude when Handling Radioisotopes and Radiation

When handling radioisotopes and radiation, for protection against both external and internal exposure, the basic three-point attitude is: “Don't be afraid; don't panic; but don't take it lightly”. For that, it is necessary to have an accurate understanding of radioisotopes and radiation.

In addition, when commencing a new task, it is of course necessary to plan the work carefully. It is also of great benefit in the prevention of accidents to practice the necessary operations several times without using real radioisotopes or radiation (cold run), in order to become familiar with the steps and procedures, and to modify them if necessary.

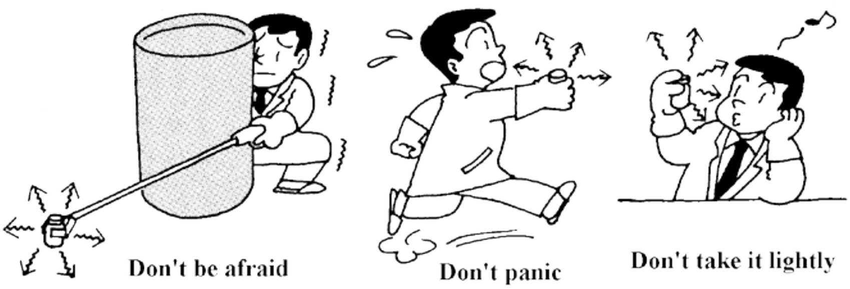


Fig. 27 Attitude when handling isotopes and radiation

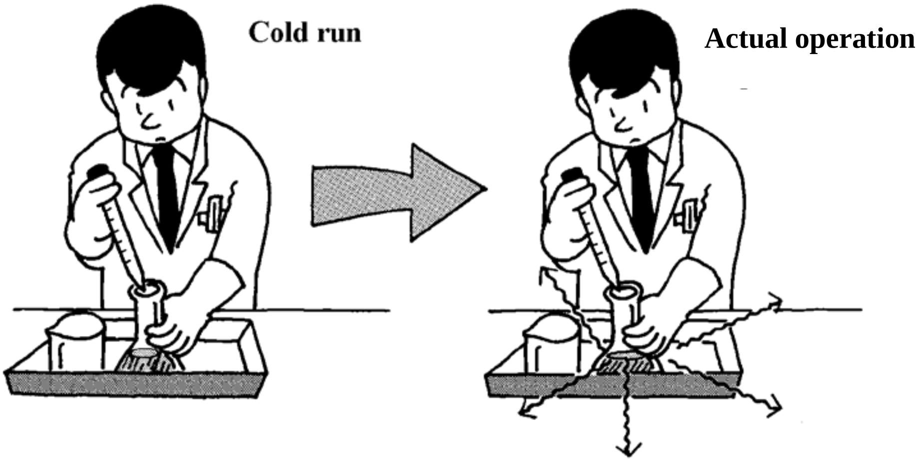


Fig. 28 Working without a rehearsal could cause an accident

5. Radiation Monitoring

Radiation cannot be felt or detected by our senses, but its existence and amount can be determined with appropriate methods.

5-1. Personal monitoring instruments

(1) External exposure

Thermoluminescent dosimeters (TLD), fluoroglass dosimeters (FLD), optically stimulated luminescence (OSL) dosimeters and electronic personal dosimeters are all instruments to measure personal dose equivalent from external exposure (see Fig.29). These dosimeters are worn on the chest (or on the abdomen for women of reproductive age). If there is any possibility of substantial exposure to other parts of the body, for example, the fingertips, those have to be monitored with special monitors such as ring badges.

(2) Internal exposure

To assess doses from internal exposure, the kind of radioisotopes and their amount of intake must be known. There are several methods for determining the intake of an isotope. Intake can be determined externally by means of a whole-body counter (Fig.30), by measuring activity concentration in the air at workplace and working time, or by the method of bioassay, i.e. radiochemical analysis of excreta. The internal dose can then be calculated based on radioisotope intake as obtained by any of these methods.

When using a whole-body counter, the amount and distribution of gamma rays can be determined by measuring gamma rays emitted by the radioisotope distributed in the body from outside. In contrast to this, in the bioassay method, radioisotope contained in urine, feces or, in cases of handling tritium, breath is used to estimate the amount of radioisotope in the body. The bioassay is appropriate to assess the intake of radioisotopes emitting only beta rays or alpha rays, but it takes much effort and time.

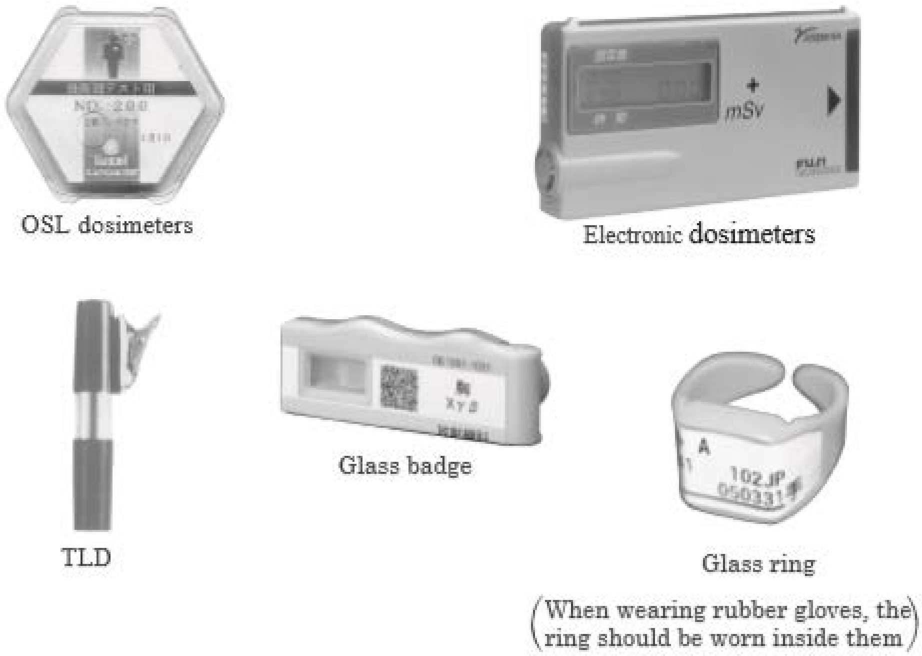


Fig. 29 There are a variety of instruments to measure personal external exposure, which are used separately or jointly.

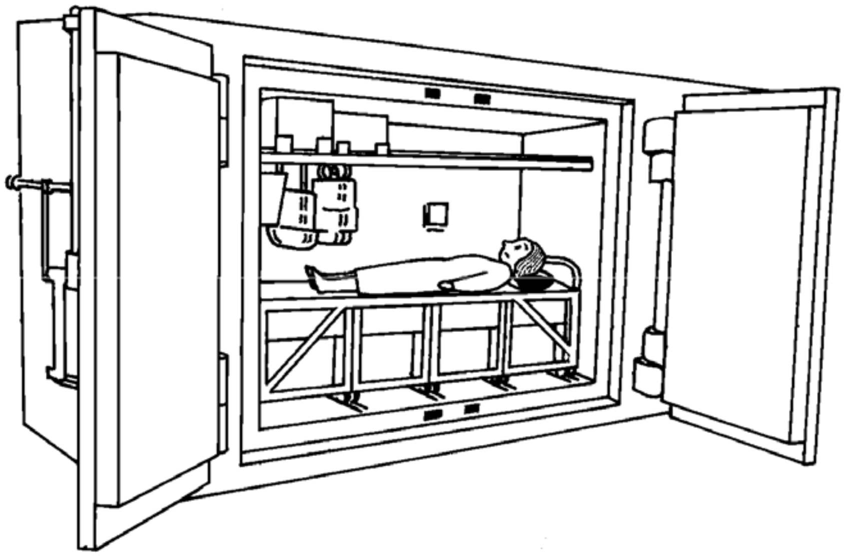


Fig. 30 Whole-body counter : This device is sensitive to gamma rays enough to easily detect even the slight amount of potassium (^{40}K) that is naturally present in the body.

5-2. Workplace monitoring

Using survey meters, it is easy to measure the dose rate in working areas. Geiger-Mueller (GM) counters, ionization chambers and scintillation counters are common types of survey meters, and each have their own strengths and weaknesses (see Fig. 31).

Fig. 31 Major types of survey meters
(1) Ionization chamber type
(2) GM counter type
(3) Scintillation counter type
(4) Neutron survey meter

In order to measure activity concentration in the air or in water, various kinds of sampling equipment and radiation measuring instruments are used, in accordance with the specific needs of that measurement.

Radiation monitors, such as area monitors, water monitors and gas monitors, are placed at specified locations to continuously measure and monitor the amount of activity concentration at that spot.

5-3. Monitoring of surface contamination

Survey meters can sometimes be used to check for surface contamination on a floor, tables and any other goods, but when the dose rate in the vicinity is high, e.g., in the case of a container of gamma ray sources, contamination on the surface can often not be measured accurately. In such cases, wipe tests are used. In that method, extraneous matter on the tested surface is wiped off with filter paper (see Fig.32). Radioactivity on the paper is then measured to detect and assess surface contamination.

For contamination on workers' bodies, body surface monitors are used at the exit of controlled areas.

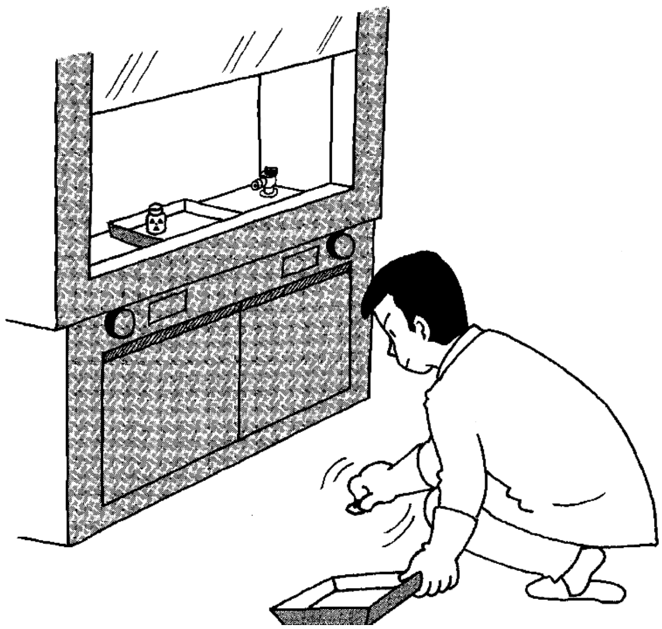


Fig. 32 Collecting a sample for a wipe test

5-4. External exposure measurement

External exposure refers to exposure when the radiation source is outside the human body. Exposure levels depend on the type and energy of the radiation. Low-penetrating radiations such as alpha rays and low-energy beta rays are blocked from reaching the body by the air, by clothes, or by the surface layer of the skin. For low-penetrating radiation, the dose equivalent at a depth of 70μm is measured and used to assess the skin equivalent dose. Otherwise, 1-cm dose equivalent must be measured to assess the effective dose.

(1) Methods for measuring external exposure

External exposure can be assessed either by measuring the radiation level in the working environment or by measuring the exposure of an individual radiation worker. Measurement and assessment of individual dose are done continuously by personal dosimeters (Fig. 29) while working in the controlled area. When the whole body is evenly exposed, the instruments should be worn on the chests for men, while on the abdomen for women.

(2) When exposure is uneven

Sometimes, because of uneven distribution of radiation, only a part of the body receives significant exposure to radiation, for example, in the case of exposure to X-rays or beta rays from small sources, or by wearing a protective apron. In such situations, tissue equivalent doses should be considered for the three regions of the body shown in Fig. 33.

(3) When measuring dose is difficult

It is sometimes difficult to measure and assess dose with personal dosimeters. In such a situation, a survey meter or other radiation measuring instrument is used. If this, too, is difficult, assessment based on calculations is permissible.

(4) Surface contamination on the skin and clothing

Usually hand-foot-clothes monitors are used.

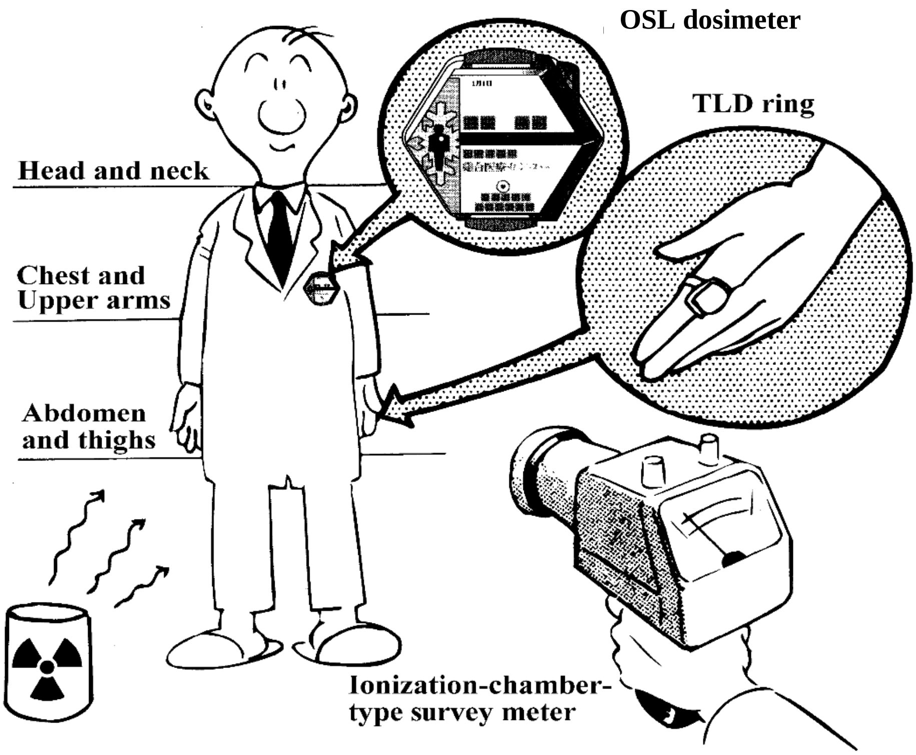


Fig. 33 Measuring external exposure

5-5. Internal exposure and its assessments

Internal exposure refers to the exposure when radiation sources are inside the body, i.e. when any radioisotope has somehow entered the body. With internal exposure, unlike with external exposure, exposure to alpha rays or low-energy beta rays becomes significant.

