Reference Document on Education and Self-Study Related to Radiation Medicine in Medical Education

(Provisional Translation)

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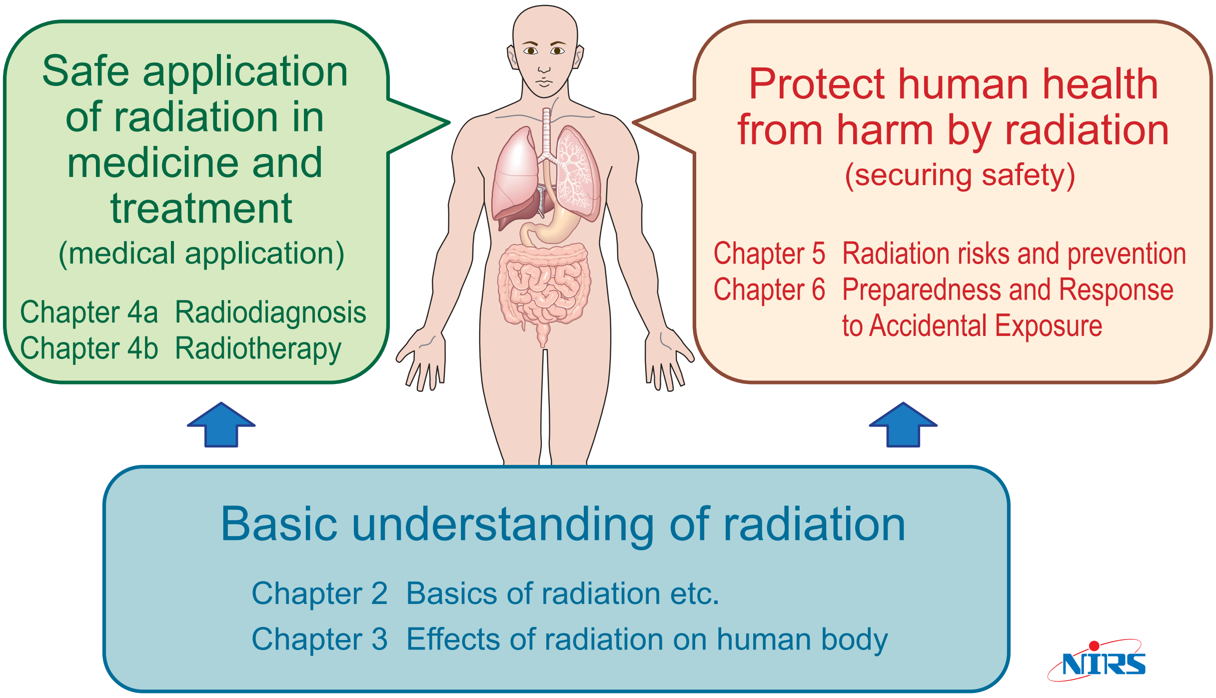
The National Institute of Radiological Sciences

Reference Document on Education and Self-Study Related to Radiation Medicine in Medical Education

Contents

Overview of This Document



Introduction

The framework of education at medical schools in Japan, while based on creative innovation by each school, follows the Model Core Curriculum for Medical Education which was compiled in March 2001 to specify targets for the essential knowledge, skill and attitude that medical students must acquire before Bed Side Learning and also graduating.

This Model Core Curriculum for Medical Education and the standard assessment test system (common examinations) are used in common by all Japanese medical schools, to raise the quality of all medical education in Japan.

In March 2011, a study considering revision of the Model Core Curriculum for Medical Education to reflect diverse social needs resulted in revisions to content, including cares for radiation exposure and disaster medicine. Coincidentally, the Great East Japan Earthquake led to the nuclear disaster at the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Plant, making the health impacts of radiation and radioactive materials a main concern for many Japanese.

In clinics, medical doctors will need basic knowledge on radiation-protection, not only for direct responses to radiation exposure and contamination with radioactive materials, but also for answering questions from disaster victims and the general public on the health impacts of radiation exposure and contamination with radioactive materials. Medical personnel will also need basic education in radiation-protection and -medicine to protect the health and safety of the public under legislation to protect civilians from terrorist attacks using radioactive materials.

However, this nuclear disaster has revealed that basic knowledge and experience in radiation protection — vital for appropriate response to a nuclear disaster — are not adequately widespread, apart from some exceptions among people involved.

Prompted by that background, this document focuses on the items concerning radiation-protection and -medicine in the revised Model Core Curriculum for Medical Education and, while centering on radiation medicine, systematically organizes basic knowledge that should be provided to medical students. It also offers themes and other contents for use in tutorial education in this field. We have also taken into consideration making it usable as reference material for self-study by medical students.

The contents selected here are diverse and include many elements that should deepen understanding in connection with education and self-study in other fields of medical education. As such, some parts may not necessarily closely follow the ideas of the Model Core Curriculum for Medical Education, with its carefully-selected contents, but it fits the character of this document, as reference material for practical use in medical education of Japan and self-study of medical students. We hope all concerned will understand this point and put this document to use in real educational situations.

We also hope that this document will be helpful for education and study in the field of radiation medicine, producing more medical personnel with interest and training in this field.

1. Scope

1.1 Radiation, Radiation Medicine and Doctors

Radiation can be detected in daily life. Soil, ores and rocks contain naturally-occurring radioactive materials; potassium 40 (K-40) and several other radioactive materials are present in the body. However, most of people have no idea they are being exposed to radiation every day. That is the first step that medical students should be aware of when learning about radiation medicine.

Since the last decade of the 19th century the use of radiation has been advancing in medicine and in many industrial activities. Recent applications of radiation in diagnosis and treatment have been astonishing. Therefore, doctors must have a correct understanding of the health impacts of radiation and only then exploit its advantages in medical applications.

As radiation is used in society, radiation accidents occur, though rarely (note 1). Furthermore, the nuclear disaster triggered by the Great East Japan Earthquake of March 11, 2011, has forced Japan to directly face the issue of the health impacts of radiation, now and for a long time to come.

Amid a background with this flow of history, radiation medicine is the field of medicine that promptly addresses concerns over the health impacts of radiation exposure. Radiation is colorless and odorless, and requires a detector to know it is there and people are often unaware they are being exposed. It also takes time after actual exposure for symptoms and signs to appear. Symptoms show themselves in diverse ways depending on the mode of exposure. With reference to the content of this document, Figure 1 takes a long–term view of the future direction of radiation medicine, which should be advanced in conjunction with a range of related fields.

Concerning radiation medicine, “The Radiation Emergency Medical Preparedness and Response” (2008 edition) by the Nuclear Safety Commission of Japan states that “anyone can receive the best medical treatment anywhere and anytime”. The implementation of that rule requires collaborative medical treatment in various fields. This is why team medical care is so important in radiation medicine. A patient-centered perspective, Communication abilities and Team medical care---these three items are included in the eight basic qualities expected of medical doctors in the Model Core Curriculum for Medical Education (2010 revised edition)(note 2). That also applies to medical doctors involved in radiation medicine.

A medical doctor must have adequate awareness of circumstances on radiation mentioned above.

Consequently, there will be a strong need in the future for medical doctors to cultivate basic education on radiation and its protection, building on the basic qualities expected of a physician, with the following perspectives:

- Appropriate adaptation to advances in the use of radiation in medicine (diagnosis and treatment).
- Appropriate treatment of patients exposed to radiation and contaminated with radioactive materials.
- Implementation of appropriate guidance, based on scientific knowledge, to address ill-defined concerns spreading in Japanese society about the health impacts of radiation.

These are important points that are expected of the positions of not only medical doctors but all medical personnel.

Note 1

A radiation accident is unintended exposure to radiation and/or contamination with radioactive materials, resulting in possible deleterious effects for the exposed and/or contaminated individuals. Exposure to radiation for diagnosis or treatment in a hospital is intentional within a range of dose calculated for the benefit of a patient. Thus, it does not fall within the scope of a radiation accident, provided the dose is controlled.

Note 2

- The professional responsibilities as a medical doctor
- A patient-centered perspective
- Communication abilities
- Team medical care
- Ability of comprehensive treatment
- Community medical care
- Interest in medical research
- Self education

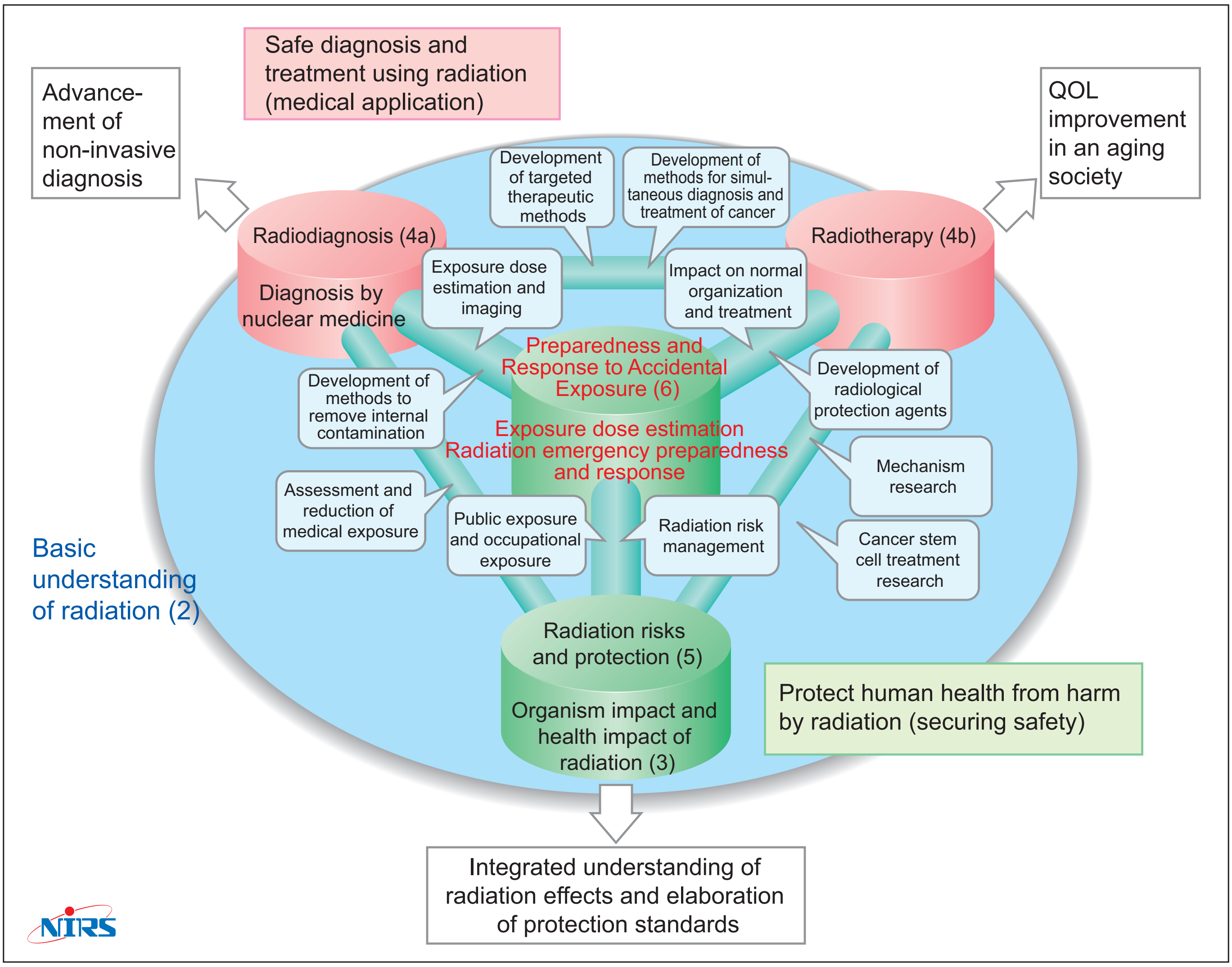


Fig. 1 The Structure and Future Outlook of Radiation Science and Radiation Medicine

1.2 Understanding the Historical Background

When studying radiation medicine, it is important to understand the basic and historical background to the progress of the field. Tables 1 and 2 are of reference for that background.

The history of radiation is a struggle against radiation exposure. Roentgen published a paper on X-rays in November 1895, and the discovery of uranium by Becquerel was reported the following year. Regrettably, the discovery by Becquerel did not attract the attention of scientists until the Curies discovered radium. At almost the same time, Becquerel reported skin injury, erythema, caused by radiation from radioactive materials, yet few people then recognized that X-rays, which were similar to light but imperceptible to human senses, could cause deleterious effects.

Edison was among those who first reported on the deleterious effects caused by X-rays, and eye damage by X-rays was reported in 1896. In the same year, Daniel reported hair loss caused by X-rays, and Thompson stated that touching an X-ray tube with a finger for 30 minutes per day over several days caused pain, swelling, stiffening, erythema and blisters. These deleterious events caused by X-rays were known within one year of Roentgen's discovery.

Radiation protection made progress as a science after 1925. In 1945, people faced the tragedy of atomic bombing for the first time in Hiroshima and Nagasaki. After that, the results of research on the health impacts of radiation were applied to the safety in various radiation-related activities. Today, worldwide securing of safety through radiation protection is discussed at the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiation Protection (ICRP), the International Atomic Energy Authority (IAEA) and the World Health Organization (WHO).

Response to the Great East Japan Earthquake and its related nuclear disaster still continues, but the knowledge and experience gained in the process must be accurately assimilated and passed on to future generations. Medical students and others who may be involved in the medical field must build up their basic knowledge on radiation so that they will be able to do so.

Table 1 Historical Table of Radiation Medicine

	X-ray diagnosis	Radiotherapy	Nuclear medicine	Radiation damage	Use in non-medical fields	Common items, and others
1895–1900	1895 Invention of radioscopy and radiography 1896 Diagnosis by radiography – Bone fractures and kidney stones – Internal foreign bodies Trial of gastrointestinal tract contrast 1897 X-ray cinematography – Frog legs 1898 Diagnosis by radiography – Gallstones	1896 X-ray treatment of nasopharyngeal cancer (death) 1897 X-ray treatment of hairy nevi (first case of successful treatment) 1898 X-ray treatment of chronic eczema (successful) 1899 X-ray treatment of skin cancer (successful)		1896 Acute damage by X-rays –Acute dermatitis –Hair loss 1899 Vascular endothelial degeneration 1900 Death due to X-ray induced skin cancer		1895 Discovery of X-rays 1896 Discovery of radioactivity 1899 Discovery of α and β rays (1899) 1900 Discovery of γ rays (1900)
1901–1920	1904 Trial of urethral contrast 1907 Trial of bronchial contrast 1918 Ventriculography announced 1919 Vascular contrast successful	1901 Start of radium treatment 1902 X-ray treatment of Hodgkin's disease 1903 Start of intraluminal irradiation with radium 1904 Development of the interstitial irradiation method using radium		1901 Burns due to radium 1902 Causality suggested with skin cancer in X-ray handlers 1903 Discovery of teratogenicity of radiation 1904 Discovery of leukocytopenia 1905 Death caused by burns due to radium 1909 Surgical treatment of radiation damage	1909 Manufacture of radium-based luminous paint (for watches)	
1921–1950	1921 Patent application for tomography	1938 Fast neutron radiotherapy	1926 Human blood flow measured using natural RaC (Bi-214) 1936 Start of leukemia treatment using Na-24, P-32 1941 Treatment of hyperthyroidism using radioactive iodine	1924 Report of osteonecrosis due to radium deposition 1947 Report of hepatic vascular endothelial sarcoma generated by thorotrast	1946 Development of the C-14 carbon dating method 1950 Successful sterilization of screwworms	1932 Discovery of neutrons 1934 Discovery of artificial radioactivity 1945 Atomic bombs dropped on Hiroshima and Nagasaki
1951–1980	1972 X-ray CT announced	1951 Start of treatment trials using the thermal neutron capture method 1952 Start of proton and helium ion treatment	1963 Single photon emission computer tomography (prototype) announced 1975 Positron emission tomography announced		1952 Discovery of radiation cross-linking of polyethylene 1954 Prototype thickness gauge 1972 Irradiation of potatoes permitted	1951 Start of nuclear power generation 1979 Three Mile Island reactor accident occurred
1981–2011						1986 Chernobyl accident 1999 JCO criticality accident 2011 TEPCO reactor accident

(Source: Revised according to "History of Radiation Medicine", Yukio Tateno, Iwanami Shoten, 1973)

Table 2 Major Nuclear and Radiation Accidents, from the Perspective of Radiation Medicine

Year	Type	Location	Summary
1957	Radiochemical plant	Kyshtym, USSR	Overheating and resulting explosion of a storage tank led to release of 740 PBq of radioactive products.
1979	Nuclear power plant	Three Mile Island, USA	Low water levels in reactor led to severe damage to fuel elements; 550 GBq I-131 released to the atmosphere. Limited evacuation.
1986	Nuclear power plant	Chernobyl, USSR	Breach of operating rules and violation of safety procedures, combined with a flawed design resulted in a steam explosion, fire and destruction of the reactor. Whole-body doses of 1-16 Gy and localized doses to skin among plant staff and emergency personnel; 30 deaths; 106 others with ARS; medical treatment, including bone marrow transplants (101 others initially examined for ARS). Significant release of radionuclides into the environment (including 1760 PBq of I-131 and 86 PBq of Cs-137).
1987	Cs-137 radiotherapy device	Goiania, Brazil	Abandoned device containing cesium source, disassembled. 21 persons had doses in excess of 1.0 Gy (up to 7 Gy); 50 persons were admitted to hospital or primary care units; 79 persons received dispensary care. ARS, skin injuries and internal contamination were problems. Local environmental contamination occurred.
1999	Fuel conversion plant	Tokaimura, Japan	Workers unknowingly added higher enriched uranium into a task bypassing criticality controls. Two fatalities (uneven exposures of around 8 and 23 GyEq), and one person with whole-body dose of around 3 GyEq.
2011	Nuclear power plant	Fukushima, Japan	On 11 March 2011 the Fukushima-Daiichi nuclear power plant suffered major damage from the failure of equipment after the magnitude 9.0 great east-Japan earthquake and subsequent tsunami. It was the largest nuclear accident since the Chernobyl accident of 1986. There was release of radioactive material from the damaged plant and thousands of people were evacuated.

(Source: Adopted from UNSCEAR 2008 Report to the General Assembly with Annexes: Sources and effects of ionizing radiation, Volume II, Scientific Annex C, 2008.)

(ARS: acute radiation syndrom)

2. Basics of Radiation etc.

Unit Name	2.1 What are Radiation and Radioactive Materials?
Items related to core curriculum	• Be able to explain types and properties of radiation and radioactivity.
General objectives	• Study the basics of the properties of radiation.
Extended objectives	• Ability to broadly explain the types and properties of radiation and radioactivity, and to understand that they are closely related to the effects of radiation on organisms.
Points to understand	• There are various types of radiation that have different properties. • All their effects are caused by ionization (including excitation).
Essential teaching points	• Make students aware that these are the most basic points for studying radiation medicine.
Keywords	Radiation, radioactivity, nuclear fission, radioisotope, radioactive material, half life, radiation generator, activation, interactions between radiation and matter, matter, the nature of radiation.
Reference tutorials	1

Outline

2.1.1 Radiation and radioactivity

Particle radiation and electromagnetic radiation that have the capacity to ionize air are called ionizing radiation (Figs. 1, 2). The representative particle radiation types are alpha rays, beta rays, and neutrons, and the representative electromagnetic waves are gamma rays and X-rays. The energy of radiation is expressed in electron volts (eV). 1eV is 1.6×10^{-19} joules (J).

The atomic nuclei of unstable atoms decay (break down) naturally, emitting radiation. The number of atoms that decay in one second is defined as radioactivity and is expressed in Becquerels (Bq). Radioactivity reduces over time. The time it takes for it to reduce to half is called the half life (Fig. 3). For example, the half life of cesium 137 (Cs-137) is around 30 years and that of iodine 131 (I-131) is around eight days.

2.1.2 Radiation emitted from radioisotopes

Elements that emit radiation are called radioisotopes (RI), and materials that include them are called radioactive materials. Radioisotopes emit alpha rays, beta rays, gamma rays, etc.

An alpha ray is a helium atom nucleus with a +2 charge, 7,300 times the weight of an electron. Elements that emit alpha rays include plutonium 239 (Pu-239), uranium 235 (U-235), radium 226 (Ra-226) and radon 222 (Rn-222).

Beta rays are electrons emitted from atomic nuclei, with a -1 charge. They are also called beta $^{-}$ rays. They are emitted by elements such as cobalt 60 (Co-60), cesium 137 (Cs-137), iodine 131 (I-131), strontium 90 (Sr-90) and potassium 40 (K-40).

Positron may be emitted from atomic nuclei, with a +1 charge. These positrons are also called beta $^{+}$ rays. Fluorine 18 (F-18) etc. are used in radiopharmaceuticals for PET.

It is common for gamma rays to be emitted at the same time as alpha rays or beta rays.

2.1.3 Radiation emitted by nuclear fission

When atoms such as uranium 235 (U-235) and plutonium 239 (Pu-239) absorb neutrons, they split into two atomic nuclei. This is nuclear fission, and the two atomic nuclei are called fission products.

Nuclear fission is accompanied by the emission of two to three neutrons. These neutrons cause further nuclear fission in nearby uranium 235 (U-235) or plutonium 239 (Pu-239). An ongoing chain reaction of such fission is the operating principle of a nuclear reactor.

The fission products have mass numbers close to 95 and close to 140. The representative of the former type is strontium 90 (Sr-90), and the representatives of the latter are cesium 137 (Cs-137) and iodine 131 (I-131). In general, fission products are unstable and radioactive, emitting beta rays and gamma rays.

2.1.4 Radiation emitted from radiation generators

X-rays for diagnostic use are made by compact generators. Those for therapeutic use are made by linac or other radiation generators. Synchrotrons and other large radiation generators generate proton beams (+1 charge, 1,840 times the weight of an electron) and carbon beams (+6 charge, 22,080 times the weight of an electron) for cancer treatment.

Radiation generators that produce high-energy radiation (several MeV or more) may cause activation, in which a portion of the target or instrument is exposed to radioactivity, therefore they must be handled with care.

2.1.5 Interaction between radiation and matter

Particle radiation that carries electricity such as alpha rays and beta rays directly ionizes matter (through Coulomb force) (Figs. 4,5). In particular, alpha rays have hundreds of times the ionization density of beta rays etc. Proton and carbon beams ionize matter with similarly high density.

Gamma rays and X-rays never ionize matter directly, but matter may be indirectly ionized by secondary electrons emitted through photoelectric effects, Compton scattering, or other effects.

Neutrons collide with hydrogen nuclei in matter and the expelled protons ionize matter at high density.

The total amount of energy provided to a counterpart during advancement for a unit distance (μm) is called the linear energy transfer (LET), and is expressed in keV/μm. The value is 100-150 for alpha rays, and 0.2 for gamma rays from Co-60. Linear energy transfer is an important index related to effect on organisms.

2.1.6 The nature of radiation

Alpha rays have high ionization density (called high-LET radiation), so they are stopped by a few cm of air or a single sheet of paper (Fig. 6). When outside the body, they cannot penetrate the skin. But, when inside the body, they are stopped within tissue, causing high-density ionization in the process, so there is potential to cause significant damage to DNA.

Beta rays are stopped by a few meters of air, 1cm of plastic, or 2-3mm of aluminum sheet (Fig. 7). When outside the body, they can pass through skin, causing a damage on the epithelium and subepithelial layer. Beta $^{+}$ rays emitted by radiopharmaceuticals immediately bond with electrons inside the body, releasing two gamma rays of 511keV.

Gamma rays can pass through tens or hundreds of meters of air. From cesium 137 (Cs-137), they are attenuated hundreds of times by 5cm of lead (Fig. 8), but can easily pass through the human body, having an effect on important organs. The same is true for X-rays. It is possible to kill cancer cells by concentrating irradiation on cancerous lesions.

Neutrons can pass hundreds of meters or more through air, but can easily be stopped by water containing hydrogen (Fig. 9). However, care is required as secondary reactions can generate alpha rays, protons and gamma rays. They are used in boron neutron capture therapy (BNCT).

Proton and carbon beams have high ionization density and are used in cancer therapy. They are made by synchrotrons or other radiation generators and can be fired into cancerous lesions. However, secondary reactions can generate neutrons in the body.

Diagrams

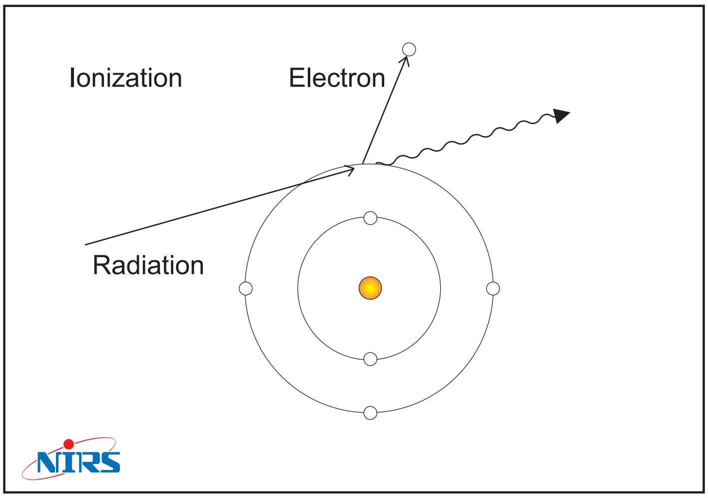


Fig. 1 Illustration of Ionization (separation into + ions and - electrons)

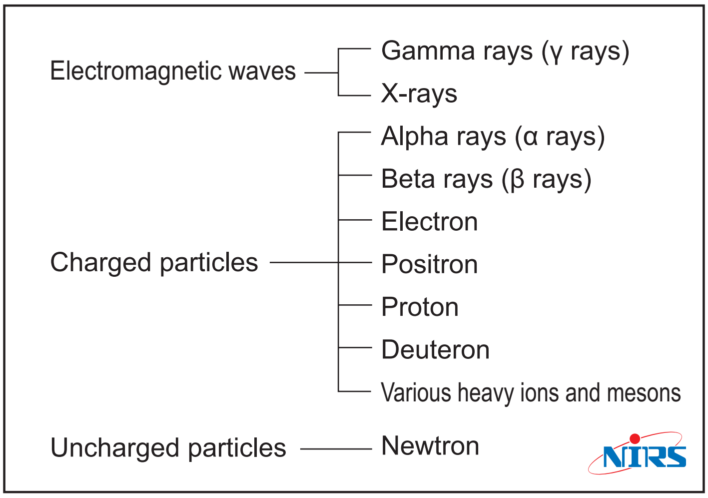


Fig. 2 Types of Radiation

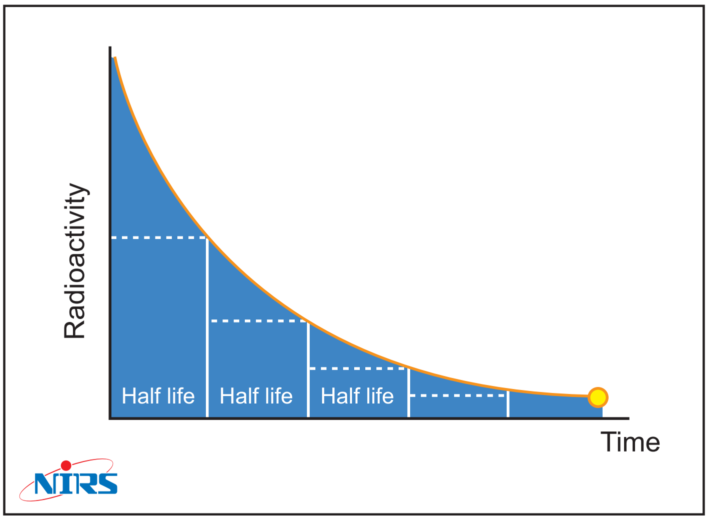


Fig. 3 The Concept of Half Life

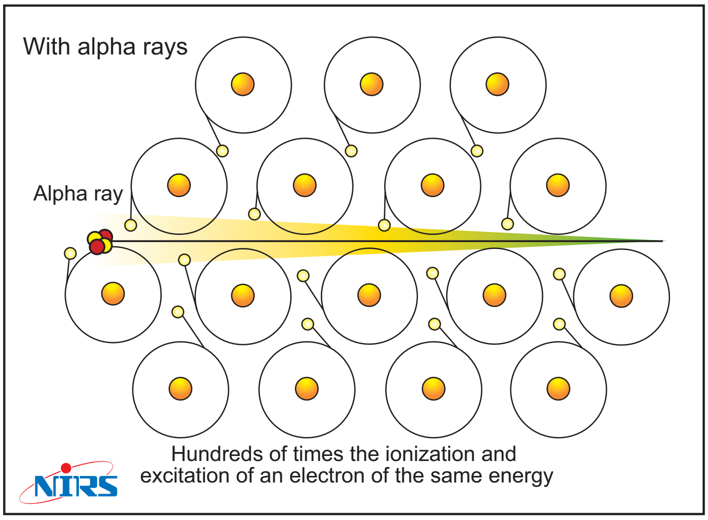


Fig. 4 Alpha ray with High Ionization Density (high-LET radiation)

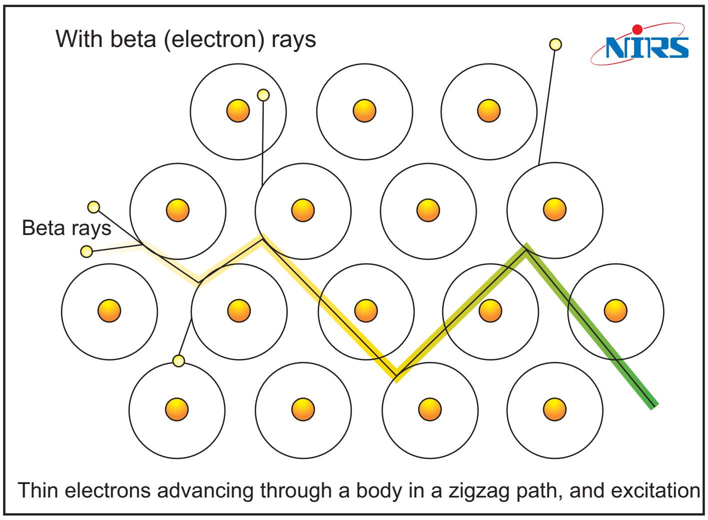


Fig. 5 Beta ray with Low Ionization Density (low-LET radiation)