(1) Routes for internal exposure

Radioisotopes can enter the body by inhalation, by ingestion, or through the skin, especially through a wound, all of which are referred to as intake. Radioisotopes move through the body along different routes, depending on their physical and chemical characteristics, and are eventually excreted from the body by urine and feces, and sometimes by exhalation.

(2) Methods for assessing internal exposure

The intake of radioisotopes can be assessed by external measurement of gamma rays emitted by the radioisotopes within the body. For this, a whole-body counter is used.

The bioassay method indirectly measures the intake of radioisotopes by measuring their presence in samples of excreta, such as urine and feces. For this, biokinetic models are necessary, which allow assessments of the amount of radioisotopes deposited in various organs. This method is useful in analyzing radioisotopes that emit only alpha or beta rays.

Calculations based on measured concentrations of radioisotopes in the air involve many variables, including the amount of inhalation, breathing rate, and how long one stays in the place. Despite these difficulties, the method is widely used.

(3) Implementation of the assessments

The calculation of internal exposure is done for an individual who may take in radioisotopes inadvertently. In actual practice, the appropriate method or combination of the methods is determined based on a judgment of cost, labour, the kind of radioisotopes handled, the nature of the work operation, and the working environment. When the inhaled or ingested amount becomes known, assessment of effective dose or tissue equivalent dose is done by using dose-to-intake conversion coefficients given by the ICRP. These coefficients are also given in the Notification by the NRA. The Act on the Regulation of Radioisotopes, etc. requires determination of internal exposure at least once every three months for those workers who work in the area where radioisotope intake may occur.

Intake through inhalation or ingestion

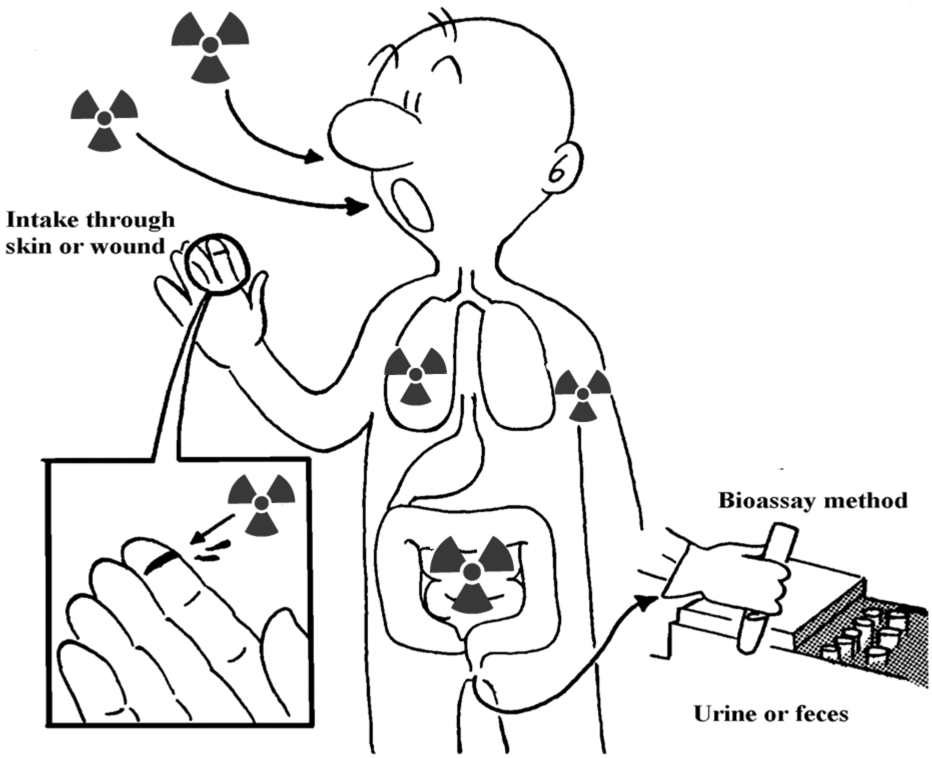


Fig. 34 Measuring internal exposure

6. Education and Training

It is essential for radiation protection that radiation workers be aware of radiation-control requirements, and that they be fully cooperative. To this end, radiation workers are required, through education and training, to understand the importance of radiation control and specific protection measures, and to have basic knowledge about biological effects of radiation. Education and training are necessary before a radiation worker deals with radiation or radioisotopes for the first time, and regularly thereafter at least once a year.

6-1. Timing of education and training

Education and training for a radiation worker must be provided before the worker enters a controlled area for the first time, and, after the worker has entered a controlled area, within one year from the beginning day of the fiscal year following the fiscal year of the day on which previous education and training were provided. Through re-education, radiation workers obtain the latest knowledge on radiation effects and techniques for safe handling, as well as have the opportunity to reconfirm regularly the importance of safe handling.

6-2. Topics to be learned through education and training

For inexperienced radiation workers, items to be taught and required hours are clearly established, as shown in the Table 4. These are minimum requirements, with each facility providing its own education and training curriculum, taking its own situation into account. Programs often go beyond mere lectures, and include opportunities to improve the skills of safe handling in realistic situations. It is also important that radiation workers learn from their more experienced colleagues and from radiation protection staffs－which is to say, on-the-job training, or OJT.

Table 4 Required items and length of education/training before entering a controlled area

Item / Classification	minimum requirements
Effects of radiation on human body	30 min.
Safe handling of radioisotopes, etc. or radiation generating apparatuses	1 hr.
Acts and regulations on the prevention of radiation hazards and a radiation hazards prevention program	30 min.

not apply to use, storage and transport in accordance with the conditions for certification for approved devices with a certification label, etc.

Fig. 35 Education and training

7. From Procurement to Waste Management of Radioisotopes

At any facility dealing with radioisotopes, there are various steps from procurement of radioisotopes to pre-disposal of them. Vital parts of each of these steps are safe handling, control and recording. Especially, the types and amounts of sealed radiation sources being brought in and taken out must be balanced.

To accomplish this, at each step—procurement, storage, use, transportation, and disposal—safety control and accurate record-keeping are essential.

7-1. Procurement

Only permitted radioisotopes and their quantities for which there has been proper notification may be received. Usually the type and quantity of the radioisotopes that can be used in each workplace are limited, so it is necessary to talk with the radiation protection supervisor and radiation protection staffs before receiving them.

It is also important that more radioisotopes than necessary are not purchased, as this will only increase the management burden.

7-2. Storage

When the radioisotopes are delivered, they are usually put into a storage facility, where they are recorded in a logbook.

7-3. Use

Prior to actual use, it is recommended that a cold run be undertaken in exactly the same way as the operation to be performed. An amount as close as possible to the exact amount required should then be taken out of storage, and any leftover should be returned to storage, with the appropriate recording entries made.

7-4. Transportation

When radioisotopes (including materials contaminated by radioisotopes) are transferred outside the facility, the type and quantity should be recorded, and they should be transported in accordance with the requirements for transportation standards. No one should bring any radioisotope out of a facility without instructions or the approval of the radiation protection supervisor.

7-5. Waste disposal

Solid and liquid radioactive waste produced as a result of testing, etc., should be sorted according to the categories, Table 5, in the room where the radioisotopes are being used, and then transferred to a radioactive waste-storage facility. The waste should be classified accurately into the prescribed categories.

7-6. Restrictions on transfer, procurement and possession of radioisotopes

License users are not allowed to transfer any radioisotopes beyond what is stated in the permit to any other user, seller or waste management operator, nor to accept or hold radioisotopes in excess of the capacity of the facility as mentioned in the permit.

8. Usage of Radioisotopes and Radiation Generating Apparatuses

The application of radioisotopes and radiation generating apparatuses varies significantly depending on the nature of the radiation source. Radiation sources can be broadly classified as sealed sources, unsealed sources, and radiation generating apparatuses. Proper handling and radiation control also differ according to the sources.

8-1. Use of sealed sources

The followings are the principal advantages of using sealed sources: (1) There is no risk of leakage or damage during use under normal conditions. (2) There is no risk of the radioisotopes being scattered and causing contamination as a result of leakage, etc. Sealed radiation sources, however, do have the potential to cause radioactive contamination if there is a problem with the sealing. To avoid this, it is necessary to check periodically for contamination.

8-2. Use of unsealed sources

Unsealed radiation sources should be handled only in a 'workroom'. The inside walls and floors of the workroom, which may become contaminated, must be constructed with a minimum of protuberances, depressions, cavities and joints. Materials should be flat and smooth, and resistant to infiltration and corrosion. The radiation source itself should be handled in a hood or a glove box.

8-3. Use of radiation generating apparatuses

In case where induced radioactivity is not produced by the use of radiation generating apparatuses, it is sufficient to control external exposure in the same manner as for sealed radiation sources. On the other hand, if an activation product is generated, controls similar to those for an unsealed radiation source are sometimes required.

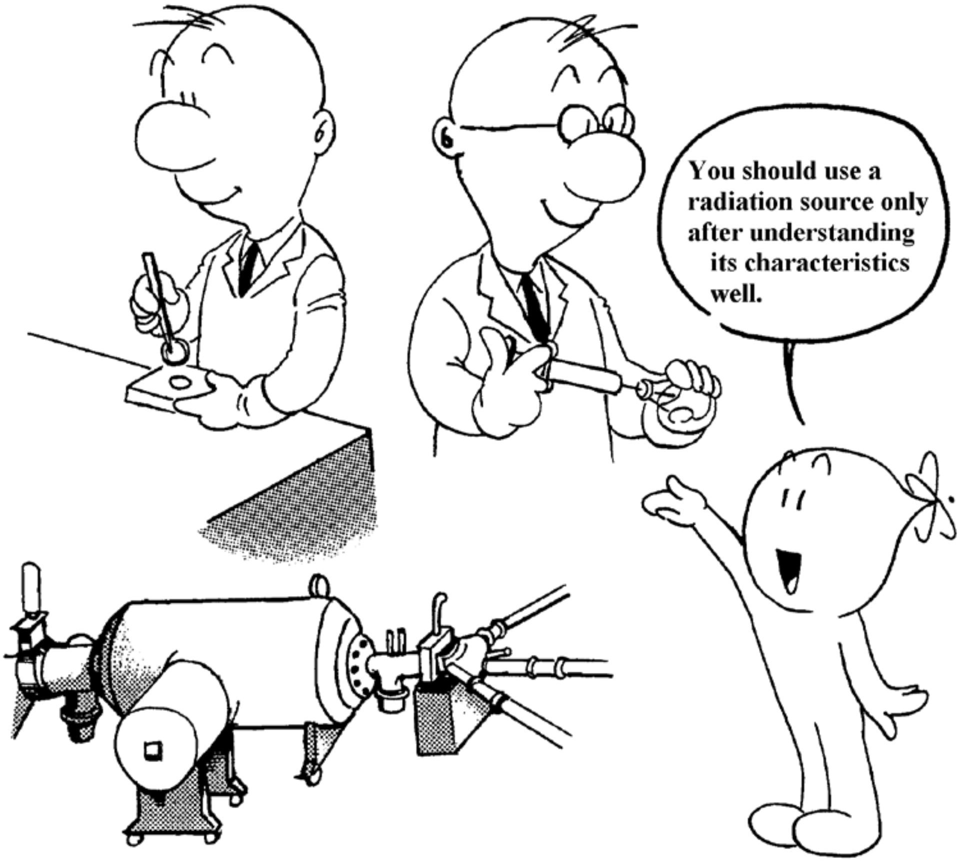


Fig. 36 Usage of radioisotopes and radiation

9. Storage of Radioisotopes

When radioisotopes are not being used, usually they should be put in an appropriate container and stored in a fireproof storage room. Sealed sources, however, can be stored in fire-proof containers in a storage facility.

9-1. Requirements for storage facilities

The main structure of the storage facility has to be of fireproof construction, and radioisotopes beyond the approved storage capacity should not be stored there. Radioisotopes should be put into containers and stored in a fireproof storage room or storage box, in such a way that they cannot be taken out easily without permission. Special fire doors should be used at the storage room entrance, and locks and other security equipment should be installed.

9-2. Requirements for storage containers

Containers for radioisotopes have to meet the following requirements:

1) They should be air-tight so as to prevent contamination of the outside air.
2) Containers for liquid radioisotopes have to be suitably impermeable and designed so that spilling is avoidable.
3) If there is any danger that a container for liquid or solid radioisotopes might become cracked or broken, it should be used with a saucer, absorber or other means to absorb and prevent the spread of the radioisotope.

9-3. Requirements for waste−storage facilities

The above requirement are also applicable to the technical requirements for waste−storage facilities.

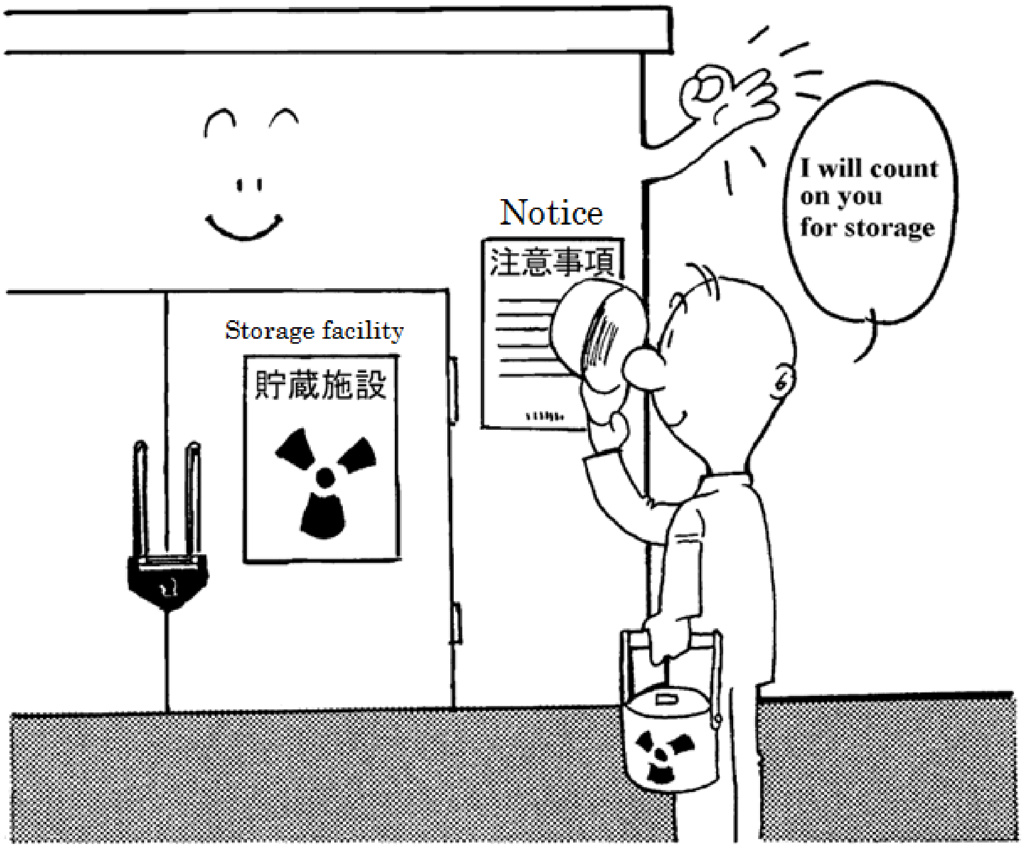


Fig. 37 Storage of radioisotopes

10. Discharge of Radioisotopes from Facilities and Radioactive Waste Management

The Act and relevant Ordinances regulate the discharge of radioisotopes from facilities and radioactive waste management.