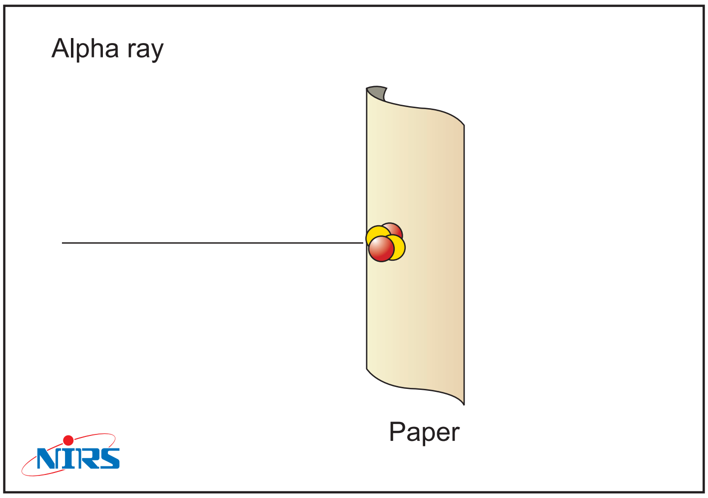


Fig. 6 Alpha Rays are Stopped by One Sheet of Paper

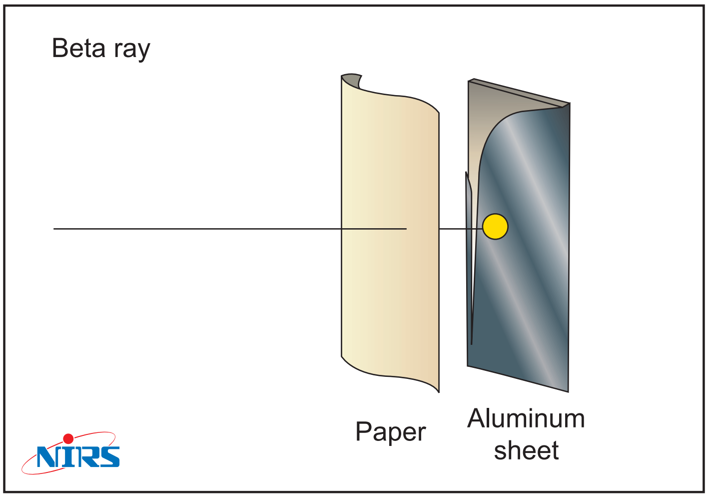


Fig. 7 Beta Rays are Stopped by 2-3mm of Aluminum Sheet

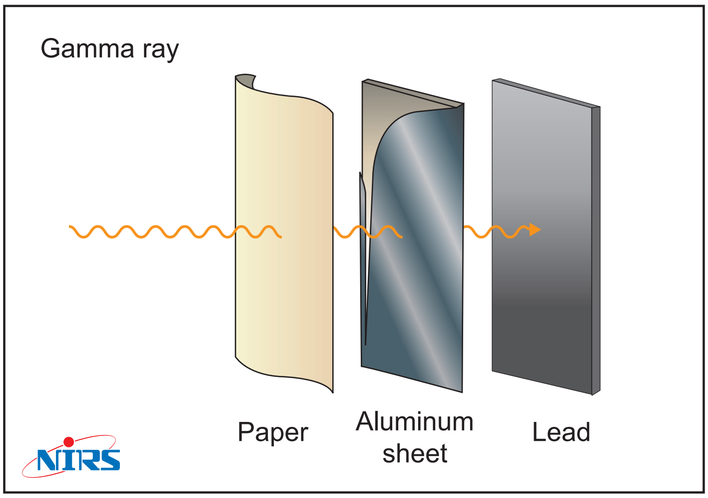


Fig. 8 Gamma rays (X-rays) Stopped by Lead ...
The Thickness of Lead for Blocking Varies, Depending on Energy

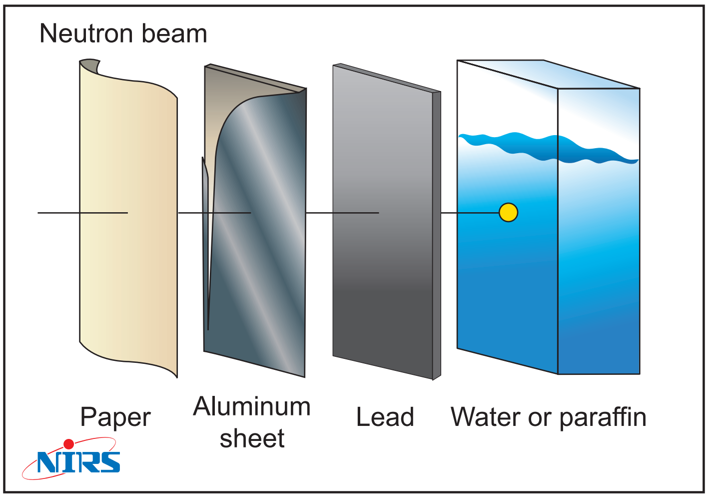


Fig. 9 Neutrons are Largely Stopped by 20cm of water

Exercises

Question 1. Which kind of radiation has the highest ionization density?

a. Gamma rays from Co-60 b. X-rays of 250keV max.
c. Proton beam d. Neutron beam e. Alpha rays

Question 2. Which radioisotope is unlikely to be dispersed in a reactor accident?

a. Cs-134 b. Sr-90 c. I-131 d. Ra-226 e. Cs-137

Question 3. Which type of radiation cannot be generated in a radiation generator?

a. Alpha rays b. Neutrons c. X-rays d. Proton beam e. Carbon beam

Exercise answers and explanations

Answer to Question 1: e

Particle radiation that weighs more than protons and has an a + charge has high ionization density. Neutrons cause ionization with bounced protons.

Here are the linear energy transfer values corresponding to ionization density values for typical radiation types. The unit used is keV/μm.

[1] Gamma rays from Co-60:	0.2	[2] X-rays of 250keV max.:	2.0
[3] Proton beam:	0.5-5.0	[4] Neutron beam:	50-150
[5] Alpha rays:	100-150	[6] Carbon beam:	100-2,500

Answer to Question 2: d

Reactor fuel rods initially contain U-235, U-238, etc. Nuclear fission creates radioisotopes (also called fission products) with mass numbers around 95 and around 140.

Only Ra-226 is a natural radioactive substance which has existed since the birth of the Earth.

Answer to Question 3: a

Neutrons are generated by accelerating protons and forcing them to collide with lithium (Li). X-rays are generated by accelerating electrons and targeting them on molybdenum (Mo) etc.

Alpha rays are emitted from the atomic nuclei of radioisotopes.

Teaching support materials for advanced students

Refer to the Educational Animations about Radiation (4 programs), published on the National Institute of Radiological Sciences website on September 20th and November 16th.

Masahiro Fukushi: Radiation Metrology, Medical View Co., Ltd. Tokyo, 10-18, 2009

Unit Name	2.2 Measurement, Dose and Units
Items related to core curriculum	• Be able to explain measurement methods and units.
General objectives	• Study the basics of the properties of radiation.
Extended objectives	• Be able to broadly explain the units and measurement methods used in radiation therapies (including radiation exposure).
Points to understand	• Understand the methods for measuring radiation doses, and the units used. • Understand the meanings of, and relationships between, dosimetry quantities such as exposure dose (C/kg, R) and absorbed dose (Gy), and radiological protection quantities, such as equivalent dose (Sv) and effective dose (Sv).
Essential teaching points	• Use absorbed dose (Gy) as the therapeutic dosage in cancer therapy. • Use equivalent dose (Sv) and effective dose (Sv) for the radiation exposure used in such cases as diagnostic radiation. • The correct measurement instruments must be used for the type of radiation and the purpose of measurement.
Keywords	Radioactivity (Bq), exposure dose (C/kg, R), absorbed dose (Gy), equivalent dose (Sv), effective dose (Sv), dosimetry quantities, radiological protection quantities, dose equivalent (Sv), operational quantities, air dose rate (μSv/h), personal exposure dose (Sv), ionization chamber detector, scintillation detector, solid state detector, badge, pocket dosimeter
Reference tutorials	2

Outline

2.2.1 Basic doses (radiation measurement quantities) and units

- If matter (air, human body, etc.) is present in an environment in which radiation is emitted from a radioactive material (radioactivity Bq) or a radiation generator (output expressed in kV or mA), the physical quantities for the transfer of energy between the radiation and that body are called radiation measurement quantities. Exposure dose (Fig. 1) and absorbed dose (Fig. 2) are commonly used.
- Exposure dose (C/kg, R) concentrates on charges (+ ions and - electrons) produced from the interaction between radiation and matter (air). C/kg is Coulombs per kg, and R is Roentgens, the old unit. The relationship between them is 1C/kg = 3,876R. These units are used for gamma rays and X-rays, and are commonly used in the performance testing, test operation, adjustment etc. with X-ray generating instruments.
- Absorbed dose (J/kg) is defined as the energy absorbed from radiation by matter (air, human body, etc.) per unit mass. If the energy required when producing charges is known, it can be derived from exposure dose. This is a quantity that can be applied to all radiation and it is important in deriving radiological protection quantities. It is used as an index for the amount of radiation applied to a lesion in cancer therapy using X-rays, gamma rays, proton beams, carbon beams, etc.

2.2.2 Doses (radiological protection quantities) and units concentrating on effect on the human body

- Absorbed dose concentrates solely on received energy, but even for the same absorbed dose, the effect on the human body (the stochastic effect as an indicator of cancer generation) varies with the type of radiation and its energy.
- For any given tissue or organ, equivalent dose is defined as the absorbed dose for each type of radiation, multiplied by the corresponding radiation weighting factor, which takes into account the type of radiation and the effect of energy on organisms. The products are totaled together.
  For example, suppose 10mGy was received from gamma rays, and 5mGy from neutrons at 1MeV. The radiation weighting factor for gamma rays is 1, and that for neutrons at 1MeV is around 21, therefore the equivalent dose is expressed by
  10mGy x 1 (the gamma ray portion) + 5mGy x 21 (the neutron portion) = 115mSv

- Effective dose (Sv) is the dose devised to express effect on the human body as a whole (Fig. 3). Effective dose (Sv) is defined as the dose multiplied by the tissue weighting factor that expresses the level of effect on each type of tissue and the products for all organs are added together. For example, suppose there were equivalent doses of 100mSv on the liver and 50mSv on the stomach, with no exposure to other organs. The tissue weighting factor for the liver is 0.04 and that for the stomach is 0.12. Therefore, the effective dose is
  100mSv x 0.04 (the portion affecting the liver) + 50mSv x 0.12 (the portion affecting the stomach) = 10mSv

2.2.3 Doses (operational quantities) and units for radiation management

- Effective dose was introduced as a concept to express effect on the human body from whole-body exposure, but it is difficult in practice to measure the equivalent dose for each organ and tissue type. This makes it impossible to measure the effective dose.
- Consequently, dose equivalent is used as a practical substitute for effective dose, as a quantity measurable by survey meters, personal exposure dosimeters and similar instruments. Because it is measured with instruments, dose equivalent (Sv) consists of physical quantities only and is expressed as absorbed dose x linear energy transfer (the function for linear energy transfer in water).

2.2.4 Radiation measurement principles and measurement instruments

- Radiation measurement instruments measure dose equivalent and dose equivalent per hour (dose equivalent rate), which are operational quantities. There are also radiation measurement instruments that measure surface contamination. They find the count rate, which is the number of radiation counts per minute (cpm).
- Absorbed dose is derived from the exposure dose (C/kg, R), which is the amount of gas ionization based on the ionizing capacity of the radiation, and then the air dose rate (μSv/h) is derived from the absorbed dose.
  ⇒ ionization chamber detector, ionization chamber survey meter (Fig. 4)
- The fluorescence produced as a result of the ionization and excitation actions of radiation is amplified, and energy information is used to derive the air dose rate (μSv/h).
  ⇒ scintillation survey meter (Fig. 5)
- Pocket dosimeters (Fig. 6) and other electronic personal exposure dosimeters contain solid state detectors and display personal exposure doses in Sv. Workers can directly read their exposure doses.
- Glass badges and other personal exposure dosimeters use the radiation storage effect that is a property of matter and are used to calculate the cumulative dose over one month. They can only be read by an instrument called a reader, and cannot be read directly. They are used to manage the exposure doses of workers in radiation-related duties.
- Specifically, the air dose rate due to gamma rays is measured by NaI (sodium iodide) scintillation survey meters and ionization chamber survey meters. Beta rays from surface contamination can be measured by GM (Geiger-Muller) tube survey meters and plastic scintillation survey meters. alpha rays are measured with ZnS (zinc sulfide) scintillation survey meters.

Diagrams

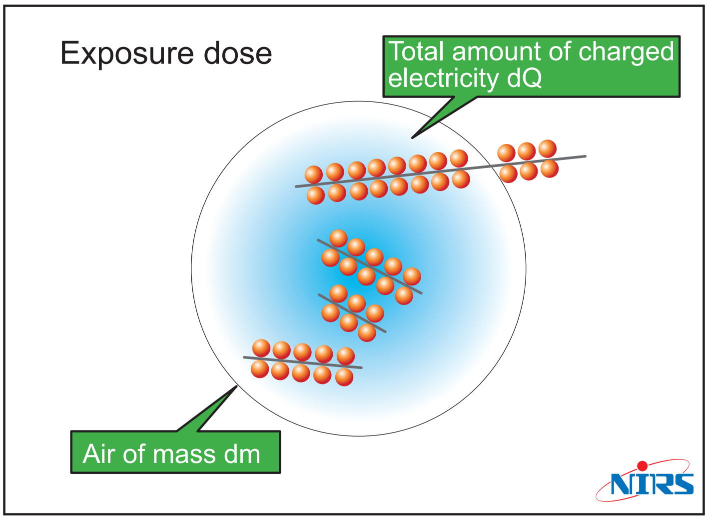


Fig. 1 Exposure Dose (defined as dQ/dm, unit is C/kg)

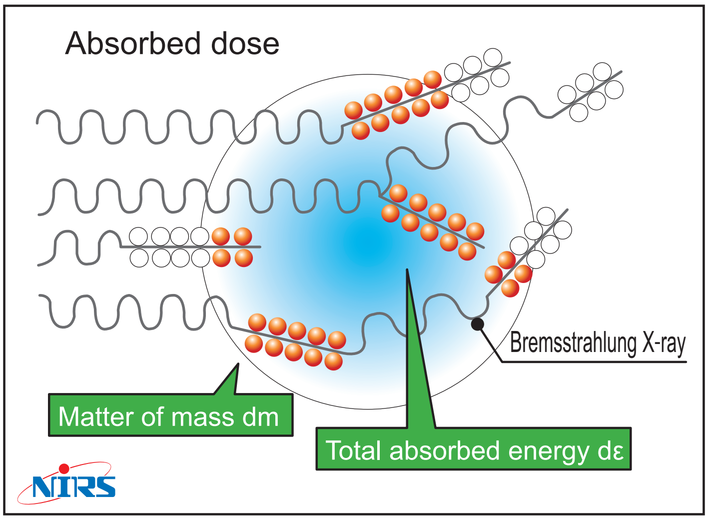


Fig. 2 Absorbed Dose (defined as de/dm, unit is J/kg or Gy)

Impact of radiation on the human body

Effective dose: E (in Sieverts: Sv)

$$E = \sum_{T}(W_T \times \sum_{R}(W_R \times D_{T\text{-}R}))$$

D_T : Absorbed dose WR for each tissue
W_R : Radiation weighting factor
W_T : Tissue weighting factor

Fig. 3 Effective Dose (unit is J/kg or Sv)

Ionization chamber survey meter

Fig. 4 Ionization Chamber Survey Meter
(measures air dose rate μSv/h, more suitable for high doses)

Scintillation survey meter

Fig. 5 Scintillation Survey Meter
(measures air dose rate μSv/h, more suitable for low doses)

Electronic pocket dosimeter

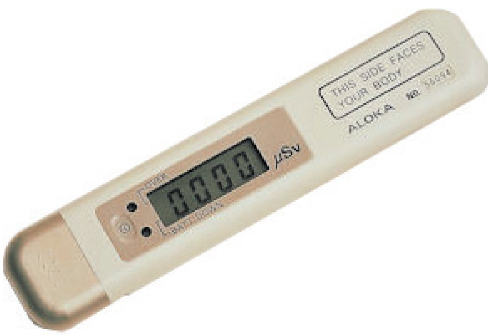


Fig. 6 Electronic Pocket Dosimeter
(measures personal exposure dose μSv)

Exercises

Question 1. Which unit expresses the absorbed dose of radiation?

a. C/kg   b. keV/μm   c. μSv/h   d. R   e. J/kg

Question 2. Which can be measured directly with a survey meter?

a. Equivalent dose   b. Air dose rate   c. Effective dose   d. Linear energy transfer
e. Personal exposure dose

Question 3. Which type of radiation has the largest radiation weighting factor?

a. Alpha rays   b. Beta rays   c. X-rays   d. Gamma rays   e. Neutrons at less than 10keV

Exercise answers and explanations

Answer to Question 1: e

- The answers are examined below:

a. C/kg:	Exposure dose	b. keV/μm:	Linear energy transfer
c. μSv/h:	Air dose rate	d. R:	Roentgens (old unit)
e. J/kg:	Absorbed dose, expressed in Gy		

Answer to Question 2: b

- Equivalent dose and effective dose are conceptual quantities that cannot be practically measured.
- Personal exposure dose is measured using a pocket dosimeter or glass badge.
- Linear energy transfer is not a dose. It indicates the ionizing capacity of radiation, and is called "radiation quality".

Answer to Question 3: a

- Beta rays, X-rays and gamma rays have low ionization density, and their radiation weighting factor is 1.
- The radiation weighting factor of neutrons varies with their energy and the factor for less than 10keV is 3 or less.
- Alpha rays have high ionization density, and their radiation weighting factor is 20.

Teaching support materials for advanced students

- Refer to the Educational Animation about Radiation (4 programs), published on the National Institute of Radiological Sciences website on September 20th and November 16th.
- Masahiro Fukushi: Radiation Metrology, Medical View Co., Ltd. Tokyo, 10-18, 2009

3. Effects of Radiation on Human Body

Unit name	3.1 Radiation Biology
Items related to core curriculum	• Be able to explain the mechanisms of cell death, as well as local and whole-body damage caused by radiation and its effects on genes and cells.
General objectives	• To learn the fundamentals of the effects of radiation on the human body
Extended objectives	• Be able to outline the biological effects of radiation.
Points to understand	• The difference in radiation sensitivity between normal cells and cancer cells • The reduction of adverse effects from radiation treatment has much in common with the alleviation of damage caused by radiation exposure accidents. • Nonspecific biological reactions to radiation are involved in the mechanisms that lead from DNA damage to carcinogenesis.
Essential teaching points	• The application of radiation treatment or IVR to patients with defective DNA repair proteins should be considered cautiously (cases with unacceptable adverse effects can turn into medical malpractice).
Keywords	Effects on genes, cells, and organisms; radiation damage; cell death; repair; mutation; relative biological effectiveness (RBE); effects on cancer cells; fractionation effect; hypoxic effect; local and whole-body radiation exposure; stochastic effect; deterministic effect
Reference tutorials	3

Outline

3.1.1 Radiation induces the excitation and electrolytic dissociation (ionization) of biological material, inflicting damage on DNA and other biological materials (Fig. 1)**.**

- When radiation hits an organism, some of that energy is absorbed and the rest passes through. As radiation passes through a substance, the orbital electrons of atoms near the path of the radiation are affected and excitation and ionization occur (see 2.1.1).
- Alpha particles and neutrons cause denser ionization along their ionization tracks than beta rays (high linear energy transfer [LET]).
- The principal target of the biological effects of radiation is DNA (Fig. 2).
- There is damage that occurs from the absorption by DNA and other substances of energy from radiation, and damage that is induced by water molecules and other substances that absorb energy. The former is called direct action, and the latter is called indirect action. The main indirect action is a result of radicals produced by interaction between water molecules and radiation (•HO, •H, hydrated electrons, and H_2O_2).
- Damage caused by low-LET radiation is mostly due to indirect action. Damage caused by high-LET radiation is mostly due to direct action.

3.1.2 The effects of radiation are modified by chemical substances.

- With low-LET radiation, biological effectiveness is increased 2.5-to-3 times higher in the presence of oxygen than when oxygen is not present.
- Cancer consists of hypoxic cells, which are the cause of its resistance to radiation.
- Substances like sulfhydryl compounds that eliminate free radicals (radical scavengers) have the effect of protecting cells against radiation.
- The radiosensitivity for cell death is enhanced by hypothermic treatment.

3.1.3 Damage from radiation is repaired, but the accumulation of non-repaired damage and incorrect repairs cause cell death and mutation.

- The cell cycle in cells with damaged DNA temporarily stops and DNA repairs are carried out.
- Cells with deficient proteins for the repair of DNA damage are highly sensitive to radiation (cell death and mutation).
- Apoptosis, the death of cells that remain damaged commit, works to suppress cancer when regarding the body as a whole.
- Apoptosis usually isn’t induced in cancer cells, and this is a cause of low radiosensitivity.

3.1.4 Biological effects occur as a result of radiation ionization and excitation and the repairs that occur in organisms.

- Biological effects are generally reduced under low dose-rate exposure (prolonged irradiation and fractionated radiation), but this effect under high-LET radiation is minimal (Fig. 3).
- Differences in the quality of radiation can be measured via relative biological effectiveness (RBE).

3.1.5 Mutation caused by radiation results in the stochastic effect and cell death results in the deterministic effect (Table 1)**.**

- In multistage models of carcinogenesis, carcinogenesis due to radiation acts as an initiator. Because malignant transformation must go through stages of promotion and progression, carcinogenesis due to radiation is thought to have a latency period (Fig. 4).
- A whole-body exposure to 2 or more Gy of X- or gamma-rays at one time leads to the deterministic effect, which is necessary for healing.
- There are great differences in the extent of damage to an individual depending on whether the same absorbed dose occurs through local exposure or through whole-body exposure.

Diagrams

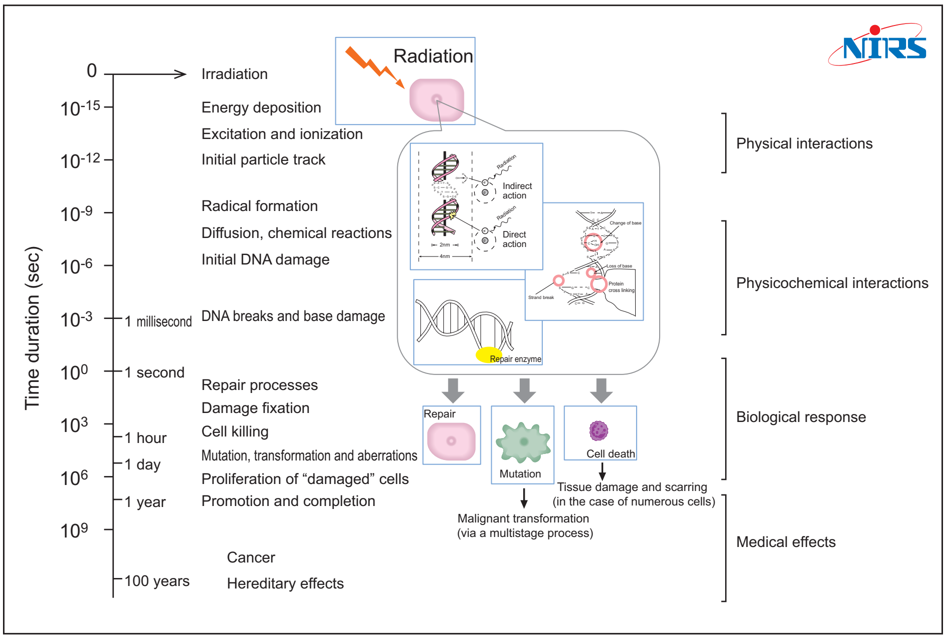


Fig. 1: The Process for Expressing the Biological Effects of Radiation
(chart revised according to UNSCEAR 2000 Report)

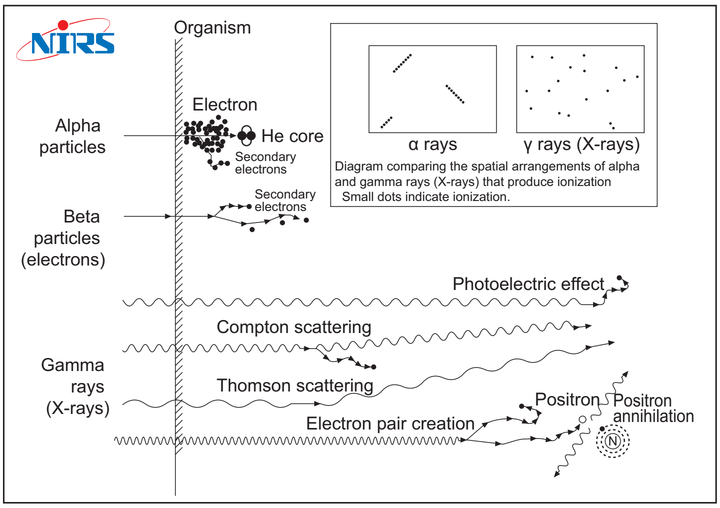


Fig. 2: Effects of Radiation on DNA
There is a large difference in the acition of alpha, beta and gamma rays (X-rays) to pass through an organism. Alpha particles have a very short range, beta particles can penetrate up to 1 cm at most, but gamma rays (X-rays) pass right through a human body.
Because the biological effectiveness of radiation varies according to LET, alpha particles produce a strong local biological effect. (Partially modified according to Fundamentals of Radiology [Kinpodo].)

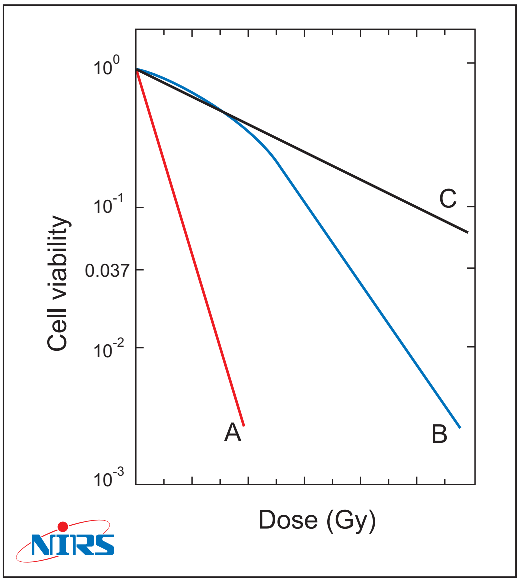


Fig. 3: Chart Showing Dose Survival Curves

- B represents low-LET irradiation and A represents high-LET irradiation.
- Heavy particle radiotherapy involves a high RBE in spite of hypoxia.
- B represents single-fraction irradiation and C represents fractionated irradiation.
- Hyperfractionated radiation therapy utilizes the slight differences in sensitivity and differences in resilience between normal tissue and tumor tissue.
- A represents cells with deficient repair capabilities and B represents normal tissues.
- The cells of patients with ataxia-telangiectasia have high radiosensitivity, therefore it is necessary to lower the dose used in radiation treatment.

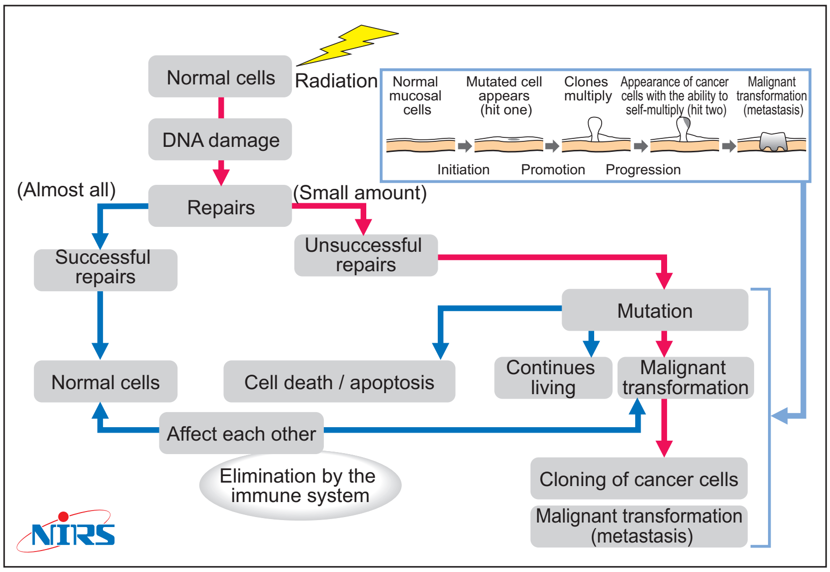


Fig. 4: Mechanisms for Carcinogenesis due to Radiation

Cancer-related genetic mutations occur due to radiation-induced DNA damage and ensuing incorrect repairs and the cells undergo malignant transformation. A latency period prior to the emergence of cancer is required as a result of the elimination of cells that fail to have their DNA damage repaired, cancer suppression and other defensive activities by surrounding normal cells and other complex activities that affect carcinogenic factors.

Table 1: The Effects of Radiation on the Human Body: Stochastic Effects and Deterministic Effects

Molecule	Cell		Tissue or organ			Individual	
Damage	Damage	Type	Clinical symptom	Category	Pathogenic mechanism (factor)	Dose-effect relationship	Dose-effect relationship
DNA damage	Mutation	Germ cell	Herediatary effect	Stochastic effect	Mutation of single cell	Rate of incidence; Background rate of incidence; Dose. No threshold assumed	Seriousness; Dose
		Somatic cell	Cancer				
	Cell death or cell degenera-tion	Germ cell	Sterility	Determin-istic effect	Cell death in multiple cells	Rate of incidence; 100%; 50%; 0%; Dose. Threshold present	Seriousness; Differences in sensitivity between exposed patients (a > b > c); (a); (b); (c); Threshold dose by which symptoms become clinically apparent (dose that affects 1% of people); Dose
		Somatic cell	Loss of function (hair loss, skin damage, acute radiation syndrome, etc.)				