10-1. Procedures for discharging radioactive materials in exhaust and rainage

Radioactive materials in exhaust are mostly discharged into the atmosphere within the radioactivity concentration not exceeding the limit specified by the NRA, through an exhaust (or ventilation) system equipped with a high-efficiency filtering unit to remove radioactive particulate.

Drainage with lower radioactive concentration are collected in a reservoir, diluted with non-radioactive drain water and discharged with the radioactivity concentration not exceeding the limit specified by the NRA to the public sewage system.

10-2. Radioactive waste management (Pre-disposal of liquid and solid wastes)

Liquid materials of higher radioactive concentration are treated by the several methods of processing; e.g. 1) after evaporation or coprecipitation to reduce radioactive concentration, and then the liquid phase is discharged to the public sewage system, the residue being treated as solid waste, 2) after being sealed in a container, which is solidified with solidification materials and stored for disposal in a waste-storage facility, 3) are incinerated to reduce volume, the residue being treated as solid waste.

Solid radioactive wastes have to be stored in waste-storage facilities until a waste management operator collects the wastes. Solid wastes should be divided into several categories and put into separate containers for the convenience of which method of pretreatment will be used afterwards.

10-3. An example of the categorization of Radioactive wastes

An example of the categorization of solid wastes is shown in Table 5. These categories apply to the collection of wastes from radioisotope users by the Japan Radioisotope Association.

Table 5 An example of waste categories for separate collection by the Japan Radioisotope Association

Classification	Items
Combustible Type Ⅰ	Paper, clothes, wood pieces
Combustible Type Ⅱ	Plastic tubes, plastic vials, polyethylene sheets, rubber gloves
Incombustible (Compressible)	Glass vials, other glass equipment, injection needles, vinyl chloride pipes, vinyl chloride
Incombustible (Incompressible)	Soil, sand, iron bars, pipes, concrete pieces, castings, clock parts, large amounts of TLC plate, machinery and equipment
Animal carcasses	Animals after being dried
Inorganic liquids※1	Fluids after testing
Combustible filters※2	HEPA filters, pre-filters, charcoal filters

Containers are normally 50-liter drums.

※1 Inorganic liquids are put first in 25-liter polyethylene bottles, which are then put into 50-liter drums. Adjust the pH to between 2 and 12, do not use HCl to adjust pH.

※2 Filters are packed in corrugated cardboard, polyethylene-sheets.

11. Record Keeping (Radioisotopes Tracking)

The amounts of radioisotopes used and the waste management should be accurately entered in a logbook. The purpose of such entries is to ensure the management of radioisotopes facilities, by recording each step in the process from procurement of radioisotopes to radioactive waste management. The records must be maintained for a prescribed period of time.

11-1. Entry items

Table 6 below shows the items that are legally required to be entered. Entries make it possible to confirm the location of radioisotopes and how they are being handled at each step in the process from procurement of radioisotopes to radioactive waste management, for all radioisotopes at the facility. Entry is a very important task from the viewpoint of radiation source control at a facility.

Table 6 Items to be entered by radioisotope or radiation generating apparatuses users

Entry Items
1. Use of radioisotopes
2. Operation of radiation generating apparatuses
3. Storage of radioisotopes
4. Transportation of radioisotopes
5. Radioactive waste management radioisotopes
6. Inspection of radiation facilities
7. Education and training

11-2. Who should make entries?

There are two kinds of entries-those made by radiation protection staff and those made by radiation workers. Radiation workers, in principle, record the use and storage of radioisotopes, as well as transfer of radioisotopes and materials contaminated by radioisotopes. Because information relating to radioisotopes, from procurement of radioisotopes to radioactive waste management, amounts to a kind of “registry” for the radioisotope, record keeping should be done accurately. The format of the logbook may be decided by each facility, so as to make its use easy for the radiation workers, taking into consideration the nature of the work in the facility. To ensure accuracy, an entry should be made every time a radioisotope is used, stored or transferred.

Accurate and timely entries should be made, not only during periods of normal operation, but when accidents or emergencies occur, updated regularly.

11-3. Custody period for entries

Logbooks should be closed annually, and then be maintained for five years.

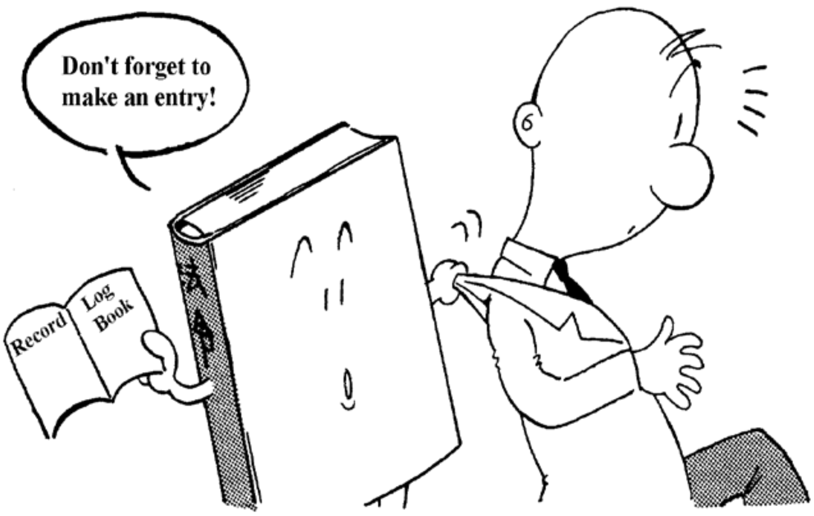


Fig. 38 Record Keeping

12. Record Keeping (Dose)

Records should be kept on the results of all legally required measurements. Such measurements relate to the working environment and to personal exposure. Recording is thus for the purpose of controlling personal exposure.

12-1. Items to be measured

Items legally required to be measured are: 1) For places where there is a probable radiation hazard, the level of radiation and the state of contamination from radioisotopes (measurement of the working environment). 2) For those who enter radiation facilities, the dose received and state of contamination by radioisotopes (assessment of personal dose).

12-2. Measurements and recording of external exposure

External dose must be measured, and the results recorded, for the three-month periods starting on each April 1, July 1, October 1 and January 1, and for one-year periods starting each April 1. For pregnant women, measurements must be made and recorded every month. Items to be recorded are: 1) name of worker measured, 2) name of person doing the measurement, 3) type of the personal dosimeter used, 4) measurement method, and 5) body parts measured and results of the measurements.

12-3. Measurements and recording of internal exposure

Internal dose to workers who enter places where there is a possibility of internal exposure must be assessed at least once every three months (at least once every month for pregnant women), and the results of those assessments must be recorded each time. Items to be recorded are: 1) date of assessment, 2) name of worker being measured, 3) name of person doing the assessment, 4) kind and type of radiation measuring equipment, 5) assessment method and, 6) results.

12-4. Custody Period for Records

Records of measurements of the working environment must be kept for five years. Records on the exposure and health surveillances of radiation workers must be kept permanently. It is recommended that records of accidents and emergencies also be kept permanently.

Fig. 39 Recording

13. Health Surveillances

Those who are to be assigned to deal with radiation and radioisotopes must be checked to see if they are suitable for the job from the viewpoint of their health. The radiological health surveillance is in contrast to an ordinary health surveillance given to every worker in the facility. There are two kinds of radiological health surveillances－one prior to starting work as a radiation worker and those given periodically thereafter.

13-1. Why is the health surveillance necessary?

Each organization conducts two kinds of health surveillances－routine health surveillances for every worker, and radiological health surveillances exclusively for radiation workers. The purposes in both cases are not only to improve the health of the workers and allow them to work without anxiety, but to discover any health-related abnormalities as early as possible so that they can be treated properly.

13-2. Medical examination items legally required

Radiological health surveillances consist of oral interviews, medical examinations and tests. Medical examination and test items are shown in the table below. These were determined from past experience and are based on a knowledge of radiation hazards and radiation effects.

	Test and Medical Examination Items
1)	Amount of hemoglobin, the counts of erythrocyte and leukocyte and the percentage of each subtype of leukocyte in the peripheral blood
2)	Skin
3)	Eyes
4)	Any other parts of the body, or items, designated by the Nuclear Regulation Authority

13-3. When are health surveillances given?

According to the Regulations on Prevention of Ionizing Radiation Hazards under the Labor Standards Act, radiological health surveillances should be conducted before starting the handling of the worker's first handling of radiation or radioisotopes, and every six months thereafter. If certain required conditions are met, however, radiation health surveillances can be omitted. On the other hand, whenever there has been any abnormal radiation exposure (exposure to radiation in excess of the effective dose limit) or abnormal contamination, workers must be examined by a doctor.

13-4. How to interpret the results of health surveillances?

If radiation and radioisotopes are controlled according to all applicable rules, radiation workers will not have any related health problems. Moreover, because the dose to each radiation worker is controlled by personal monitoring, there is practically no chance that a worker will be found in a medical examination to exhibit any abnormal values as a result of his or her normal radiation work.

Results of blood counts, one of the items in a radiological health surveillance, commonly fluctuate for a variety of reasons. Thus, if an abnormal value is found, it is entirely possible that the body has a problem due to a cause other than radiation. The health of radiation workers should be evaluated based on the results of both radiological health surveillances and general medical tests.

14. Procedures at the Time of an Accident or Emergency

14-1. What is an accident and what is an emergency?

When radioisotopes are stolen, missing, leaked or unplanned exposure, the situation is referred to as an accident. When there is a danger of a radiation hazard, or when it actually occurs, the situation is referred to as an emergency.

14-2. Principles for immediate measures at the time of an accident

When the whereabouts of a radioactive source becomes unknown, the worker should make contact with a radiation protection staff member and ask for instructions on measures to be taken.

14-3. Principles for immediate measures at the time of an emergency.

Immediate measures to be taken by a radiation worker at the time of an emergency are: 1) avoid endangering him- or herself, or others, and ensure safety, 2) promptly notify others about the occurrence of the emergency, and 3) take measures to prevent contamination from spreading and to prevent the situation from worsening. It is necessary for radiation workers to learn about possible emergency situations in detail, through education and training, so that they will be able to accurately assess them and implement all needed measures immediately and effectively.

14-4. To whom and how to notify?

It is essential for radiation workers to immediately let the people around them know that an accident has occurred, in order to secure their safety and to prevent the spread of contamination. They should also notify a radiation protection staff member of the accident and ask for instructions. Procedures for notification are posted at various locations where radiation workers can easily see them, such as at the entrances to controlled areas.

When notifying, the radiation workers should calmly state 1) when, 2) where, 3) what, and 4) why. When a fire occurs, the radiation protection supervisor or the operator is required to contact the fire department, and to report to the NRA.

14-5. Specific measures to prevent worsening of an accident

The way to prevent an accident from worsening depends on the situation. In the event of contamination with unsealed sources, identifying and clearly marking off the contaminated area is the key to preventing contamination from spreading.

14-6. Preventing reoccurrence of an accident

In order to prevent the reoccurrence of an accident, it must be analyzed carefully to accurately determine its cause. Then, anything needed to improve the facility, equipment or method of handling should be done as promptly as possible. For the investigation to be effective, the cause of the accident and the responsibility for it should be pursued separately.

15. Procedures in the Event of Excess Exposure or Contamination

If excess exposure or contamination occurs, radiation workers should immediately report to the radiation protection staff to ask for appropriate instructions. When an accident does occur, however, avoiding danger to the body and preventing spread of contamination are the first priority.

15-1. What is excess exposure?

When exposure exceeds the dose limit for occupational exposure, it is called excess exposure. Such a dose limit is not the limit of safety, however, and a radiation hazard does not necessarily exist even at excess exposure.

15-2. Measures in the event of excess exposure

If there is any possibility that a radiation hazard involving excess exposure exists, it is necessary to see a doctor without delay. The cause of the accident should then be investigated to avoid reoccurrence.

15-3. What is contamination?

Contamination refers to the existence of radioisotopes where they should not be. Contamination can occur on floors, table surfaces where radioisotopes are being handled, or on the surface or inside of the body. Radiation workers should make it a routine to check their workplace frequently with, for example, a survey meter, both before and after handling of radioisotopes, in order to detect contamination. Radiation workers should also check for contamination with a hand-foot-clothes monitor in a contamination monitoring room when leaving a controlled area.

15-4. Measures in the event of contamination

In order to prevent contamination from spreading, decontamination should be carried out immediately, after clearly identifying the contaminated area. Radiation workers have to notify a radiation protection staff member of the contamination and ask for instructions on the most suitable method of decontamination under the circumstances.

15-5. Transfer of a radiation worker who received excess exposure

Whenever necessary, transferring a radiation worker who experienced excess exposure to a different department, or restricting his or her access to the controlled area, should be considered.