Table 2 Estimates of excess relative risk (ERR) per Gy and 95% CI for major causes of death.

Cause of death	Excess relative risk per 1 Gy* Values in parentheses give the 95% confidence interval
All solid carcinomas	0.47 (0.38, 0.56)
Cancers of specific sites	
Esophagus	0.51 (0.11, 1.06)
Stomach	0.28 (0.14, 0.42)
Colon	0.54 (0.23,0.93)
Liver	0.36 (0.18, 0.58)
Gallbladder	0.45 (0.10, 0.90)
Lungs	0.63 (0.42, 0.88)
Breasts	1.60 (0.99, 2.37)
Bladder	1.12 (0.33, 2.26)
Ovaries	0.79 (0.07, 1.86)

* Excess relative risk (ERR) was estimated using the linear model, in which city, sex, age at exposure, and attained age were included in the background rates.

Source: Ozasa et al., Radiat. Res., 177, pp. 229-243 (2012)

Exercises

Question 1. Which of the following is not related to low-LET radiation?

a. The indirect effects of this radiation are greater than the direct effects.
b. The dose rate effect is remarkable.
c. On the whole, it has high relative biological effectiveness (RBE).
d. The oxygen effect is great.
e. The survival curve of normal cells due to irradiation shows a shouldered curve.

Question 2. Which of the following is not related to repairing radiation damage?

a. Fractionation effects
b. Chromosomal abnormalities
c. p53
d. Misonidazole
e. G1 arrest

Question 3. Which of the following is not related to the sensitivity of cancer cells to radiation?

a. Apoptosis
b. Differentiation and undifferentiation
c. Tumor size
d. Chromosome number
e. Inverse dose-rate effect

Exercise answers and explanations

Answer to Question 1: c

Relative biological effectiveness (RBE) is represented by the following formula:

RBE = (absorbed dose of the relevant radiation required for some reaction) / (absorbed dose of standard radiation required for some reaction)

For standard radiation, 200 kV of X-rays or Co-60 gamma rays are usually used. The RBE value will vary according to the type of effect, including acute radiation injury, carcinogenesis, genetic effects and cell death, as well as the state of the organism and the conditions of the irradiation. But, when the same effect and same dose are being compared, RBE is generally higher with high-LET radiation than with low-LET radiation.

Answer to Question 2: d

a. Recovery from sublethal damage is thought to be related to the effect per unit dose of fractionated irradiation or low dose-rate irradiation, unlike single-fraction high dose-rate irradiation.
b. Chromosomal abnormalities result from errors in the repairing of chromosomal damage.
c. p53 is a tumor suppressor gene involved with DNA damage checkpoints.
d. Misonidazole is a hypoxic cell sensitizer used in radiation treatment because it has an electron affinity as well as oxygen.
e. When DNA is damaged by radiation, the cell cycle is stopped at the G1 phase (G1 arrest) to buy time for carrying out damage repairs. Even so, if the damage is irreparable, there exists a mechanism for eliminating the cell through apoptosis.

Answer to Question 3: e

a. Apoptosis is usually not induced in cancer cells and this causes resistance to radiation.
b. Undifferentiated tumors have higher radiosensitivity than well-differentiated tumors.
c. As a tumor grows larger, the ratio of hypoxic cells inside increases and radiosensitivity decreases.

d. Many cancer cells exhibit abnormal chromosome numbers. As chromosomes increase, it becomes easier for radiation to hit them, which causes greater sensitivity.
e. Inverse dose-rate effect is a phenomenon rarely seen with high-LET irradiation. It is a phenomenon in which biological effectiveness increases more when the dose rate is low than when the dose rate is high.

Even in normal cells, an undifferentiated tissue with higher division potential leads to greater radiosensitivity. (Examples include intestinal epithelial cells, germ cells, and hematopoietic cells.)

Teaching support materials for advanced students

Kimura, Hiroshi, Hidenori Yonehara, Makoto Ikebuchi, Yosuke Ejima and Takehiro Nishidai. *Hōshasen kiso igaku* (Fundamentals of Radiology), 11th ed. (Tsutomu Sugahara, editor-in-chief. Takashi Aoyama and Ōtsura Niwa, editors). Tokyo: Konpodo, 2008.

Unit name	3.2 Effects of Radiation on Health
Items related to core curriculum	• Be able to explain the differences in radiosensitivity of various normal tissues. • Be able to explain the characteristics of the effects of radiation (acute effects and late effects) on the human body (including fetuses)
General objectives	• Study the basics of the effects of radiation on the human body.
Extended objectives	• Be able to outline the effects, the acute and late effects, of radiation on health
Points to understand	• The effects are different depending on the type of exposure. • The effects of acute exposure are larger than the effects of chronic exposure if the doses are same. • The LNT model • Acute radiation syndrome • Radiation carcinogenesis
Essential teaching points	• The LNT model • Concept of the dose-effect relationship of radiation carcinogenesis
Keywords	Organ-level effects, acute effects, late effects, carcinogenesis, effects to fetus, local exposure, whole-body exposure, differences according to dose
Reference tutorials	4, 5, 6, 7, 10, 13, 14, 15, 16

Outline

3.2.1 Types of Exposure

- The types of exposure can be categorized as external exposure and contamination. Contamination is divided into body surface contamination and internal contamination (internal exposure) (Fig. 1). (See 6.1 “Preparedness and Response” for details.)
- External exposure types are whole-body exposure and local exposure. Given the same radiation dose, the effects of whole-body exposure are larger (Fig. 2).
- Acute exposure in a shorter duration gives larger effects than chronic exposure in a longer duration, providing that the doses are same.
- Internal exposure continues over a long time while the radioactive materials inside the body decrease in its activity. (See 6.1 “Preparedness and Response” for details.)

3.2.2 Acute Effects

- In general, tissues are more radiosensitive if their cells divide more rapidly, have a greater proliferative capacity and are less-well differentiated (Bergonie-Tribondeau’s law).
- In case a person receives whole-body acute external exposure more than 1 Gy, radiation causes successive organ dysfunction, that is referred to as acute radiation syndrome. Such instances include cases without clinical manifestation if the radiation dose is small, but as the dose increases, hematopoietic system dysfunction, which has short cell life and has active regeneration by cell division, gastrointestinal system dysfunction and neurovascular system dysfunctions appear in order (Figs. 3-5). These damages appear in tissues and organs with high radiosensitivity.
- Typically, looking at the time course of acute radiation syndrome, a prodromal phase is followed by a latent phase and a critical phase, then leads to either recovery or death (Fig. 6).
- In the case of local exposure, damage naturally appears in organs in the volume exposed. The greater the volume exposed at the same dose, the greater the effect. This is a basic principle for studying the morbidities of radiotherapy.
- The skin, which covers the surface of the whole body, is easily damaged. As the dose increases, symptoms appear that include erythema, dry desquamation and moist desquamation. In general, these symptoms appear after several days have passed, but in some cases the initial skin erythema may appear immediately after exposure.

3.2.3 Late Effects

- "Late effects" refers to effects that appear after several weeks following exposure.
- Late effects appear in various organs throughout the body, depending on dose. —For example, lens of the eyes have relatively high sensitivity, and cause cataract by radiation.
- One particularly important type of late effect is carcinogenesis—that is, the induction of a malignant tumor. The minimum latency period until the tumor's development is about two years for leukemia and 5-10 years for most solid cancers. After that period, the incidence increases.
- It is generally thought that cancer induction is a stochastic effect with no threshold value and the incidence increases in accordance with increasing the dose. A model assuming linearity of incidence to dose, which is known as the linear non-threshold (LNT) model, is among proposed models. It should be noted that even with an exposure dose of 0, cancer may occur due to other factors (e.g. cigarette smoking or diet).
- According to ICRP, the lifetime probability of death by cancer would increase by almost 0.5 % per 100 mSv in case of low dose rate exposure.

3.2.4 Fetal Exposure

- Fetal exposure is a special type of exposure. Depending on the stage of pregnancy, fetal death, malformation or mental retardation may occur, but these are all deterministic effects. There is also an increase in cancer, which is a stochastic effect.
- When it comes to embryonic/fetal death, sensitivity in the implantation phase (nine days from fertilization) is high, with a threshold value of about 100 mGy. For malformation, sensitivity during the organogenesis period (2–8 weeks) is high, with a threshold value of about 100 mGy. For severe mental retardation, sensitivity during the fetal period from the 8th to the 15th week is high, with a threshold dose of at least 300 mGy. (See 5.4.)

Diagrams

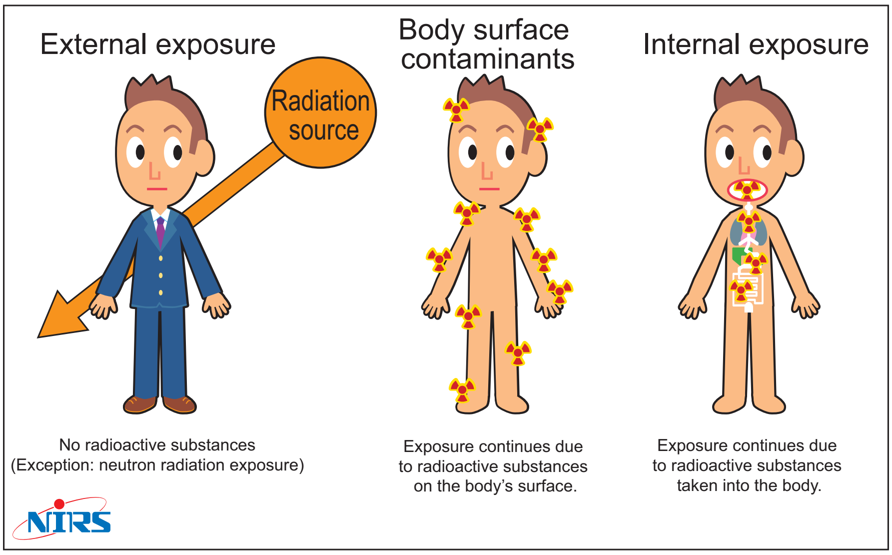


Fig. 1 Types of exposure

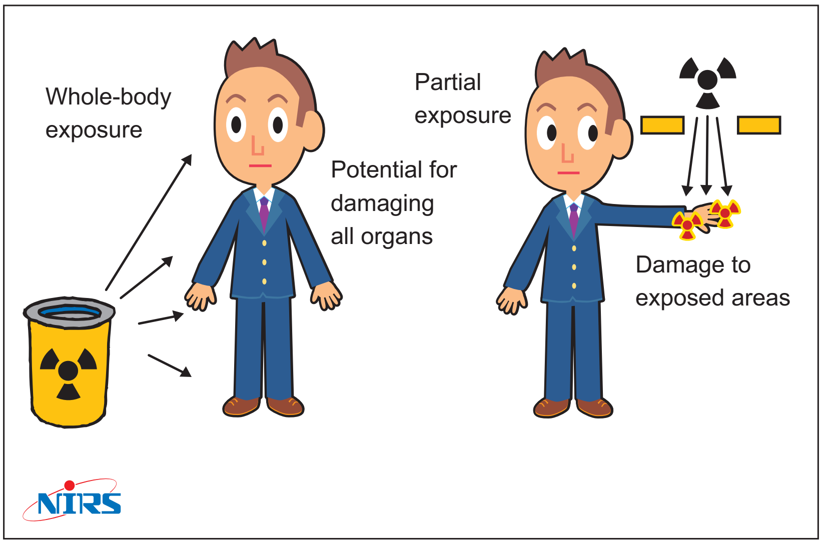


Fig. 2 Whole-body exposure and local exposure

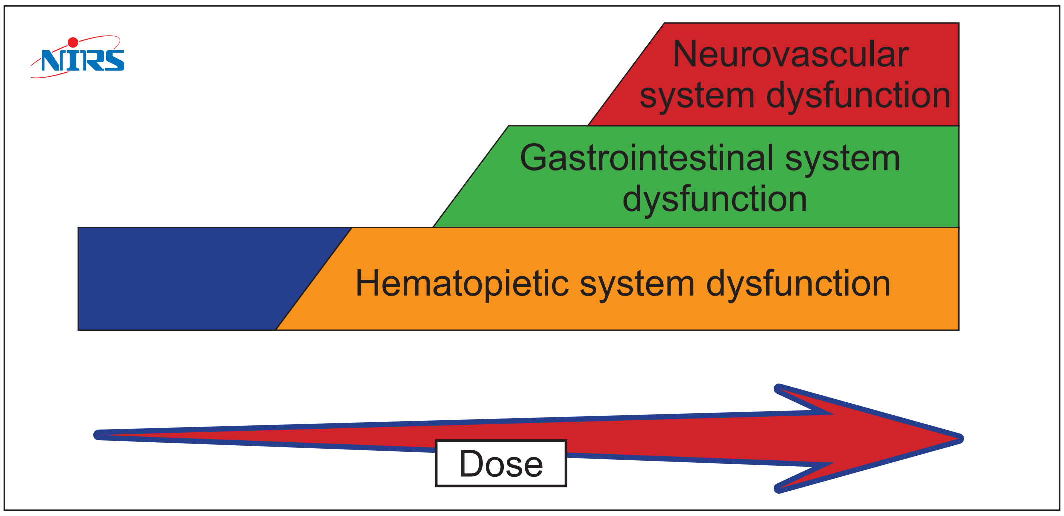


Fig. 3 Radiation Doses and Symptoms of Acute Radiation Syndrome

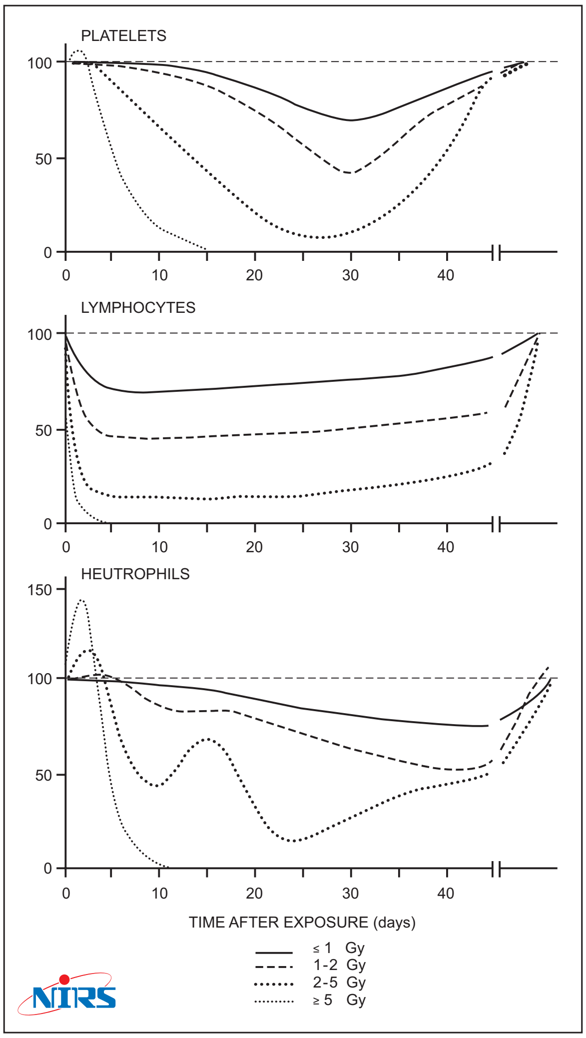


Fig. 4 Changes in Blood Cell Count
(source: UNSCEAR 1988 Report, Annex G)