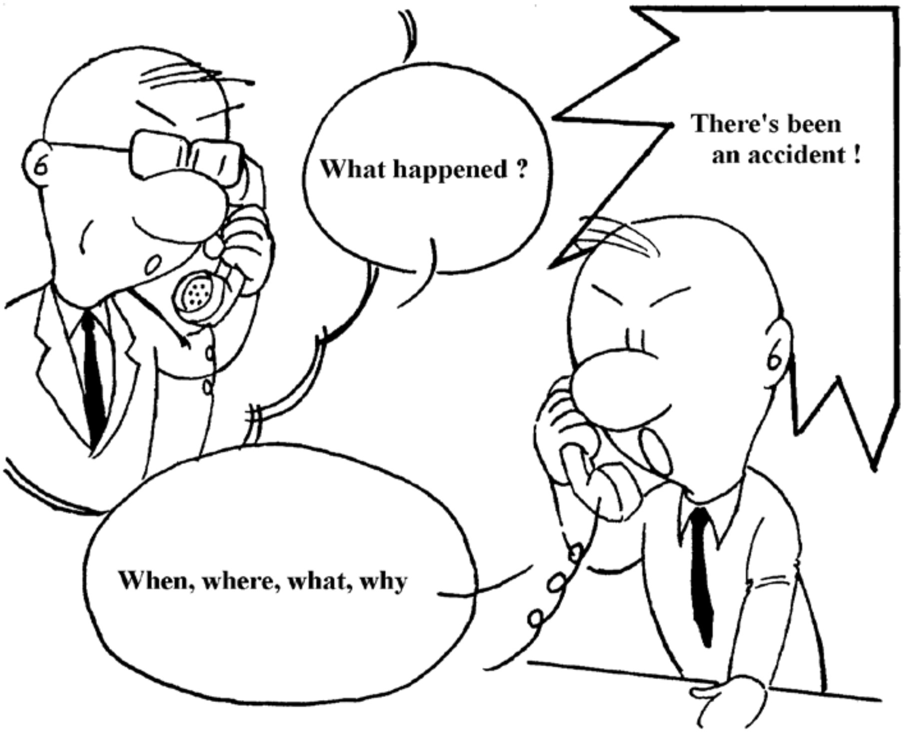


Fig. 40 Notification

IV. Biological Effects of Radiation

1. Classification of Radiation Effects on the Human Body

Effects of radiation on the human body can be categorized into those that appear in the person who are exposed and those that appear in his / her offspring. The former is called **somatic effects**; the latter is called **heritable effects**.

Somatic effects are further categorized into **acute effects** and **late effects**, based on the time from radiation exposure to the appearance of the effect. Acute effects appear within a relatively short time after exposure, usually in several weeks. Late effects appear in several years to decades. The period until the effect appears is called the **latent period**.

Even when total dose is the same, severity of the effect differs depending on whether the exposure was all at one time (**acute exposure**), or multiple occasions over a long period of time (**chronic exposure**). This is because, in the latter case, the body is able to exercise its inherent ability of recovery in between exposures. Effects also differ between **whole-body exposure** and **partial exposure** (see Fig. 41).

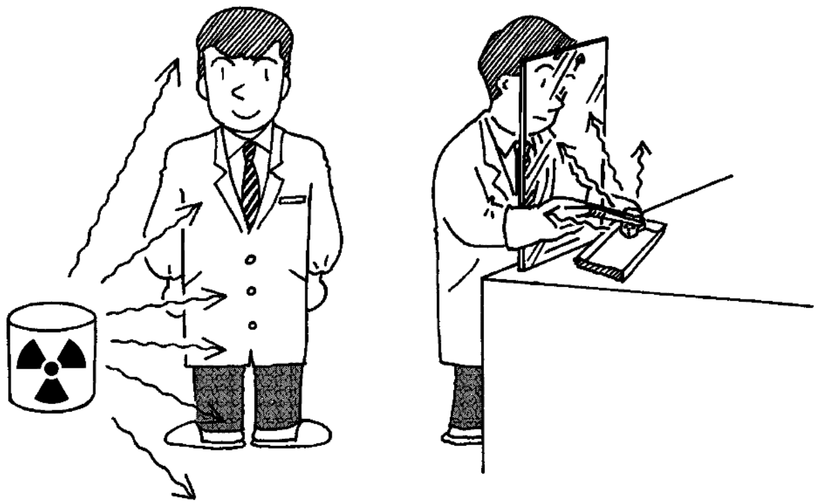


Fig.41 Whole-body exposure and partial exposure. Radiation effect appears on radiosensitive organs by whole-body exposure whereas only on the exposed organs by partial exposure.

2. Acute Effects

Acute effects by single whole-body exposure with gamma rays (X-rays) are shown in Table 7. No clinical symptoms are recognized at doses of 0.25 Gy or lower. A dose of 0.5 Gy causes a temporary reduction in the number of leukocytes, but it returns to the normal level thereafter. Radiation sickness to 50%, including a hangover-like symptoms, occurs by an exposure of 1.5 Gy or higher. A dose around 4 Gy brings death to 50% of exposed individuals in 60 days without appropriate medical care. At 7 Gy, the probability of death is almost 100%.

Table 7 Dose-dependent symptoms of acute effects (Whole-body, single exposure to gamma rays (or X-rays))

Dose (Gy)	Symptoms
0.25 or less	Almost no clinical symptoms
0.5	Temporary reduction of leukocyte (lymphocytes)
1	Nausea, vomiting, whole-body languor, substantial reduction of lymphocytes
1～2	Death to 10% within 60 days*
1.5	Radiation sickness to 50%
～4	Death to 50% within 60 days*
5～7	Death to 90% within 60 days*
7～10	Death to 50% within 2 weeks

*) without medical care (aseptic treatment, bone-marrow transplantation etc.)

In this table, absorbed dose (in Gy) is used instead of equivalent dose or effective dose (in Sv). That is because the radiation weighting factors (see 7-2) recommended by the ICRP are based on the stochastic effects such as cancer induction and not applicable to the deterministic effects.

3. Late Effects

The latent period of late effects can be up to decades. Typical late effects are cancer and cataracts.

The length of latent period for cancer differs by exposed organ or tissue, age at the time of exposure and dose, although it ranges from several years to decades. The probability of cancer incidence also varies depending on the organ or tissue and age. According to the ICRP Publication 103 (2007), the approximated overall fatal risk coefficient of cancer is 5% per Sv on which current international radiation safety standards are based.

The latent period for cataracts, the clouding (opacification) of the lens of the eye, ranges from several years to a few decades. The minimum dose to cause cataracts is considered as 0.5 Gy.

As many factors are involved in the onset of cancer and cataracts, it is difficult to distinguish whether these diseases are the result of radiation exposure or not.

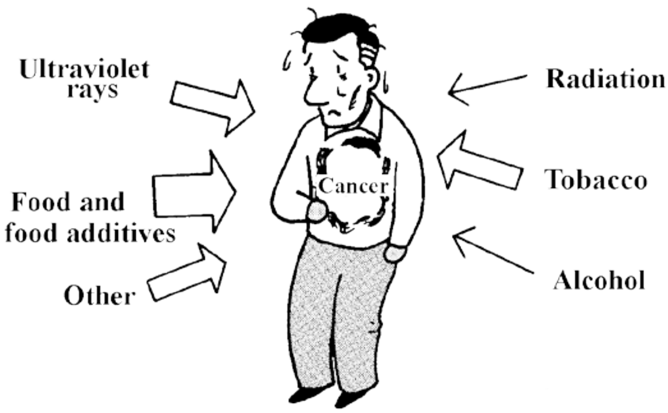


Fig. 42 Today in Japan, cancer is the leading cause of death. Various factors are involved in cancer incidence, and radiation is only one of them. It is not possible to distinguish cancer caused by radiation from cancer arising from other causes.

4. Heritable Effects

Heritable effects caused by radiation have not been verified in human beings.

The heritable effects of radiation have been studied for a long time, and there continues to be no direct evidence that exposure of parents to radiation leads to excess heritable disease in offspring including children of atomic bomb survivors in Japan. In 2001, the United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) reported this issue by using the method of doubling dose which is the dose to induce the same number of spontaneous mutations in one generation.

Because there are no data on frequency of radiation-induced mutations in humans, the doubling dose has been estimated using spontaneous mutation rates of human genes and radiation-induced mutation rates of mouse genes by low dose, sparsely ionizing radiation of the order of 1Gy. On the basis of the report, ICRP estimates genetic risks to second generation of about 0.2% per Gy.

5. Biological Effects Depend on the Dose Received

Radiation effects on the human body can also be categorized into stochastic effects and deterministic effects, depending on the relationship between the radiation dose and the rate of occurrence.

A threshold value identifies a dose below which there is no radiation effect, whereas the occurrence frequency and severity of radiation effects increases starting around the threshold dose (Fig.43, left panel). All of the acute effects and cataracts are considered to have their own threshold value and are called as **deterministic effects**.

In contrast, risks of cancer including leukemia and heritable effects simply increase with the dose. No threshold values are assumed to exist, and the severity of the effect dose not change by the dose received (Fig.43, right panel). These effects are called as **stochastic effects.**

Classification of biological effects of radiation by using categorizations described above are shown in Table 8.

The relative contribution of a specified organ or tissue to the overall radiation detriment from stochastic effects, as a result of systemic irradiation, is called the tissue weighting factor (W_{T}, see also Table 9) for tissue(T). **Effective dose**(E) is defined by the following formula:

$$E = \sum_{T} W_{\mathrm{T}} \cdot H_{\mathrm{T}}$$

Here, H_{T} is the equivalent dose for tissue T.

Within the low-dose range of exposure with properly implemented radiation protection, the occurrence of deterministic effects in radiation workers are virtually negligible. There must be concern, however, about stochastic effects. Thus, radiation monitoring and dose evaluation are very important for radiation protection.

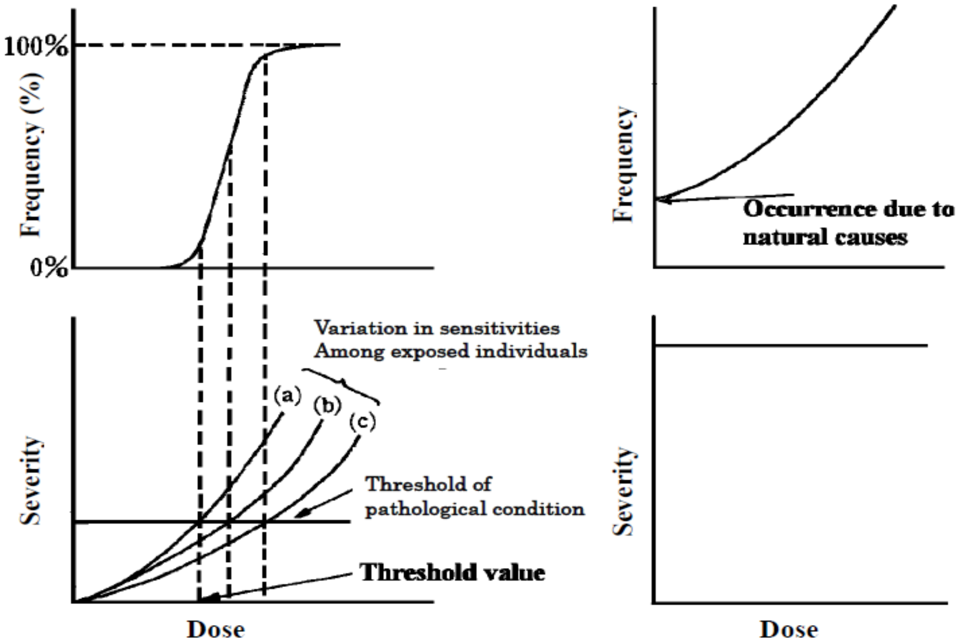


Fig. 43 Schematic expression of variations for occurrence and severity of deterministic effects (left) and stochastic effects (right)

Table 8 Classification of biological effects of radiation

<table>
<tr><td rowspan="4">Radiation effects</td><td rowspan="3">Somatic effects</td><td>Acute effects</td><td>Erythema on the skin
Loss of hair
Reduction of leukocytes
Infertility, etc.</td><td rowspan="2">Deterministic effects</td></tr>
<tr><td rowspan="2">Late effects</td><td>Cataracts
Effects on embryos, etc.</td></tr>
<tr><td>Leukemia
Cancer</td><td rowspan="2">Stochastic effects</td></tr>
<tr><td colspan="2">Heritable effects</td><td>No evidence in human</td></tr>
</table>

6. Effects from External and Internal Exposures

In planning and implementing measures for radiation protection, it is important to distinguish external exposure and internal exposure - that is, exposure from radiation sources outside the body and exposure from radioisotopes within the body.

When handling sealed radiation sources or operating radiation generating apparatuses that do not produce radioisotopes, only external exposure is to be considered. When handling unsealed radioisotopes emitting low energy beta-rays or alpha-rays only, internal exposure is generally considered (though this depends also on the handling method and conditions). Otherwise, both external and internal exposures should be considered.

In the case of external exposure, strongly penetrating radiation such as gamma rays (or X-rays) or neutrons, is the main concern. In contrast, with internal exposure, radiation with low penetration power, such as alpha-rays and beta-rays, are the crucial problem.

The radioactivity taken into the body decreases in accordance with its inherent physical half-life $T_{p.}$ The activity in the body is also reduced by metabolism. The reduction is assumed to be expressed by a simple exponential function and the “biological half-life” T_b is defined. Thus, the body burden radioactivity is reduced in accordance with the effective half-life T_{eff}, as shown by the following formula:

$$\frac{1}{T_{eff}} = \frac{1}{T_p} + \frac{1}{T_b}$$

For evaluation of internal doses, more precise biokinetic model is constructed for major individual radioisotope in any physical and chemical forms. Based on the model, the conversion coefficients of committed effective dose per unit intake, **“dose coefficients”**, are obtained. Examples are shown in Table 10.

The intake of radioisotopes by ingestion may be negligible because eating and smoking should be strictly prohibited in any controlled area where unsealed radioisotopes are handled.

Regardless of external or internal, the severity of health effect is assumed to be the same if the received effective dose is the same.