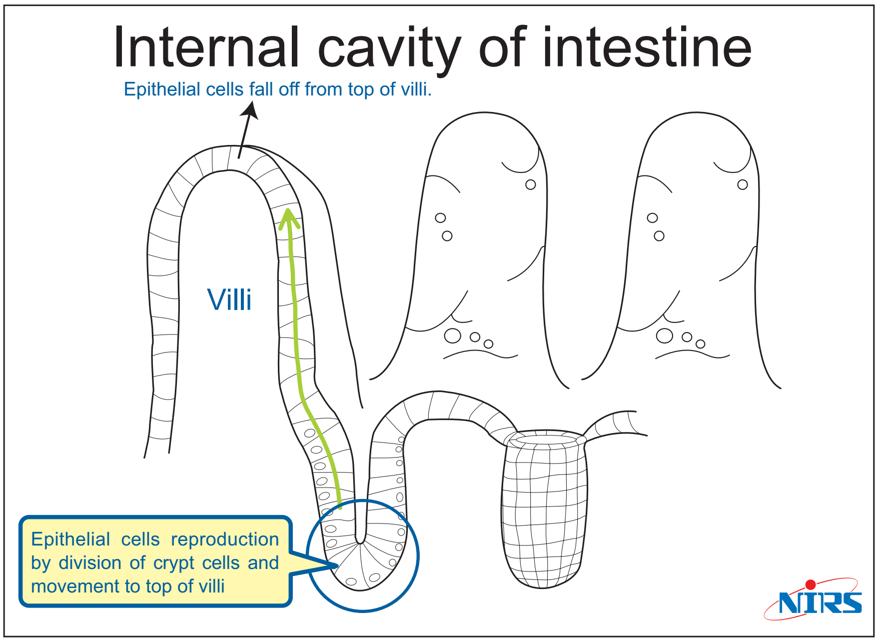


Fig. 5: Structure of inner surface of small intestine
(adopted from UNSCEAR 1988)

Table 1: Thresholds for Tissue Reactions (radiation doses that cause a 1% reaction)

Projected threshold estimates of the acute absorbed doses for 1% incidences of morbidity and mortality involving adult human organs and tissues after whole body gamma ray exposures.

Effect	Organ/tissue	Time to develop effect	Absorbed dose (Gy)[e]
Morbidity:			1% Incidence
Temporary sterility	Testes	3–9 weeks	~0.1[a,b]
Permanent sterility	Testes	3 weeks	~6[a,b]
Permanent sterility	Ovaries	< 1 week	~3[a,b]
Depression of blood-forming process	Bone marrow	3–7 weeks	~0.5[a,b]
Main phase of skin reddening	Skin (large areas)	1–4 weeks	< 3~6[b]
Skin burns	Skin (large areas)	2–3 weeks	5~10[b]
Temporary hair loss	Skin	2–3 weeks	~4[b]
Cataracts (visual impairment)	Eyes	Several years	~1.5[a,c]
Mortality:			
Bone marrow syndrome:			
without medical care	Bone marrow	30–60 days	~1[b]
with good medical care	Bone marrow	30–60 days	2~3[b,d]
Gastro-intestinal syndrome:			
without medical care	Small intestine	6–9 days	~6[d]
with good medical care	Small intestine	6–9 days	> 6[b,c,d]
Pneumonitis	Lung	1–7 months	6[b,c,d]

a) ICRP (1984)
b) UNSCEAR (1988)
c) Edwards and Lloyd (1996)
d) Scott and Hahn (1989), Scott (1993)
e) Most values rounded to the nearest Gy; ranges indicate area dependence for skin and differing medical support for bone marrow.

(Source: ICRP Publication 103 (The 2007 Recommendations of the International Commission on Radiological Protection))

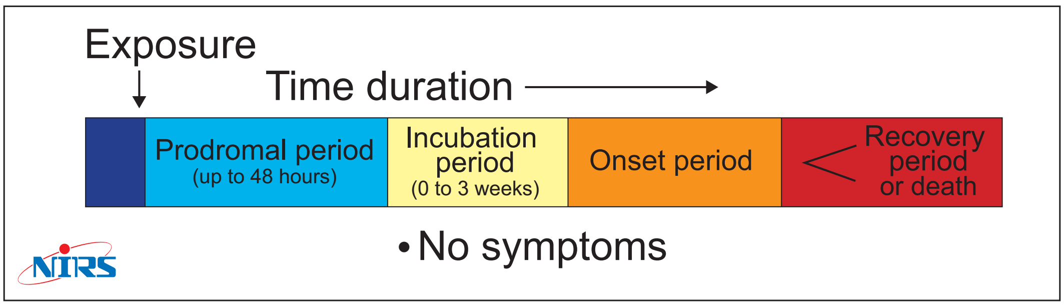


Fig. 6: Stages of Acute Radiation Syndrome

Exercises

Question 1. Which of the following is not a characteristic of external radiation exposure by low-energy gamma rays without contamination?

a. The radiation source is outside the body.
b. The duration of the radiation exposure can be short or long.
c. The distribution of the absorbed dose depends on the energy and direction of the radiation.
d. Nearby medical staffs do not receive exposure.
e. Measurement with a whole body counter gives an abnormal value.

Question 2. Which of the following is not a part of acute radiation syndrome?

a. Gastrointestinal system dysfunction
b. Central nervous system dysfunction
c. Bone marrow injury
d. Skin injury
e. Bone injury

Question 3. Which of the following is a characteristic of radiation carcinogenesis for solid cancer?

a. It is believed to be a deterministic effect.
b. Onset takes several years or more to occur.
c. Once developed, it can be distinguished via tissue samples whether the cause is radiation or something else.
d. Incidence decrease as radiation doses increase.
e. Children have about the same level of sensitivity as adults.

Exercise answers and explanations

Answer to Question 1: e

External exposure is exposure from radiation that comes from a radiation source outside the body. It is classified as acute or chronic exposure depending on the duration of exposure. With the exception of neutron or other unusual radiation, general exposure does not produce radioactive materials inside the body, so there is no secondary radiation exposure by the radiation emitted from the patient.

Answer to Question 2: e

The typical symptoms of acute radiation syndrome include bone marrow injury, gastrointestinal system dysfunction, and neurovascular system dysfunction. Skin injuries and lung injuries have a significant effect on prognosis

Answer to Question 3: b

Radiation carcinogenesis is regarded as a stochastic effect with no threshold value. An increase in pediatric thyroid cancer can be seen after a few years, but the incidence of most solid cancers increases after about ten years. At present, there is no method to diagnose whether the cancer was caused by radiation or not. Children are thought to be two-to-three times more sensitive than adults.

Teaching support materials for advanced students

- ICRP. *ICRP Publication* 103: The 2007 Recommendations of the International Commission on Radiological Protection.
- Hall, E.J. *Radiobiology for the Radiologist*, 7th Ed. Philadelphia, PA, USA: Lippincott Williams & Wilkins, 2011.
- UNSCEAR: *UNSCEAR 1988 Report to the General Assembly, with Annexes*. Vienna, Austria: UNSCEAR, 1988.

4. Medical Applications of Radiation

Unit Name	4a.1 Principles, Practice and Adverse Effects in Radiodiagnosis
Items related to core curriculum	• Be able to explain the principles of X-ray, CT, MRI and nuclear medicine examinations. Be able to explain adverse effects and impairment caused by radiodiagnosis. • Be able to summarize therapies using radiation contrast methods. • Be able to explain the principles of imaging for X-ray (plain and contrast), CT, MRI and nuclear medicine examinations.
General objectives	• Study the basics of using radiation for diagnosis.
Extended objectives	• Be able to broadly explain the principles of X-ray diagnosis, based on the characteristics of each diagnostic modality. Ability to broadly explain the potential side effects and impairment caused by radiodiagnosis.
Points to understand	• Various modalities are used in diagnostic imaging, and some of them do not use ionizing radiation. • Ionizing radiation has adverse effects, the mitigation of which must be considered in medical action. • Children are physically smaller and highly radiosensitive, therefore special care is required in examination selection and methods.
Essential teaching points	• Details of adverse effects from examinations using ionizing radiation (contrast media) • Matters that must be considered to reduce medical exposure.
Keywords	Principles (absorption of X-rays), characteristics of each diagnostic modality (plain X-ray photography and radioscopy, X-ray CT, interventional radiology), non-X-ray diagnostic imaging (MRI, US), details of radiodiagnosis of each organ system and each disease, potential for adverse effect from radiodiagnosis (including contrast media), CTDI and other dose indices
Reference tutorials	6, 8, 9, 10, 12, 14

Outline

4a.1.1 Instruments used for diagnostic imaging and how these are applicable to diseases

- In medical treatment, diagnostic methods that present the internal state of the body as images are used for conditions other than functional diseases such as diabetes, essential hypertension and mental disorders. These methods are called diagnostic imaging. Methods used in diagnostic imaging include plain X-rays, radioscopy, CT, MRI, ultrasound, and nuclear medicine. As Table 1 shows, each has its own characteristics and applications and they are each used as they best suit the circumstances for diagnosis. Diagnostic imaging devices can be divided between those that use radiation and those that do not. Those that use radiation are plain X-rays, radioscopy, CT and nuclear medicine examinations. (4a.2 Nuclear Medicine is a separate item)
  In diagnostic imaging, contrast media may be administered from outside the body to perform examinations. Contrast examinations using X-rays utilize iodine and barium preparations. This examination method makes use of the high radiation absorption of iodine and barium. In angiography and CT, iodine preparation is injected into a blood vessel and its distribution in blood vessels and organs is observed to obtain diagnostic information. Adverse effects such as heat sensitivity, vomiting or rash may occur. There are rare cases of shock, potentially leading to death, therefore care is required when injecting contrast media.
- CT and MRI are the methods that present the interior of the body in the most detail. Fig. 1 shows a CT image, a T1-weighted image and a T2-weighted image side by side. The characteristics of each can be observed by examining the eye, cranial bone, and superficial fatty tissue. An MRI acquires cross-sections along various axes and provides better contrast than a CT, but has the drawbacks of being difficult to discern bones or calcification and taking a long time for examination, consequently limiting its capture of images to a short scope. Metal objects within the body can also prevent imaging. Currently, the only contraindication for CT use is that some defibrillators and pacemakers embedded in the body can malfunction when irradiated. CT is essential for general imaging tests and as an examination method for the head and internal organs in emergency fields.

Lung cancer checkup by low-dose CT is spreading in Japan. Detection of cancer nodules that were overlooked with simple chest X-ray imaging has improved. Exposure is high when the normal settings for detailed examination are used, so the rule is to examine at a low dose. A large-scale trial was conducted in the USA on 50,000 people at high risk of lung cancer. It confirmed that low-dose CT lung examination reduced the fatality rate. (See reference below)

- Shortcomings of ultrasound include it being difficult to discern the condition of deep tissue in the body and air in the intestinal tract can block sound. But, it is widely used because it is simple to maneuver the instrument and there is no exposure to radiation, so it is often the first method applied for examination of abdominal organs. It is also possible to examine inside the cranium of newborns.

Reference

The National Lung Screening Trial Research Team: Reduced Lung-Cancer Mortality with Low-Dose Computed Tomographic Screening,N. Engl. J. Med., 2011; 365:395-409.

4a.1.2 The mechanism of CT

- In a CT scanner, a radiation tube and a radiation detector face each other, rotating around the body axis to acquire data on position and radiation absorption. A computer is used to calculate cross-sectional images of the body from these data. Compared to plain radiography, the amount of data collected on the body is greater by an order of magnitude, but the amount of exposure is also high.
- The development and history of CT instruments are presented in Fig. 2. At first, they could only capture an image of one section at a time. Once one image had been captured, the gantry was moved to take footage of the next position. Scanning proceeded by moving a slowly and slightly along the axis of the body, therefore it took a long time to complete the examination. It is now possible to capture a multi-section image in a shorter time by moving the gantry during scanning and adopting a helical motion. Also, detectors are arrayed in multiple rows, where there was only one row in the first instruments, so image capture is faster. This type of device is called Multi-Detector row Computed Tomography (MDCT). The main factors in making MDCT practically useful were that detectors were made more compact, computer processing accelerated, and image calculation algorithms improved. Cone beam CT instruments have been developed as advanced types of MDCT, with arrays of 256 or more rows of detectors, so that they can take images of a given area with only one rotation. Examination time is very short, allowing it to track sequential changes, giving it the name 4D CT. However, the amount of exposure increases with prolonged use, therefore examination protocols must be considered with great care.
- MDCT and cone beam CT have increased the amount of exposure somewhat compared to a single-section CT instrument, but they make it easy to obtain three-dimensional information on organs, blood vessels and other tissues. The development of these instruments has greatly reduced examination time and improved diagnostic precision.

4a.1.3 Measurement of CT exposure

- CT involves high exposure, so correct dose estimation is required. As a general rule, CT instrument dose estimation is performed using an acrylic phantom and a CT ionization chamber. It is not possible to measure exposure directly during an examination, so the Computer Tomography Dose Index (CTDI) is used. It simulates the dose from phantom imaging data. CTDI is an assessment of one rotation on one slice. The unit is Gy. There are a number of options for CTDI, and CTDIw is the average value for the phantom. CTDIvol compensates for the gaps and overlaps in helical scans. Recent CT instruments report dosage by displaying CTDIvol when a scan is finished. Also, DLP (Dose Length Product) is used as an assessment value, reflecting the fact that multi-section CT imaging is generally used. The DLP value is produced by multiplying the CTDIvol by the length along the body axis. The unit is Gy cm.

- Table 2 provides approximate calculations of exposure from standard CT instruments.
  Extract from 2005 Pediatric CT Guidelines (Japanese Society of Radiological Technology, Japan Radiological Society, Japan Society of Pediatric Radiology).
  These are values for 2005, but exposure dose is falling yearly as CT instruments are developed to that end.

  (Reference) Radiation exposure guidelines compiled by the Japan Association of Radiological Technologists, 2006
  http://www.jart.jp/guideline/

4a.1.4 How to reduce CT exposure dose

- Looking at a cross section of the human body, it is not circular. The head is an oval, with the longer axis from front to back, while the torso is an oval with the long axis running left-right. The radiation dose used for CT can be reduced in areas where the body is thinner, without degrading image quality, so computer control (CT-AEC) is generally used to reduce the dose in thinner parts of the body. Individual companies apply their own techniques to reduce noise and exposure. The newer available instruments should be used to reduce exposure. The newer the instrument, the more improvements for exposure reduction it will employ, the higher the image quality will be, and the better the image quality that can be achieved with reduced exposure. Other necessary ways to reduce exposure are, in the same way as for other examinations that use radiation, to get further away from the source, to block radiation with protective clothing and screens etc., to reduce the duration of irradiation, to objectively measure or estimate the amount of exposure to the patient and the technician and to keep the radiation equipment properly maintained.
- Children are highly radiosensitive, therefore special care is required. The range of pediatric diseases is limited and it is necessary to consider the conditions necessary for diagnosis when performing the examination. In general, dose and image quality are directly proportional, but it is unacceptable to apply high doses to obtain a needlessly detailed image at the cost of needless exposure. If a CT is performed on a child at adult settings, that child would be exposed to excessive radiation. The Japan Radiological Society publishes a pediatric CT protocol, which must be checked before performing an examination. The most powerful method for reducing exposure is to avoid performing pointless examinations. For children, in particular, you must think carefully about whether the CT examination is really necessary.
- CT during pregnancy is another problem. The standard up to the 1980s was the “10 days rule”, by which examinations using radiation were to be performed within 10 days of the start of menstruation. That standard was withdrawn when it became clear that it had no scientific basis. As of 2012, there is no evidence of fetal problems from doses of up to 100mGy, and a single abdominal CT does not reach that dose. If a pregnancy is discovered after an abdominal CT has been performed, a considerable proportion of women opted for an abortion. The doctor has a serious responsibility to consult with the patient.