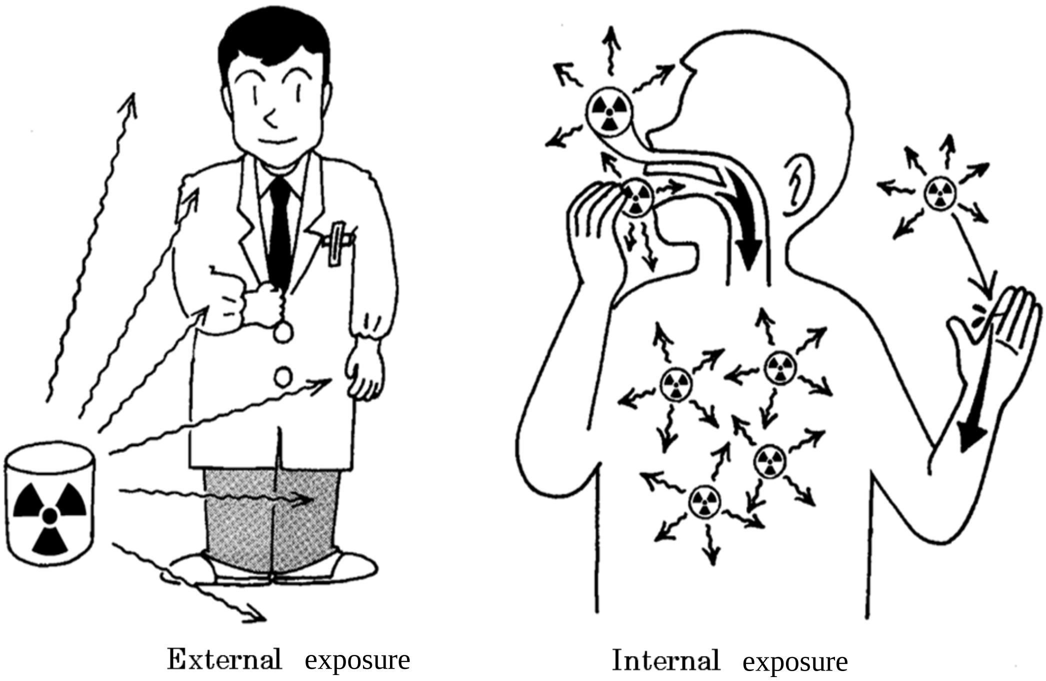


Fig. 44 In implementing measures for radiation protection, it is important to understand radiation environment where the worker is subject to external or internal exposure.

7. What is Equivalent Dose?

Equivalent dose is the basic dose concept used in radiation protection, the unit is the sievert (Sv). Regardless of the type of radiation, when the equivalent dose to a particular tissue is the same, the radiation effects to the tissue are assumed to be the same. Equivalent dose can be obtained by multiplying absorbed dose (a mean energy imparted to tissue) by a radiation weighting factor, which is a function of the type and energy of the radiation.

7-1. Protection quantity in tissue level

Radiation can be easily measured based on physical property, such as ionization effect. However, the effect on human body differs by the type of radiation. In order to use the measured quantity to assess the effect on the human body, the values of **radiation weighting factors (W_R) in different radiation types are selected by judgement on the basis of broad range of experimental relative biological effectiveness(RBE) data which are relevant to stochastic effects.** The result obtained by multiplying the absorbed dose by the radiation weighting factor is defined as the **equivalent dose**. Equivalent dose is the basic protection quantity in tissue level.

7-2. Radiation weighting factors

In ICRP 2007 Recommendations, the following radiation weighting factors are recommended:

1 for photons (gamma-rays and X-rays) and electrons (beta-rays)
2 for Protons
20 for alpha-rays
2.5 to about 20 for neutrons (a continuous function of neutron energy)

Equivalent doses corresponding to 1 mGy from gamma-rays and 1 mGy from alpha-rays are, 1 mSv and 20 mSv, respectively.

7-3. Assessing Equivalent Dose

Equivalent dose is used in assessment of the effect at a specific part of the body and is measured by using various kinds of personal dosimeters (see III.5).

For assessment of the dose to the skin, the personal dose equivalent with 70μm depth dose equivalent can be used.

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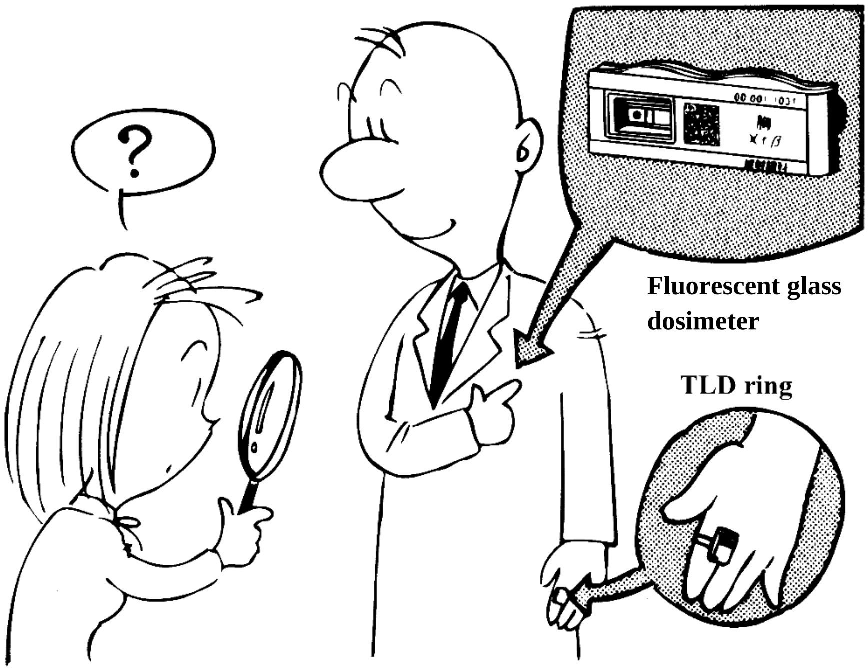

Fig. 45 Measurements of 1cm- and 70μm depth dose equivalents

8. What is Effective Dose?

Effective dose is a concept quantifying radiation risk of stochastic effects. Sievert (Sv) is also the unit of effective dose. Equivalent dose for each tissue or organ is multiplied by the tissue weighting factor W_T (Table 9), and the sum is performed over all organs and tissues to obtain the effective dose. The dose limit of 50 mSv/y and 100 mSv/5y for radiation workers, specified in Chapter V, is expressed by effective dose.

8-1. Accounting for the radiation sensitivity of each tissue or organ

Even if the equivalent dose is the same, the probability that stochastic effects will appear depends on irradiated tissue or organ because of different sensitivity to radiation. Effective dose was therefore created to represent overall radiation detriment from stochastic effects. The unit is sievert (Sv). The unit is the same for equivalent dose as well as for some operational quantities. Effective dose is used in implementation of the radiation protection system.

8-2. Applicable regardless of exposure type

By using effective dose, the risks of stochastic effects by external exposure, regardless of whole body or local, and internal exposure can be combined to assess overall effects.

8-3. Use of operational quantities for measurements of external dose

Effective dose and equivalent dose are called as protection quantities and are not measurable. Therefore, operational quantities are used for assessment of effective dose or mean equivalent doses in tissues or organs by which area monitoring and individual monitoring of external exposures are performed. For assessment of effective dose, the personal dose equivalent with a depth of 1cm dose equivalent is used. Operational quantities are defined by the International Commission of Radiation Units and Measurements (ICRU) with simplified source-detector geometry to avoid underestimation of both equivalent dose and effective dose.

Table 9 Tissue weighting factors provided in the 2007 Recommendations of the ICRP

Tissue/Organ	Tissue weighting factor W_T	Tissue/Organ	Tissue weighting factor W_T
Bone marrow (red)	0.12	Liver	0.04
Colon	0.12	Thyroid	0.04
Lung	0.12	Bone surface	0.01
Stomach	0.12	Brain	0.01
Breast	0.12	Salivary glands	0.01
Gonads	0.08	Skin	0.01
Bladder	0.04	Remainder tissues*	0.12
Oesophagus	0.04	Total	1.00

*Remainder Tissues (14 in total): Adrenals, Extrathoracic (ET) egion, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix.

Table 10 Some examples of effective dose coefficients for inhalation

Nuclides	Chemical form	Dose coefficients (mSv/Bq)
^{3}H	Elementary Methane Water Organic compounds except methane Other compounds	1.8×10^{-12} 1.8×10^{-10} 1.8×10^{-8} 4.1×10^{-8} 2.8×10^{-8}
^{14}C	Gaseous organic compounds Carbon monoxide Carbon dioxide Methane	5.8×10^{-7} 8.0×10^{-10} 6.5×10^{-9} 2.9×10^{-9}
^{32}P	Compounds except tin phosphates Tin phosphates	1.1×10^{-6} 2.9×10^{-6}
^{60}Co	Compounds except oxides, hydroxides, halogenides, nitrates Oxides, hydroxides, halogenides, nitrates	7.1×10^{-6} 1.7×10^{-5}
^{131}I	Elementary Methyl iodide Compounds except methyl iodide	2.0×10^{-5} 1.5×10^{-5} 1.1×10^{-5}
^{137}Cs	All compounds	6.7×10^{-6}

9. Assessment of Internal Dose

Radioisotopes taken into the body by inhalation or by ingestion are excreted or remain in the body as radiation sources until the they completely decay or are excreted. Dose from such remaining radioisotopes is estimated taking future dose into account. This is called committed equivalent dose to the relevant tissue or organ. The committed effective dose is a total sum of these committed equivalent doses multiplied by the tissue weighting factor for each tissue or organ.

9-1. Exposure from radioisotopes taken into the body

Radioisotopes taken into the body are either excreted from the body mainly in urine and feces, or remain in the body while irradiating the tissues emitting until they completely decay.

9-2. Committed dose is used for internal exposure

The internal radioactivity may give rise to doses to body tissues for many months or years after the intake. The need to regulate exposures to radionuclides and accumulation of radiation dose over extended periods of time has led to the definition of committed dose quantities. The time integral of the equivalent dose rate in a particular tissue or organ that will be received following intake of radioisotopes into the body is called **committed equivalent dose**. The sum of the products of the committed organ or tissue equivalent doses and the appropriate tissue weighting factors is called committed effective dose. When the committed period is not specified, it is taken to be 50years from the intake for adults (including radiation workers) and 70 years old of age for infants and children.

9-3. Assessments of committed equivalent dose and effective dose

Assessments of committed dose is based on the amount of intake and the reference dose coefficient. The dose coefficients for specified radionuclides and their physical/chemical forms (Sv/Bq) were calculated by using defined biokinetic and dosimetric models, and were published by the ICRP.

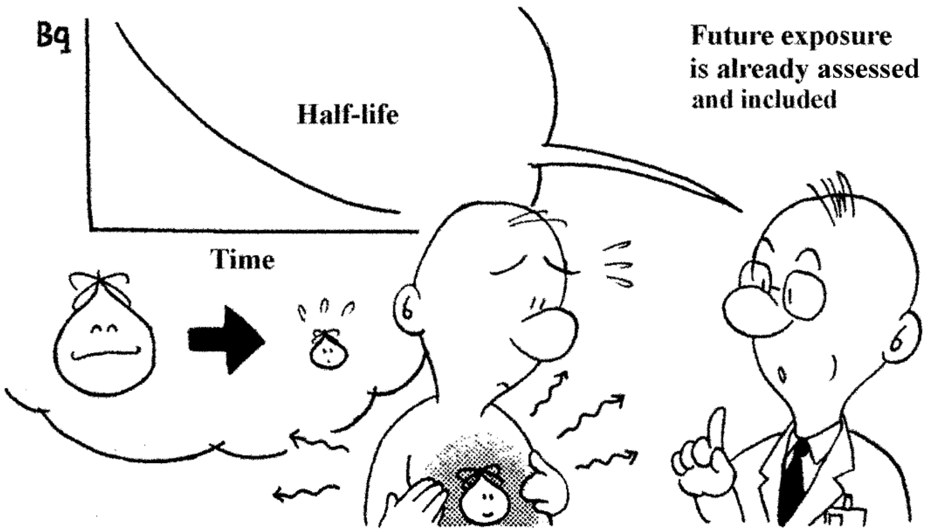

Fig. 46 Committed dose

10. Natural Radiation and Artificial Radiation

Between natural and artificial radiations, there is no difference in biological effects on human body.

From the point of view of the effects on human body, whether it is natural radiation or artificial radiation does not matter. Natural and artificial radiations of the same type and with the same energy have the same effect on the body.

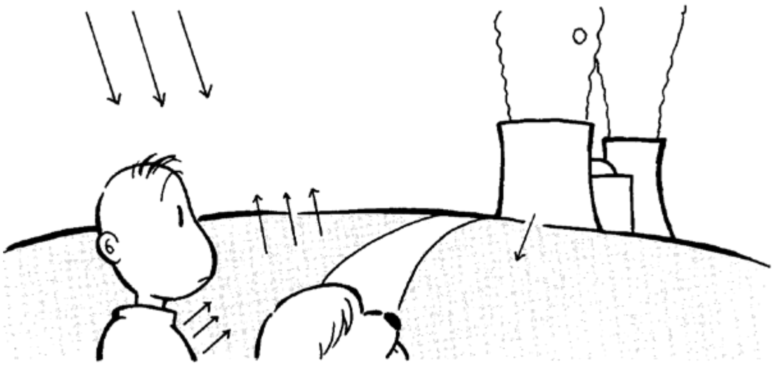

Fig. 47 Natural and artificial radiations

People living on the earth are inevitably exposed to naturally occurring radiation. Exposure to artificial radiation for medical purposes would be added depending on the person. Average of annual dose from various radiation sources are shown in Fig. 48 and Table 11.