  Reference URL
  Pediatric CT Guidelines, 2005
  http://nv-med.mtpro.jp/jsrt/pdf/2005/61_4/493.pdf

4a.1.5 Application of pediatric cranial CT examination

- The following is the recommendation from the Committee on Clinical Policies and Research, American Academy of Family Physicians, Committee on Quality Improvement and American Academy of Pediatrics Commission on the absolute applicability of pediatric head CT examination on an infant of two years or younger, who has a previous injury and is responsive. Remember that even if the child’s condition is better than that described below, a CT may be required in some cases.

a. Depressed
b. Exhibiting localized neurological symptoms. (Paralysis, abnormal ocular motion, etc.)
c. Signs of cranial fracture
d. Convulsions
e. Restlessness, irritability
f. Bulging anterior fontanel
g. Vomiting that continues for five or more times, or for six hours or longer
h. Impaired consciousness for one minute or longer

- Trauma may be caused by high-energy or low-energy forces. Cases such as falling from some height or being run over by a car are high-energy injuries. In such injuries, considerable force may have been applied to the head or internal organs and it is appropriate to make a detailed examination by means such as CT even if there is no clear injury or surface impairment. Falling on the floor, a kind of accident commonly seen in infants, is a low-energy injury. There are exceptions where the location of the impact is unfavorable, but it is commonly unnecessary to conduct a detailed examination in case of low-energy injuries.

Reference

Schutzman SA, Barnes P, Duhaime AC, et al: *Evaluation and Management of Children Younger Than Two Years Old With Apparently Minor Head Trauma. Proposed Guidelines*. Pediatrics 2001; 107:5 983-993.

4a.1.6 The nature of interventional radiology (IVR) and exposure involved

- Interventional Radiology (IVR) is a therapeutic method that uses technique of radiodiagnosis. Before IVR appeared, treatment of a coronary stenosis, for example, required open chest surgery, placing a significant strain on the patient. With the advent of IVR, it became possible to insert a catheter through a blood vessel in the hand or foot, greatly reducing the strain on the patient. IVR may use CT, ultrasound, or MRI instruments, but it is common to use a television X-ray instrument to operate under radioscopy. Consequently, this method can easily involve high exposure. There is no way harm from radiation applied for a CT examination would manifest itself in a visible form, but such harm is reported from IVR.

- Exposure dose may be particularly high in treatment within the heart or related blood vessels under radioscopy. Such treatments include coronary angioplasty and ablation of arrhythmia. Manipulation under radioscopy takes a long time, so exposure can easily reach high levels. This exposure is a problem not just for the patient, but also for the surgeon with hands exposed in the radioscopy area. Reports of erythema and hair loss are not uncommon. Ulceration can even occur in extreme cases.
- With increasing reports of harm, related associations prepared guidelines for the prevention of harm in 2004. The guidelines consist of patient informed consent, the setting of target exposure values, the setting of instrument dose rates and explanations to patients if the impact dose for skin damage is exceeded. Doctors performing IVR must read these guidelines thoroughly.

Reference

Guidelines for the Prevention of Skin Damage Due to Radiation Associated with IVR, 2004:
URL: http://www.fujita-hu.ac.jp/~ssuzuki/bougo/book/ivr.pdf
Reference URL: http://www.jstage.jst.go.jp/article/jjrt/64/4/473/_pdf/-char/ja/

Diagrams

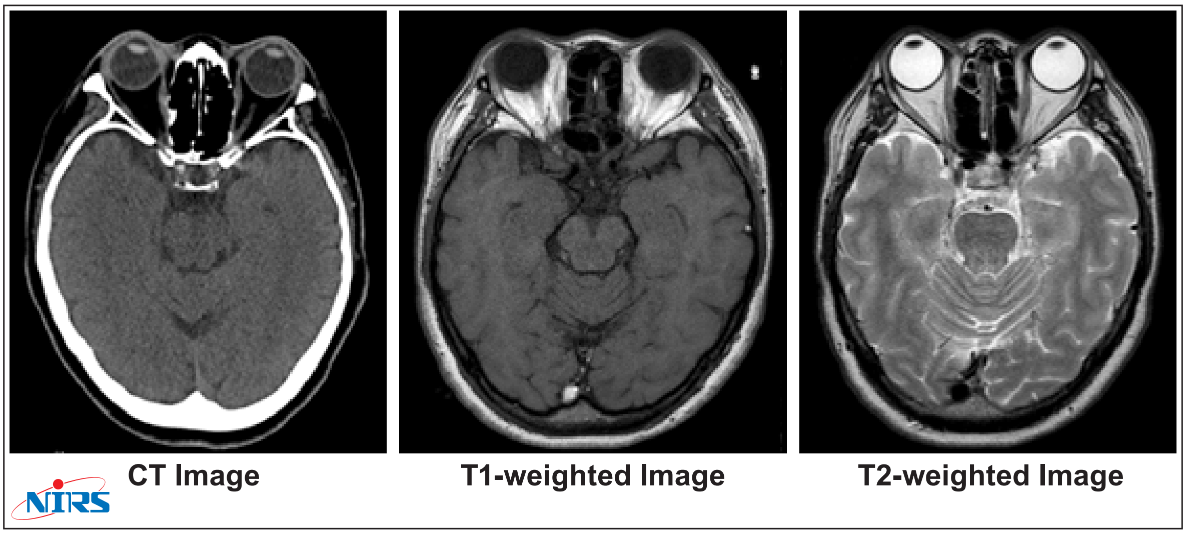


Fig. 1 Comparison of cranial CT and MRI imaging

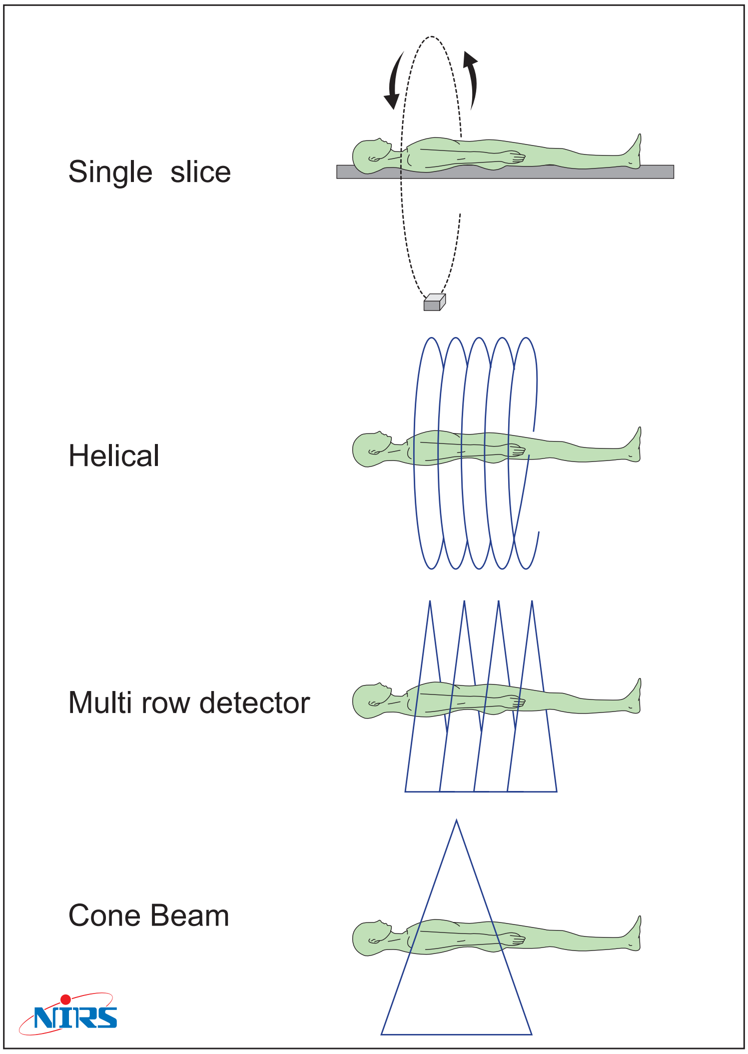


Fig. 2 Histry and development of CT instruments

Table 1 Characteristics of each diagnostic modality

	Plain X-ray, radioscopy	CT	MRI	Ultrasound
Principles	• X-rays that have passed through the body are captured by film, or detectors are used to display them on a monitor.	• The radiation tube and detectors are rotated about the center of the body, to capture the image. A computer creates the cross-sectional image from the data obtained. • Only cross-sectional images are obtained.	• In this examination method, hydrogen nuclei in a strong magnetic field are excited by external electromagnetic waves and the electromagnetic waves emitted when the excitation is released (relaxed) are measured to graphically visualize conditions in the body. • Images of various directions are obtained.	• High-frequency sound is emitted into the body from the surface and the reflected waves returning from the interior are measured to learn the state within the body.
Equipment	• The instrument is simple, but a special room is required to prevent radiation from leaking outside.	• A special room is required to prevent radiation from leaking outside. • There is a computer for calculation operations and a rotating gantry, so a large room is required .	• A room is required that can prevent leakage of electromagnetic waves. • There is refrigeration equipment to preserve extremely low temperatures and large magnets, so a large room is required.	• No special room is required.
Exposure dose	Low for radiography. Various for radioscopy.	High	None	None
Contrast media	Barium (gastrointestinal). Iodine preparation (vascular)	Iodine preparation	Gd (gadolinium) preparation	Microbubble (extremely small air bubbles)
Applicable position	Whole body	Whole body	Whole body	Whole body, skin
Defects	• Unable to obtain detailed information about internal organs.	• Image quality is rather poor for parts surrounded by bone, such as the spine.	• Image quality is poor for organs that move with respiration, such as lungs. • Unable to depict bones and calcification. • Long examination time.	• Unable to depict bone tissue, lungs, deep parts of body, and GI tract.
Applicable diseases	• Valuable for diagnosis of bone diseases. • Used, in combination with contrast media, in the diagnosis of GI tract and vascular diseases. • Used in interventional radiology through X-ray radioscopy.	• Essential for the diagnosis of disease in internal organs. • IVR	• Essential for the diagnosis of disease in soft tissue. • Particularly effective for cranium and spine, where surrounded by bone. • IVR	• Vascular disease Abdominal organs Skin lesions • IVR
Main adverse effects	Burns and hair loss in IVR.	Burns and hair loss due to prolonged CT examinations, such as cerebral circulation examinations.	Burns due to electric current abnormalities and internal metal objects.	Diagnostic ultrasound instruments cause no adverse effects.

Table 2 Exposure dose in various condition on CT

Scan conditions								
		kV	mA	mAs	Beam width	Pitch factor	Effective dose, male [mSv]	Effective dose, female [mSv]
Chest	SSCT	120	70	70	5	1.5	1.5	1.8
Child	MDCT	120	50	50	10	1.5	2.1	2.5
Chest	SSCT	120	40	40	5	1.5	1.3	1.4
Infant	MDCT	120	30	30	10	0.8 (0.75)	3.4	3.9
Abdomen	SSCT	120	100	100	5	1.5	4.6	5.7
Child	MDCT	120	80	80	10	1.5	7	8.7
Abdomen	SSCT	120	60	60	5	1.5	2.9	4
Infant	MDCT	120	50	50	10	0.8 (0.75)	8.8	11.9

SSCT: Hispeed Advantage, GE...MDCT: Light Speed Qx/I, GE
0.63 times when photographing at 100kV.
Child body weights: 27-36 kg, infant weights: 4-5.9 kg

Exercises

Question 1. Parents heard a bump in the kitchen, ran to the scene and found their 2-year-old child on the floor. The child appeared to have fallen from a table around 1m high.

- The child was initially somewhat dazed, but quickly returned to normal. The parents were worried and took the child to a hospital.
- Facial color is normal. There is what appears to be grazing on the head. There is no vomiting. There are no neurological abnormalities. What should the doctor do?
  - a. Take a simple X-ray of the head. Send the patient home if there are no problems.
  - b. Perform a cranial CT.
  - c. Perform cranial MRI imaging.
  - d. Send the child home for continued observation there.
  - e. Hospitalize for continued observation.

Question 2. Woman aged 29. She was in a car involved in an accident and thrown from the vehicle. She has pain in the upper abdomen. There are no broken bones. Consciousness is normal. She will begin menstruation shortly, but has not started yet. What should be the sequence of examinations?

- a. Abdominal ultrasound examination → Abdominal CT
- b. Abdominal ultrasound examination → Abdominal X-ray Perform an abdominal CT after menstruation commences.
- c. Only perform an abdominal ultrasound examination, then perform an abdominal X-ray and CT after menstruation commences.
- d. Abdominal X-ray → Abdominal CT
- e. Abdominal CT only

Question 3. A 3-year-old child was brought to a pediatric outpatient clinic with the main complaint being a lack of energy. On examination, the child had many bruises.

There were also marks that appeared to have been left by burns. There is also poor development and joint deformation. Facial expression is in the normal range. What should the doctor examine first?

- a. Schedule a bone scintigraphy.
- b. Take plain X-rays of the whole body.
- c. Perform a whole-body CT.
- d. Perform a stained sample examination.
- e. Cranial MRI

Exercise answers and explanations

Answer to Question 1: b

- According to the Committee on Clinical Policies and Research, American Academy of Family Physicians, Committee on Quality Improvement and American Academy of Pediatrics Commission, a CT is appropriate in cases of a fall from 1m or more accompanied by impaired consciousness. The situation corresponds to a high-energy injury from falling from a high place. In a simple fall with no broken bones or other external injuries, no impaired consciousness, no vomiting and no neurological abnormality, a CT is not appropriate. In this case, it is necessary to explain to the parents about what they should look for in observation after returning home (vomiting, impaired consciousness, paralysis).
- MRI is superior as a pediatric cranial examination method, because it involves no radiation exposure, but it does require a long period of immobility.

A number of accidents have been reported, due to the anesthesia used to provide immobility. Consequently, it is undesirable except in cases where it is completely impossible to use CT. Additionally, an MRI will not show broken bones.

(Reference)
Committee on Quality Improvement, American Academy of Pediatrics. Commission on Clinical Policies and Research, American Academy of Family Physicians. *Pediatrics: The management of minor closed head injury in children*. 1999 Dec;104(6):1407-15.