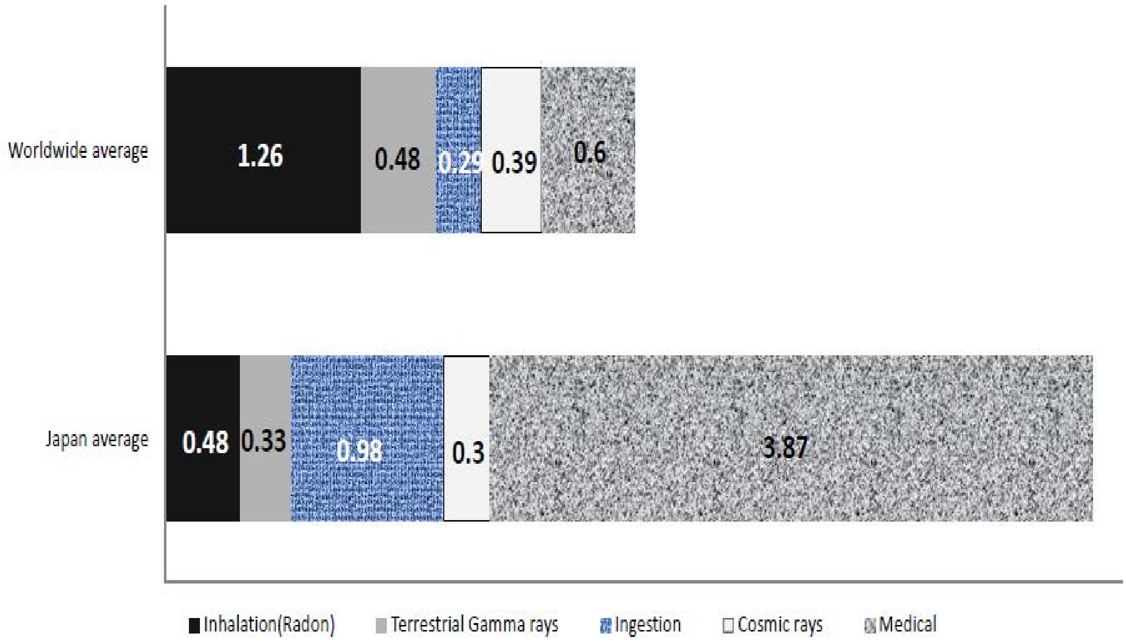

Fig. 48. Average of annual effective dose (mSv) in worldwide and Japan
('Environmental Radiation in Life' by the Nuclear Safety Research Association 2011)

Table 11 Typical estimated values of annual effective dose to people in the world (UNSCEAR 2008)

Average per person (mSv)

Natural background 2.4 mSv	Inhalation (Radon)	1.26
	Ingestion	0.29
	Terrestrial gamma rays	0.48
	Cosmic rays	0.39
Artificial exposure 0.6 mSv	Medical exposure (diagnosis)	0.6
	Atmospheric weapon testing	0.005
	Occupational exposure	0.005
	Nuclear power generation	0.0002

11. Radiation and Health Effects

Effects that can clearly be attributed to radiation do not occur unless one is exposed to a large amount of radiation due to, for example, an accident.

In addition, a person's recovery from the effects of radiation exposure depends on the dose received. When the dose is small, effects are temporary and disappear after some time. The higher the dose becomes, however, the more serious the effects are, and the more difficult to recover from them.

For example, assume that the skin is exposed partially in an accident to a large amount of weakly penetrating radiation such as beta rays or soft X-rays (low energy X-rays). If the dose is 3 to 5 Gy*, the skin will become red and hair will fall out. These effects are not temporary, however, and the skin will return to normal in several months. If the dose is 5 to 10 Gy, blisters will form, as when the skin is burned, but here, too, it may recover in several months. On the other hand, if the dose exceeds 25 Gy, the exposed skin will become ulcerated and never return to healthy structure. The surface of the skin (epidermis) will become thinner, and the tissues beneath (dermis) become harder and thicker, and the skin appears blotchy.

The important thing to remember is that the dose needed to cause such deterministic effects is far higher than the dose limit for the skin (0.5 Sv/y) for radiation workers.

Additionally, there is no evidence that radiation workers catch colds more easily or become physically weaker during normal operations. Easily catching colds and being weak physically are in large part related to the body's immune mechanism. Immune system consists of various kinds of immune cells, such as lymphocytes, monocyte/macrophages, and polymorphonuclear leukocytes, which are generated in the bone marrow. Unless the bone marrow is exposed to radiation with doses, the number of these cells do not change. Thus, there is no risk of affecting the immune system when engaging in normal radiation work.

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* Here absorbed dose (Gy) is used instead of equivalent dose (Sv), because tissue weighting factor recommended by the ICRP is applicable only to low dose where stochastic effects are relevant.

Fig. 49 Radiation and health effects

12. Exposure Categories

12-1. Occupational exposure

Occupational exposure is defined as all radiation exposure of workers incurred as a result of their work. Doses from occupational exposure varies depending on the task and the type of radiation source. The average exposure dose per person for various occupational fields excluding workers in Nuclear Power Plants is surveyed by the Council on Personal Dosimetry Service every year. The results of 2017 are shown in Table 12. Workers of Non-destructive Testing received the largest exposure dose, with an average dose of 0.392 mSv. In contrast, workers in research and education area received the lowest dose at 0.022 mSv. According to the statistics for nuclear workers in 2017 by the Radiation Effects Association, the annual average effective dose per person was 0.7 mSv.

Table 12 Annual average dose per person (mSv) (Japan FY 2017)

Occupational Field	Effective Dose (mSv)	Number of workers
Medicine	0.339	360,123
Dentistry	0.026	23,929
Veterinary Medicine	0.031	16,151
Non-destructive Testing	0.392	3,678
General Industry	0.067	67,256
Research and Education	0.022	66,078
Nuclear Power Plant	0.7	67,004

12-2. Medical Exposure

Medical exposure is incurred by patients as part of their own medical or dental diagnosis or treatment. There are increasing cases to receive diagnostic radiation such as X-ray examinations, computerized X-ray tomography (CT scans), interventional radiology (IVR), and radioisotope examinations. In addition, radiation therapy is one of the major options for cancer treatment. Medical exposure also includes the exposure of volunteers in a program of biomedical research.

12-3. Public Exposure

Public exposure is incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation. Public exposure is mainly attributable to atmospheric nuclear weapon testing, nuclear power generation as shown in Table 11.

13. Risk

The use of radiation and radioisotopes brings various benefits to our daily lives. The use of radiation in medicine contributes significantly to keeping us healthy. Radiation and radioisotopes thus contribute positively to human society; yet exposure to radiation itself is considered harmful to the body. Harmful effects, however, do not necessarily appear whenever one is exposed to radiation. In particular, the dose a person receives daily is so small that it is not clear whether there are any harmful effects.

The degree of harmful effects that may occur as a result of usage of radiation. The probability of the occurrence of the effects, is called risk. Risk does not mean that harmful effects will occur; it just means the possibility that they may occur.

Fig. 50 Double-edged sword

14. Limits of Personal Exposure

Exposure dose of radiation workers is controlled to remain below a certain level. This level is the dose limit. The tissue equivalent dose and the effective dose limit are specified in the Enforcement Regulation.

14-1. Dose limit for radiation workers

The dose for radiation workers should be controlled so as not to exceed the specified limits for either effective dose or tissue equivalent dose. The effective dose limit and tissue equivalent dose limit are both controlled based on one-year periods starting April 1, except in the case of women. Values are shown in Table 13.

Table 13 Effective dose limits and tissue equivalent dose limits for radiation workers

<table>
<tr><th colspan="2">Item</th><th>Radiation Worker</th></tr>
<tr><td colspan="2">Effective dose limits</td><td>(1) 100 mSv/5 years[*1]
(2) 50 mSv/any single year[*2]
(3) Female worker[*3] 5 mSv/3 months[*4]
(4) Pregnant worker
The internal exposure limit set for this woman is 1mSv for a period starting from the time when her employer and others are informed of her pregnancy by her reporting or any other means up to the time of the delivery of the baby</td></tr>
<tr><td rowspan="3">Equivalent dose limits</td><td>(1) The lens of the eye</td><td>150 mSv/year[*2, *5]</td></tr>
<tr><td>(2) Skin</td><td>500 mSv/year[*2]</td></tr>
<tr><td>(3) Abdomen surface of pregnant worker</td><td>2 mSv for a period of time starting from the time when her employer and others are informed of her pregnancy by her reporting or any other means up to the time of the delivery of the baby</td></tr>
</table>

* 1: Each period of time derived from the division of years from April 1, 2001 into increments of 5 years

* 2: The time span of 1 year with April 1 as the starting date

* 3: Excluding those who were diagnosed as being unable to achieve a pregnancy, those who made an offer of having no intention of becoming pregnant in writing, and those who are currently pregnant

* 4: Three-month periods each with the starting date set on April 1, July 1, October 1 and January 1

* 5: This dose limit is in revision. The new dose limit will be set at 100mSv in 5 years and 50mSv in any single year.

14-2. Application of dose limit

According to the Act on the Regulation of Radioisotopes, etc., electrons and X-rays devices with energy less than 1 MeV are not subject to regulation, but exposure dose from such radiation devices must be included in total personal exposure. Radiation doses from medical exposure and natural radiation exposure are not subject to the dose limits.

14-3. Equivalent dose limits other than those mentioned above

Dose limit for radiation workers engaging in emergency operations in radiation facility is stipulated as 100 mSv in the Act; this is limited to men and to women who are diagnosed as infertile.

V. The Act and Regulations

1. Act on the Regulation of Radioisotopes, etc.

"Act on the Regulation of Radioisotopes, etc. including its Enforcement Regulations and notifications etc. (Acts and Regulations)" apply uniformly regardless of the nature of the facility. It is appropriate to think of them as stipulating the minimum standards that the facility and the radiation workers must observe, and, accordingly, each facility, while of course meeting the legally prescribed standards, should implement radiation control appropriate for its own activities.

1-1. Why is control based on the Acts and relevant Regulations necessary?

Radiation and radioactive materials may be causes of hazardous effects. When people attempt to use them, their use should always be controlled.

1-2. Historical background for the Act and Regulations concerning radiation hazards in Japan

Radiation, especially X-rays, came into use relatively early in the medical and research fields. It wasn't until the mid-1950s that the use of radiation and radioisotopes in areas other than medicine and research began. In response to the new developments, the Atomic Energy Basic Act and the Act on Prevention of Radiation hazards due to Radioisotopes, etc., and relevant Ordinances were passed in 1955 and 1957, respectively. Both have been revised many times since then, based on the latest scientific and technological knowledge. Because the Act on Concerning Prevention of Radiation Hazards (former Act on the Regulation of Radioisotopes, etc.) was drafted and modified in line with recommendations of the ICRP, its provisions on radiation control are not significantly different from those in other countries.

1-3. Characteristics of the Act

The purpose of the Act on the Regulation of Radioisotopes, etc. is to prevent radiation hazards due to such activities, to secure specified radioisotopes and to ensure public safety. In order to attain this purpose, the Act provides for the regulation of facilities (requirements for facilities) and for the regulation of people's actions, etc.　(requirements for actions).

Fig. 51　Role of the Act and the Regulation

2. Hierarchy of the Act and Relevant Regulations

Act is enacted by the National Diet, which is the national legislative body. Various administrative bodies are then empowered to establish statutory instruments - Cabinet Order, Enforcement Regulations, and Notifications by any minister directly to the public. In this chapter, these are collectively called Acts and regulations.

2-1. Relationship among Acts and Regulations

An example of the relationships among Acts and Regulations is shown in Table 14. Acts are enacted by the Diet, establishing fundamental principles. Details are then provided in enforcement ordinances, enforcement regulations, and public notices.

2-2. Administrative Guidance

Despite the existence of Acts and Regulations, many actual situations involving radiation may not be adequately dealt with by specific provisions. Therefore, administrative bodies sometimes provide guidance in the form of guidelines and notifications, in order to attain the administrative purpose.

2-3. Rules in each facility

Each facility is required to establish local rules called **Radiation Hazards Prevention Program**, in accordance to the Act on the Regulation of Radioisotopes, etc. and the Enforcement Regulation. Under the Act for the Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Reactors, they are called **Security Rules**.

Many facilities, moreover, in addition to their rules, maintain their own radiation control manuals, which can be revised as appropriate at any time.

Table 14 Hierarchy of the Act and the Regulation

Acts and Regulations	Diet	Act	Act on the Regulation of Radioisotopes, etc.
	Cabinet	Cabinet Order	Order for Enforcement of the Act on the Regulation of Radioisotopes, etc.
	NRA*	Enforcement Regulations	Ordinance for Enforcement of the Act on the Regulation of Radioisotopes, etc.
	NRA*	Notifications	Notification to Specify Standards for the Amount, etc. of Radioisotopes
NRA*		Announcement	For example, Safety for Incineration of Waste Liquid Scintillator
Facility		Internal practices	Radiation Hazards Prevention Program

*NRA: Nuclear Regulation Authority

3. Acts and Regulations Concerning Radiation

In order to prevent radiation hazards for radiation workers and the general public, while furthering the use of radiation and radioisotopes, many Acts and Regulations have been enacted from various points of view, and the facilities where radiation and radioisotopes are used are regulated by these Acts and Regulations.

3-1. Acts and Regulations concerning radiation

Acts and Regulations concerning radiation include the **Atomic Energy Basic Act**, which deals with the development and use of nuclear power; the **Regulations on Prevention of Ionizing Radiation Hazards**, concerned with the protection of radiation workers at radiation facilities; the **Medical Care Act**, regulating the use of radiation for diagnosis and therapy; and the **Rules to Manufacture and Handle Radioactive Pharmaceuticals**, on the production of radiopharmaceuticals.

3-2. Acts and Regulations to promote the use of atomic energy

The principal Act governing promotion of research and development, and the use of nuclear power, is the Atomic Energy Basic Act. Under the Act, research and development, and use of atomic energy, are limited to peaceful purposes, with assured safety, independent operations, government oversight results made available to the public, and a commitment to international cooperation.

The Atomic Energy Basic Act also provides for the separate enactment of the Act on the Regulation of Radioisotopes, etc. to prevent such hazards and ensure public safety; and of the Act on the Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Reactors (shortly, **the Nuclear Reactor and Fuel Regulation Act**), to regulate safety control in regard to nuclear materials and reactor operations.

4. What is the Act on the Regulation of Radioisotopes, etc.?

Pursuant to the Atomic Energy Basic Act, the Act was enacted to prevent radiation hazards and ensure public safety, by regulating the use of radiation and radioisotopes, and management of contaminated objects. Originally enacted in 1957, it has been revised in accordance with recommendations of the ICRP.

4-1. Requirements for facilities

Prior to the use of radiation or radioisotopes, permission or notification to the Nuclear Regulation Authority (NRA) is required. Upon granting permission, the NRA confirms that the location, structure and equipment of facilities to be used, for storage and to manage wastes meet the technical standards (standards for facilities) prescribed in the Act and Regulation. Even after permission is granted, the NRA conducts regular periodic inspections of all facilities handling radioisotopes in excess of a defined quantity, to see that the technical standards are maintained (regular periodic inspections, etc.).

Table 15 Standards for facilities requiring permission or notification

Permission User	Notification User
The use of radioisotopes or radiation generating apparatus (excluding those for which the notification requirement applies)	The use of sealed radiation sources of the quantity exceeding the exemption limit but not exceeding 1,000 times the lower bound quantity

4-2. Requirements for actions

Permission or Notification users must comply with a series of standards for safety control, in order to prevent radiation hazards. Specific standards apply in the following areas: education and training, measurement of personal dose, health surveillances shall be provided for any radiation workers who enter a controlled area. Dose rate at places where there is risk of radiation hazard shall be measured.

4-3. Local Rules on Radiation Safety Control

Detailed rules on radiation safety control, in accordance with the conditions and circumstances of the facility, must be provided in each facility's Radiation Hazards Prevention Program.

5. Acts and Regulations to Protect Workers

Regulation on Prevention of Ionizing Radiation Hazards was established under the Industrial Safety and Health Act, solely to protect workers at working sites from radiation hazards. Similar regulations are established under different Acts for seamen, government employees, self-defense-force members, miners, and others.

5-1. A Regulation of the Ministry of Health, Labor and Welfare: "the Regulations on Prevention of Ionizing Radiation Hazards"

The Regulations on Prevention of Ionizing Radiation Hazards was established under the Industrial Safety and Health Act providing for regulations based on the principle that employers (operators) should try to minimize ionizing radiation to which workers are exposed in the course of their jobs.

An industrial physician and a safety supervisor must be appointed under the regulations. Safety supervisors deal with technical matters associated with safe operations of X-ray apparatuses such as X-ray analyzers and X-ray diffraction devices.

These regulations, unlike the Act on the Regulation of Radioisotopes, etc., cover X-rays and electrons with energy less than 1 MeV, and the mining of nuclear source materials.

5-2. Working Environment Measurement Act

This Act, together with the **Industrial Safety and Health Act**, stipulates qualifications of experts and organizations for monitoring.

5-3. Rules of the National Personnel Authority

The Rules of the National Personnel Authority 10-5 (Prevention of Radiation Hazards for Employees) were established under the **National Public Service Act**, to protect regular government employees from radiation hazards. The contents are almost the same as those of the Regulations on Prevention of Ionizing Radiation Hazards that are not applicable to government officials.

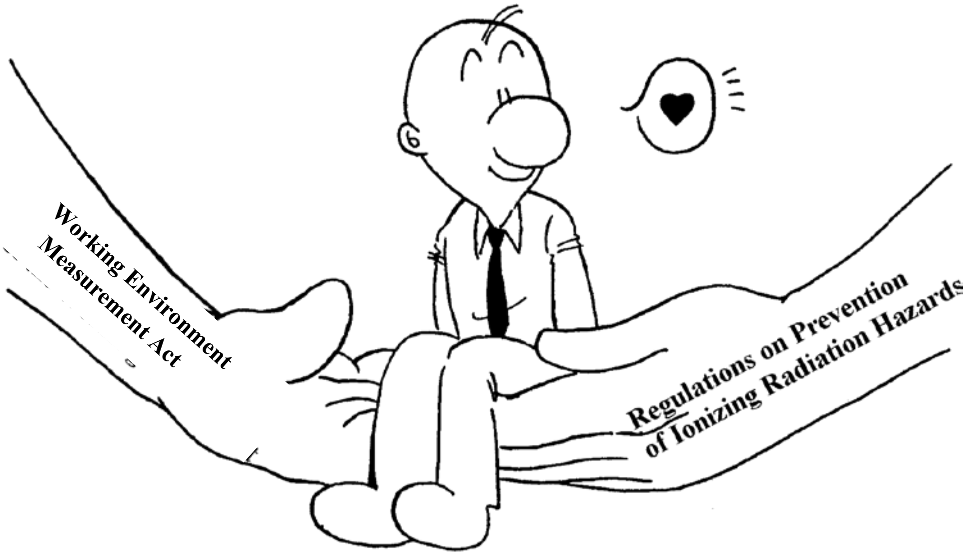

Fig. 52 Working Environment Measurement Act and Regulation on Prevention of Ionizing Radiation Hazards

6. Who are Radiation Workers?

Those who handle radiation generating apparatus or radioisotopes mainly in controlled areas are called **"radiation workers"** under the Act on the Regulation of Radioisotopes, etc. **Because radiation workers handle radiation and radioisotopes, which are considered to be harmful materials, such workers must fully understand the basic concepts regarding radiation and its deleterious effects, and observe the provisions in Acts and Regulations and in the Radiation Hazards Prevention Program at their facility.**

6-1. Why is it necessary to specifically identify "radiation workers"?

Radiation and radioisotopes are considered harmful, and should not be handled by just anyone. Only those who have completed specific steps to work in controlled areas are allowed to use radiation or radioisotopes - i.e., to become as radiation workers. Radiation workers, in the course of their handling of radiation and radioisotopes, are concurrently subject to necessary regulations control (education and training, exposure control and health surveillance).

6-2. Steps in becoming a radiation worker

Only those who have had required education and training and have had health surveillances, are allowed to enter controlled areas as radiation workers. Education and training are given to radiation workers to ensure that they have the enough knowledge and skills required as radiation workers. Health surveillances are required to determine if the individual is medically suitable for assignments involving the handling of radiation and radioisotopes.

If a radiation worker has experience handling radiation at, for example, another facility, his or her previous exposure dose records must be checke

6-3. Regulations

Workers designated as “radiation workers” may handle radiation and radioisotopes in controlled areas according to all applicable rules and procedures.

Radiation workers receive on a regular basis: 1) education and training, 2) health surveillances, and 3) personal monitoring in controlled areas. Radiation workers must be informed of the results of their personal monitoring each time, and they themselves should make a habit of confirming such results.

7. Who are Radiation Protection Supervisors?

In order to conduct appropriate and thorough radiation safety control at a facility, it is necessary to have a management structure or mechanism in place that is responsible for radiation protection control within the facility. In such a situation, the radiation protection supervisor is playing a key role. The radiation protection supervisor makes the radiation protection programs for the facility, taking its nature and specific circumstances into consideration, and over sees operations to make sure the programs are implemented properly.

7-1. Who are radiation protection supervisors?

Radiation protection supervisors are the person responsible for supervising efforts to prevent radiation hazards. They are appointed at any facility where radiation or radioisotopes are handled in the course of using, selling, or leasing, of them and waste management.

7-2. Role of radiation protection supervisors in the facility

Radiation protection supervisors are responsible for supervising all matters associated with radiation control and radiation safety in their facility. Radiation workers must follow the instructions of the radiation protection supervisor concerning radiation safety control. The employer must also pay serious attention to the decisions of the radiation protection supervisor on matters necessary for radiation safety control.

7-3. Categories of radiation protection supervisor certificate

To be qualified as a radiation protection supervisor, a person must complete required pass a national examination and training courses. The certificate are three classes of radiation protection supervisors - first class to third class. Which class is required by a particular facility depends on the kind and level of radiation or radioisotopes handled. Radiation protection supervisors must attend periodic training on an on-going basis, in order to always have the latest information in the field of radiation protection.

7-4. Cooperation with radiation protection supervisors

The radiation protection supervisors are responsible for supervising radiation safety control at a facility. Good radiation safety control will be implemented by good communication among radiation protection staff and radiation workers under a leadership of the radiation protection supervisors (see Ⅲ1).

7-5. Periodic Training for Radiation Protection Supervisors

A radiation protection supervisor must attend periodic training within one year from the day of the appointment as a radiation protection supervisor (however, persons are excluded, who have received periodic training for radiation protection supervisors within a period of one year prior to the appointment as a radiation protection supervisor). Moreover, the radiation protection supervisors who received periodic training, must receive periodic training within a period of three years, (within a period of five years for a notification seller or a notification lessor) starting from upcoming fiscal year in Japan; that is April 1.

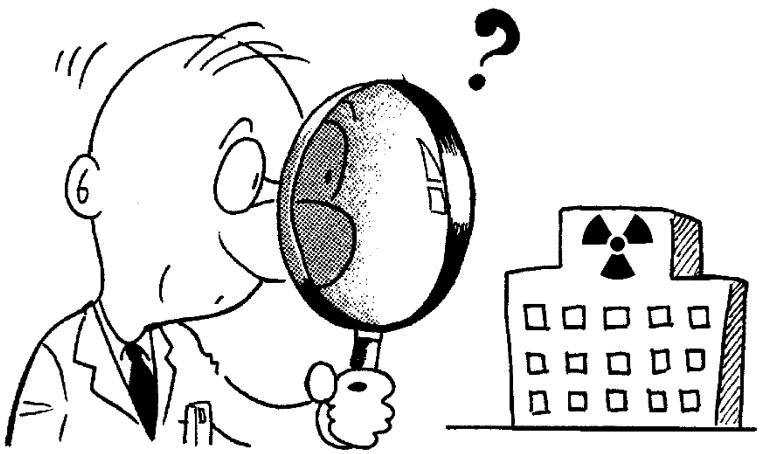

Fig. 53 Radiation protection supervisor

8. What is Radiation under Acts and Regulations?

"Radiation" as used in Acts and Regulations does not mean radiation as the word is understood in physics; rather, it means radiation as specified in the Atomic Energy Basic Act. Among the many kinds of electromagnetic waves and particles, the Act defines radiation as alpha rays, gamma rays and other radiations with the ability to directly or indirectly ionize the air.

8-1. There are various types of radiation

Radiation broadly means all electromagnetic waves and corpuscular beams. X-rays from X-ray generating apparatus, alpha and beta rays emitted during the decay of atomic nuclei, and gamma rays, are all well-known types of radiation. Particles emitted during nuclear reactions, mutual transformations of elementary particles, and cosmic rays are also type of radiation.

Legally, however, radiations generated artificially and that have the ability directly or indirectly to ionize air are defined as "radiation", as shown below.

The radiation defined in the Cabinet Order for the Definition of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactor is:

1) Alpha rays, deuterons, protons and other heavy charged-particles, and beta rays;
2) Neutrons;
3) Gamma rays and characteristic X-rays (limited to characteristic X-rays generated at the time of electron capture); and
4) Electrons and X-rays with energy of 1 MeV or more.

8-2. Definitions of radiation in other Acts and Regulations

According to the Laws and Regulations, electrons and X-rays with energy over 1 MeV are classified as "radiation", whereas the Medical Care Act regulates X-ray generating apparatus with a tube voltage of 10 kV or more. Also, under the Regulations on Prevention of Ionizing Radiation Hazards by the Ministry of Health, Labour and Welfare (MHLW), although the regulations do not specify an energy limit, and the MHLW has decided that X-ray generating apparatus with tube voltage of 10 kV or more must be regulated for the purpose of radiation protection.

8-3.　Radiation subject to dose evaluation

Electrons and X-rays less than 1 MeV are not “radiation as defined by the Act on the Regulation of Radioisotopes, etc., and the Nuclear Reactor and Fuel Regulation Act, whereas they are included in the Regulations on Prevention of Ionizing Radiation Hazards.

However, when dose is assessed, exposure to such radiation is to be added to exposure from other legally defined “radiation”.

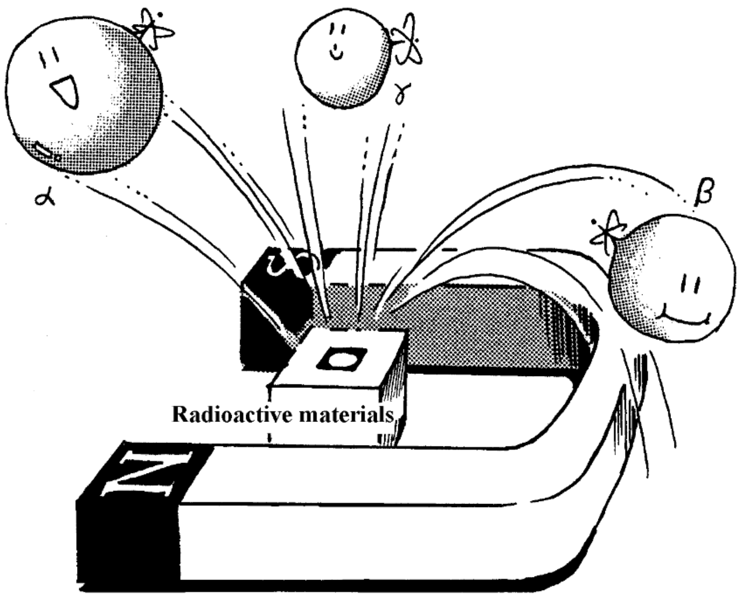

Fig. 54　Various types of radiations

9. What are Radioisotopes?

Legally, "radioisotopes" are isotopes emitting radiation, compounds of them, and materials containing them (including those equipped in instruments), in quantities or concentrations exceeding those stipulated by the Cabinet Order.

Such quantities or concentrations are called "**exemption limit**", because radioisotopes below the limit quantity or concentration are exempted from regulations for radioisotopes.

Table 16 shows examples of the exemption limit for radioisotopes frequently used in laboratories and factories. This means that anyone who has no experience to deal with radioisotopes can have or use 10^8 Bq or 10^5 Bq/g of tritium of any form without permission by or notification to the NRA.

It should be noted that the exemption level is not the activity level for disposing of radioactive wastes without permission nor notification (**clearance**).

Table 16 Quantities and concentrations of main radioisotopes above which are subject to regulations

Radioisotopes	Activity (Bq)	Activity concentration (Bq/g)
^{3}H	1×10^{9}	1×10^{6}
^{14}C	1×10^{7}	1×10^{4}
^{32}P	1×10^{5}	1×10^{3}
^{60}Co	1×10^{5}	1×10^{1}
^{131}I	1×10^{6}	1×10^{2}
^{137}Cs	1×10^{4}	1×10^{1}

10. What is Radiation Generating Apparatus?

At present, many kinds of radiation generating apparatus are in use. There are substantial differences in capacity among such equipment, and the applicable Acts differ. Under the Act on the Regulation of Radioisotopes, etc., several types of devices, including cyclotrons and linear accelerators, are subject to regulation.

10-1. Radiation generating apparatus under Acts and Regulations

"Radiation generating apparatus" covered by the Acts and Regulations includes such devices as cyclotrons or synchrotrons generating radiation by accelerating charged particles, as shown in the Table 17. Ordinary X-ray generating apparatus for health surveillances are not included because the X-ray energy is below 1 MeV. Also, when the maximum equivalent dose rate at a point 10 cm away from the surface of the equipment is 600 nSv/h or less, such equipment is not included.

10-2. Use of radiation generating apparatus

At the entrance to a room where radiation generating apparatus is operated, there must be automatic display systems which shows whether the apparatus is in operation or not, and additionally there must be interlocking systems at the entrance.

Table 17 Radiation generating apparatus under the Act on the Regulation of Radioisotopes, etc.,*

Radiation Generating Apparatus
1. Cyclotron
2. Synchrotron
3. Synchro-cyclotron
4. Linear accelerator
5. Betatron
6. Van de Graaff accelerator
7. Cockcroft-Walton accelerator
8. Other type of radiation generating apparatus by accelerating charged particles, specified by the NRA: transformer-type accelerator, microtron, and plasma generating equipment capable of attaining a critical plasma condition for the D-T reaction

*Equipment for which the 1 cm depth dose equivalent at a point 10cm away from the surface of the equipment is 600 nSv/h or less are excluded.

11. What is Sealed Radioisotopes?

Radioisotopes are classified into two categories for the purpose of control – sealed radioisotopes (sealed sources) and unsealed radioisotopes (unsealed sources). Included in the sealed sources are sources for radiation therapy, industrial sources, calibration sources, and sources for electron-capture detectors for gas chromatography. Sealed sources present no danger inregard to contamination, but external exposure must be a concern.

11-1. Safe handling of sealed sources

Sealed radioisotopes are basically used in circumstances that involve no danger of their being opened or damaged under normal conditions, and they present no risk of the contents being scattered and causing contamination as a result of leakage, infiltration, etc. It is, however, always important to prevent overexposure by taking appropriate measures for protection, regardless of the size or nature of the source. Also, leak testing should be done regularly, though it is not required legally.

One of uses of sealed sources is in “Approved device with a certification label”. These are instruments that the NRA has recognized as meeting technical standards in their mechanisms for the prevention of radiation hazards. One example is an electron capture detector (ECD) for gas chromatography. In handling an ECD, there is no danger of overexposure and the controlled area does not extend outside the cabinet of the chromatography device, but it is important to always control the whereabouts of the sources.

11-2. Management of disused sealed sources

Management of sealed sources that are no longer needed may be different from the handling of radioisotope waste because a radioisotope contained in a sealed source is usually high in activity and has a long half-life. Therefore, recovery of disused sealed sources, including those installed in devices, should be asked of the manufacturer or of the Japan Radioisotope Association.

Fig. 55 Return of sealed sources

12. What is the Controlled Area?

At any facility where radiation or radioisotopes are dealt with, any area where there is a possibility that the level of radiation or the concentration of radioisotopes in the air or on surface might rise above a specified level is designated a controlled area, and access to that area must be restricted. When unsealed radioisotopes are used, they must be used in a "workroom", where measures for cleaning the exhaust air, the floor and the wall are provided.

12-1. Radiation levels in controlled areas

At frequently entered places (e.g., "workroom") within controlled area, in order to maintain total effective dose from external and internal exposure at under 1 mSv per week, shielding material should be installed and working hours restricted when necessary.

In addition, outside the boundary of the controlled area, effective dose from external radiation must not to exceed 1.3 mSv per 3 months. Radiation levels in areas where people live are requested to be the same as those at the boundary of the site of facility, i.e., 250 μSv per 3 months.

The radiation levels to be maintained are shown in Table 18. At the entrance of a controlled area, a notice required to prevent radiation hazards is to be posted at clearly visible locations in usage facilities or in a controlled area.

12-2. Radiation work in controlled areas

When unsealed radioisotopes are handled at a facility, it must be done in a specifically provided "workroom". Because such a "workroom" is a place where a person can regularly enter within radiation facilities, the radiation level is controlled not to exceed 1mSv per week and the surface density of radioisotopes on the objects shall be kept not exceeding the limit of surface density.

12-3. Contamination inspection room

At any facility where unsealed radioisotopes are used, a contamination inspection room has to be provided near the entrance/exit regularly used by workers. In the contamination inspection room, there are washing facilities, a place to change clothes, radiation measuring equipment, etc. When workers leave the controlled area where radioactive contamination may occur, they must confirm that their bodies are not contaminated.

When skin contamination is detected, it must be removed (decontaminated) using the washing facilities. If any significant contamination still remains on the skin after the decontamination procedure as instructed, radiation protection staff member shall be notified of the matter.

Table 18 Radiation limit to be maintained in and around a controlled area

Area/Item	Frequently entered place within a controlled area	Outside boundary of a controlled area
Effective dose	1 mSv per week	1.3 mSv per 3 months
Concentration of radioisotopes in the air	Average concentration for 1 week: as mentioned in column 4 of Table 2 attached to the Notification on Quantity of Radioisotopes*	1/10 of the values in the left column
Concentration of surface density	Radioisotopes emitting alpha rays: 4 Bq・cm^{-2} or less; Radioisotopes not emitting alpha rays: 40 Bq・cm^{-2} or less	1/10 of the values in the left column

* Specifying Standards for the Quantities, etc. of Radiation-Emitting Isotopes

13. What is meant by "Radiation Levels outside Controlled Areas"?

In order to prevent hazards to the public and non-radiation workers from radiation and radioisotopes, limits for radiation levels apply to various areas other than controlled areas. Pursuant to the Acts and Regulations, limits for radiation levels around the controlled areas and area for residence inside of factory or place of business are set.

Radiation levels are also regulated at the boundary of the place of business, to ensure the safety of the public, separately from regulations for the safety of radiation workers working in controlled areas. Limits for radiation levels outside the controlled areas of a facility are shown in Table 19.

Table 19 Limits for radiation levels at various locations outside controlled areas

Item	Locations
Effective dose from external and internal exposure	Outside the boundary of the place of business: 250 μSv for 3 months; residence inside of factory or place of business: 250 μSv for 3 months; Sickrooms in hospitals and clinics: 1.3 mSv for 3 months
Average concentration of radioisotopes in the exhaust or air	Average concentrations for 3 months are the same as those mentioned in column 5 of Table 2 attached to the Notification
Average concentration of radioisotopes in liquid discharge or drain water	Average concentrations for 3 months are the same as those mentioned in column 6 of Table 2 attached to the Notification

14. Secure Specified Radioisotopes Manager

To prevent radiation hazards caused by those radio activities, to secure specified radioisotopes and to ensure public safety, specified radioisotope security manager is appointed from among the persons who satisfy the requirements provided for in the NRA Regulation concerning the knowledge on handling of specified radioisotopes, etc., in order to have the manager supervise uniformly the duties on the security of specified radioisotopes, pursuant to provisions of the NRA Regulation.

Moreover, the facility prepares specified radioisotope security program, and they have to take periodic training for specified radioisotope security managers.

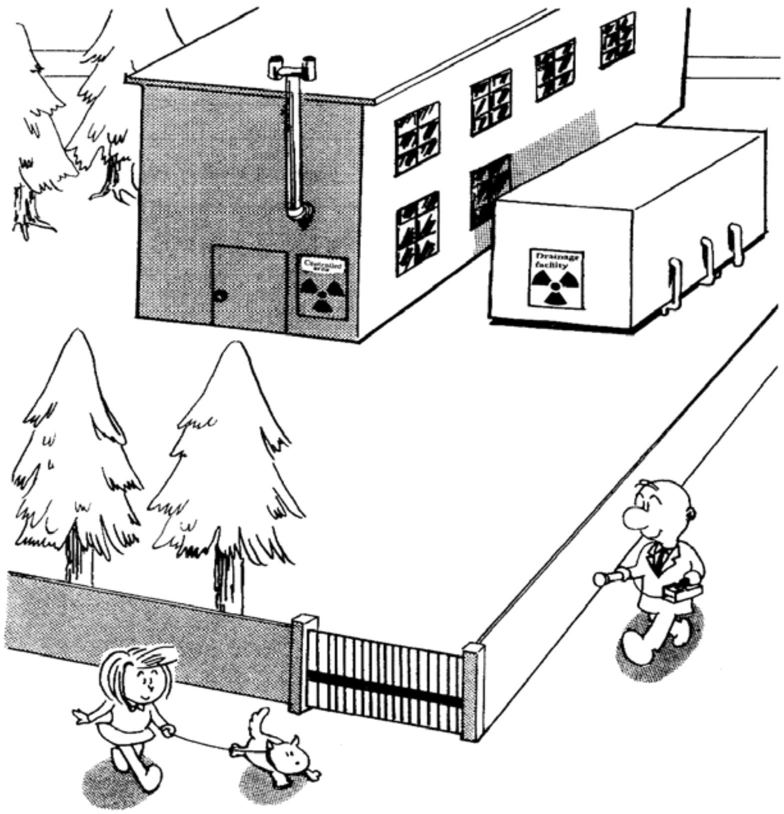

Fig. 56 Boundary of a place of business

VI. Radiation Hazards Prevention Program

1. What is the Radiation Hazards Prevention Program?

The Radiation hazards prevention Program is the basis for radiation protection at a facility. In the Program, the basic concepts of radiation protection at the facility, the safety control structure, and specific practices that radiation workers must adhere to, are all spelled out. The operating management of the facility, the radiation protection supervisor, radiation protection staffs and radiation workers must thoroughly understand and observe the Radiation Hazards Prevention Program. For radiation workers, an explanation of the Radiation Hazards Prevention Program is required to be given prior to the actual start of work in the course of education and training.

1-1. The Radiation Hazards Prevention Program

The Radiation Hazards Prevention Program is a specific rules for the implementation of radiation safety control and the prevention of radiation hazards at each facility.

The Radiation Hazards Prevention Program is the pledge regarding radiation control at the facility. The responsibilities of the operating management of the facility, the radiation protection supervisor, radiation protection staffs, and radiation workers are prescribed.

Items legally required to be included in the Radiation Hazards Prevention program are listed below.

1-2. Relationship between radiation workers and the program

Because the rules at each facility are based on the Act on the Regulation of Radioisotopes, etc., radiation workers are not required to know all the details of the Act itself. However, they must fully understand all items in the Radiation Hazards Prevention Program relating to what they themselves must do. For this reason, lectures on the program are included within the education and training curriculum provided prior to the worker's handling of radiation or radioisotopes for the first time.

Items to be covered in the Radiation Hazards Prevention Program

(1) matters concerning the duties and organization of radiation protection supervisors and other persons engaged in safety management in handling of radioisotopes, etc. or radiation generating apparatuses (including the duties and organization of persons engaged in handling of radioisotopes, etc. or radiation generating apparatuses);

(2) matters concerning of a deputy of a radiation protection supervisor;

(3) matters concerning the maintenance and management of radiation facilities (including management of persons who enter the area deemed not to be controlled area as special exception of a controlled area pertaining to radiation generating apparatus (Article 22-3 Paragraph 1) and the inspection of radiation facilities (controlled area in cases where a notification user uses sealed radioisotopes or manages disused sealed radioisotopes or wastes contaminated with radioisotopes);

(4) matters concerning the use of radioisotopes or radiation generating apparatuses (including matters pertaining to the method for confirmation of the quantity of unsealed radioisotopes in the case where outside a usage facility a permission user uses unsealed radioisotope of the quantity not exceeding the lower bound quantity per day (Article 15 Paragraph 2);

(5) matters concerning receipt, delivery, storage, transport or waste management of radioisotopes, etc. (for a notification lessor, including measures taken when radioisotopes leased to a permission or notification user are not properly stored);

(6) matters concerning measurements of the quantity of radiation and condition of contamination by radioisotopes and the measures for the prepare books and the records of results of the measurements (Items of Article 20 Paragraph 4);

(7) matters concerning education and training required to prevent radiation hazards;

(8) matters concerning health surveillance;

(9) matters concerning measures necessary for the health of a person who has suffered or is likely to suffer radiation hazards;

(10) matters concerning preparation and storage of books as obligation to prepare books (Article 25 of the Act);

(11) matters concerning measures to be taken when an earthquake, fire or other

disaster occurs (excluding measures pursuant to the provisions of the following Items);

(12) matters concerning emergency measures;

(13) matters concerning provision of information in cases where radiation hazards are likely to occur or have occurred;

(14) matters concerning required items to take measure emergency responses as emergency measures prescribed in Article 29 Paragraph 1 of the Act that those set forth in the following Items (limited to using radioisotopes or radiation generating apparatus provided for the NRA),

a. matters concerning the duties and organization of persons engaged measured to emergency responses,

b. matters concerning maintenance of required facilities or equipment engaged measured to emergency responses,

c. matters concerning procedure for implementation of emergency responses,

d. matters concerning enforcement of training about emergency responses,

e. matters concerning cooperation with prefectural police, fire services and medical institution or other related organs;

(15) matters concerning business improvement for prevent radiation hazards (limited to specified permission user or permission waste management operator);

(16) matters concerning report of status of radiation control;

(17) matters concerning measures to be taken for prevention of radiation hazards according to the decay of radioactivity in burial wastes that are buried in waste burial site (limited to the case where waste burial is conducted);

(18) other necessary matters concerning prevention of radiation hazards.

Appendix 1(Sign)

Radioisotope Use Room	Radiation Generating Apparatus Use Room	Radioactive Waste Repacking Room
		
Waste Management Workroom	Contamination Inspection Room	Activated Objects Storage Equipment (No Entry without Permission)
		
Container Prepared in an Activated Objects Storage Equipment	Storage Room (No Entry without Permission)	Storage Box (No Touch without Permission)
		

Container Prepared in a Storage Facility (Radioisotopes)	Container prepared in a Storage Facility (Radioactive Waste)	Exhaust Equipment (No Touch without Permission)
		
Drainage Purification Tank (No Entry without Permission or No Touch without Permission)		Predisposal Equipment (No Entry without Permission)
		
Container Prepared in a Predisposal Equipment	Usage Facility(No Entry without Permission)	Storage Facility (No Entry without Permission)
		

<table>
<tr><td>Waste Management Facility (No Entry without Permission)</td><td>Waste Repacking Facility (No Entry without Permission)</td><td>Waste Storage Facility (No Entry without Permission)</td></tr>
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<tr><td>Controlled Area (Place of Use of Radioisotopes) (No Entry without Permission)</td><td>Controlled Area (Place of Use of Radiation Generating Apparatus) (No Entry without Permission)</td><td></td></tr>
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Basic Knowledge of Radiation and Radioisotopes（2019）

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担 当	監修協力（敬称略）
1･5･6 章 Appendix1	桧垣正吾（東京大学）
2 章	柴田理尋（名古屋大学）
3 章	平田雄一（北海道大学）
4 章	松田尚樹（長崎大学）

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