Answer to Question 2: a

- If it is judged that there is no need to perform an emergency CT, it is certainly not necessary to do so, but if a CT is judged to be necessary, perform it regardless of menstruation (pregnancy). The 10 days rule (radiation-related examinations should be performed within 10 days of the start of menstruation) existed in the 1960s and '70s, but it has become clear there is no scientific basis for the rule.
- If there is suspicion of internal injury with no laceration on the surface of the abdomen, the general rule is to start with an ultrasound examination, which uses no radiation exposure. In the case of simple abdominal pain, X-ray radiography may be worthwhile, but it takes time. In an acute situation it may be preferable to skip the X-ray and perform an abdominal CT.

(Reference)
Current Role of Emergency US in Patients with Major Trauma. RadioGraphics, 2008; 28:225-244.

Answer to Question 3: b

Traces of multiple fractures are important evidence of an abused child. Bone deformation could be caused by a congenital condition, but X-rays of the skeleton are sufficient to judge whether deformation is the result of congenital skeletal abnormality or the effects of past fractures caused by abuse. It is easy to diagnose a skull fracture with CT, but in long bones, it is difficult to identify fine fractures. With bone scintigraphy, it is very simple to identify past bone fractures in the whole body, but it is not generally used. If bone scintigraphy indicates fractures in the body as a whole, it leads as a result to X-ray examination of the whole body, with resulting excessive exposure.

(Reference)
From the Archives of the AFIP. *Child Abuse: Radiologic-Pathologic Correlation*, RadioGraphics, 2003; 23:811-845.

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- Necessary Radiological Protection Knowledge for Practicing Doctors, Yasuo Yoshizawa, Nikkei Medical (not for sale), Tokyo, 1990
- *Encyclopedia of Atomic Power*, ATOMICA
  http://www.rist.or.jp/atomica/database.php? Frame=./data/bun_index.html

Unit Name	4a.2 Principles, Practice and Adverse Effects in Diagnostic Nuclear Medicine
Items related to core curriculum	• Be able to explain the principles of diagnostic nuclear medicine. • Be able to explain adverse effects and radiation exposure caused by diagnostic nuclear medicine.
General objectives	• Study the basics of using radiation for diagnosis.
Extended objectives	• Be able to broadly explain principles of diagnostic nuclear medicine, characteristics of radiopharmaceuticals, characteristics of each modality, and dose estimation. • Be able to broadly explain potential adverse effects and radiation exposure caused by diagnostic nuclear medicine.
Points to understand	• The differences between nuclear medicine diagnosis and diagnostic imaging using X-rays. • Characteristics of radiation exposure in diagnostic nuclear medicine, and the principles of dose estimation (the medical internal radiation dose (MIRD) method.
Essential teaching points	• Nuclear medicine examination is accompanied by administration of radiopharmaceuticals into the body. • Nuclear medicine examination causes mainly internal radiation exposure.
Keywords	Gamma ray, positron, single photon emission computed tomography (SPECT), positron emission tomography (PET), positron emission tomography-computed tomography (PET/CT), attenuation correction, radiopharmaceuticals, physical half-life, biological half-life, effective half-life, internal radiation exposure, medical internal radiation dose (MIRD) method
Reference tutorials	8, 9, 10, 12

Outline

4a.2.1 Principles and characteristics of nuclear medicine examination (Fig. 1)

- Nuclear medicine examination requires administration of radiopharmaceuticals into the body.
- Radiation emitted by a radiopharmaceutical distributed within the body is detected and converted to images.
- Since administered radiopharmaceutical circulates within the body, whole-body can be evaluated after a single administration of the radiopharmaceutical.
- Since this is a highly sensitive examination, the amount of radiopharmaceutical administered is very low compared to contrast media in CT/MRI, and there are no pharmacological effects.

4a.2.2 Gamma camera imaging and positron emission tomography

- Gamma camera imaging: A gamma camera is used for the imaging of the dynamics and distribution of a radiopharmaceutical that is labeled with gamma ray-emitting radionuclide. There are two kinds of imaging methods, planar imaging (Fig. 2) and SPECT (single-photon emission computed tomography, Fig. 3).
- PET (positron emission tomography, Fig. 4): PET can produce tomographic images by detecting the pair of annihilation radiation rays emitted when a positron is annihilated, and can evaluate the dynamics and distribution of radiopharmaceuticals labeled with positron-emitting radionuclides.
- PET/CT (Fig. 5): CT and PET instruments are installed as single equipment. PET data acquisition is conducted after CT imaging.

4a.2.3 Radiopharmaceuticals

- These are pharmaceuticals that accumulate selectively in specific lesions or organs, or have characteristics that reflect various physiological functions, and are labeled with radioisotopes. Gamma camera imaging uses radiopharmaceuticals labeled with gamma ray-emitting radionuclides and PET uses the ones labeled with positron-emitting radionuclides.
- Each radionuclide has its own specific physical half-life and energy (Table 1, Table 2). Among them, I-131 emits short-ranged beta rays (β^-) as well as gamma rays, so it is used for internal radiotherapy as well as for diagnostic nuclear medicine.

- Many radiopharmaceuticals are available for the assessment of diverse physiological functions and pathological conditions, and appropriate one should be selected for the purpose. Administered radiopharmaceuticals exhibit dynamics that reflect their properties and radioactivity within the body is reduced according to effective half-life (Teff), which is determined by the combination of physical half-life (Tp) reflecting the physical decay of the radionuclide and biological half-life (Tb) reflecting the metabolism and excretion of the radiopharmaceutical (1/Teff=1/Tp+1/Tb).

4a.2.4 Adverse effects and radiation exposure caused by diagnostic nuclear medicine.

- Since the amount of administered dose as a drug is very small, no pharmacological effects occur and the probability of adverse effects is extremely low. According to the 2009 Survey Report on Side Effects (Kaku Igaku Vol. 48, No.1, pp29-41, 2011), only 12 cases of adverse effects were reported (0.0011%) among 1,044,677 administrations of radiopharmaceuticals.
- Radiation exposure of a subject receiving nuclear medicine examinations is mainly come from internal radiation exposure due to the administration of radiopharmaceuticals.
- The medical internal radiation dose (MIRD) method (Fig. 6) is used for the assessment of the internal radiation exposure associated with the administration of radiopharmaceuticals within the body.
- The exposure dose from a nuclear medicine examination varies with the content of the examination, but whole-body exposure from one examination is estimated to range from 0.5 to 15 mSv.
- For attenuation correction in PET examination and in PET/CT examination, the corresponding external source or X-ray CT is used and cause external radiation exposure. The CT in PET/CT examination, in particular, has a widely variable radiation exposure dose, depending on the purpose (attenuation correction only ~ high-precision diagnosis), so it is very important to set CT imaging parameters suitable for the purpose.
- For children, caution is necessary to optimize the administered dose and avoid excessive administration, considering children are more radiosensitive than adults and have a longer remaining lifespan.
- Since administration to the wrong patient, or leakage of radiopharmaceutical outside the blood vessel on administration, leads to needless radiation exposure, close attention is required to avoid such errors.
- Medical staff should follow the three rules for the protection of external radiation exposure (time, distance, shielding) to minimize the radiation exposure from a patient administered with a radiopharmaceutical as a radiation source.
- It is also necessary to consider the general public’s radiation exposure from patients who have been administered with radiopharmaceuticals, but in the case of diagnostic nuclear medicine, the administered dose of radiopharmaceutical is small. In most cases, it is estimated not to exceed one fifth of the annual dose limit for the general public (1 mSv). (In the case of internal radiation therapy using the administration of large amounts of radionuclide such as I-131, a criteria for discharge of patients administered with radiopharmaceuticals has been determined and such patients must be hospitalized in special treatment rooms until they meet the criteria.)
- For FDG-PET examination, it is recommended to instruct patients to shorten the contact time with and maintain a distance from pregnant women and children, who are susceptible to radiation within two hours after FDG administration. (Cited from “Safety guideline for FDG-PET examination”.) It appears that similar care is required for other nuclear medicine examinations.
- It is preferable to avoid nuclear medicine examinations for pregnant women and the necessity of such examinations should be judged carefully. On the other hand, even if a woman receives a nuclear medicine examination while unaware of pregnancy, this will not cause deterministic effect (congenital anomaly, mental retardation, etc.) on the fetus, and cannot be the reason for artificial abortion.
- If the subject is breast feeding, it will be necessary to restrict breast feeding for a certain period, depending on the radiopharmaceutical administered.

Diagrams

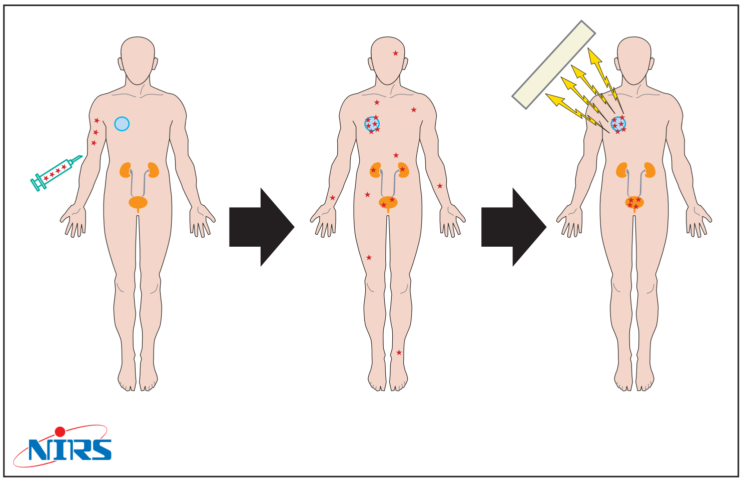


Fig. 1 Processes of Nuclear Medicine Imaging

1. Administer radiopharmaceutical (commonly intravenously)
2. The radiopharmaceutical circulates throughout the body, accumulates in the target organ (lesion) and is excreted from other parts the body.
3. Once the background has dropped, imaging is conducted using a detector to detect radiation emitted from the radiopharmaceutical.

Note) Consequently, the time frame suitable for imaging differs depending on the radiopharmaceutical.

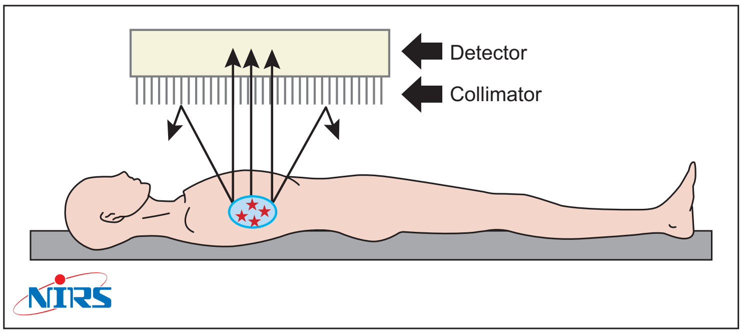


Fig. 2 Principles of Planar Imaging

For planar imaging, a gamma camera is fixed in one direction and gamma rays emitted from within the body are detected to obtain a planar image. Since gamma rays are emitted randomly in all directions, to limit the direction of gamma ray flight, the detector is equipped with a collimator, so that only gamma rays entering from a specific direction are detected.

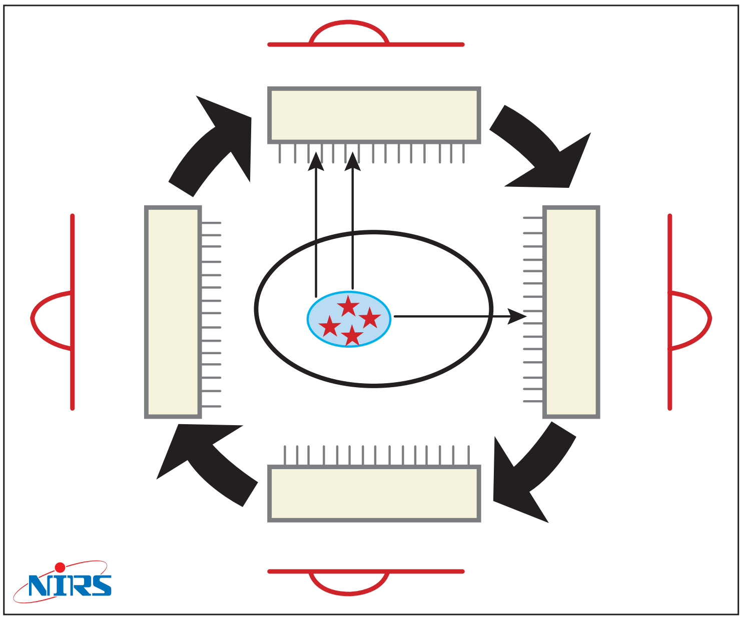


Fig. 3 Principles of SPECT

For SPECT, one or more gamma cameras are rotated around the subject to detect gamma rays from many directions. Detected gamma rays are used as projection data, from which tomographic images are reconstructed using a computer.

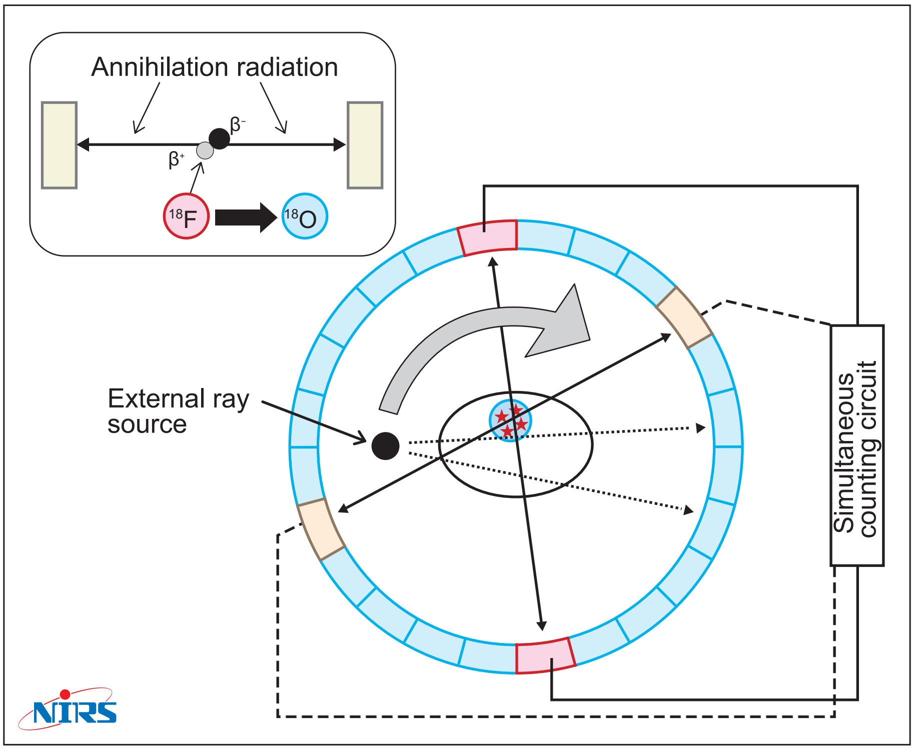


Fig. 4 Principles of Positron Emission Tomography (PET)

Positrons (β^+) emitted from a positron-emitting radionuclide immediately bind with nearby electrons (β^-) and are annihilated. In this process, they emit a pair of radiation rays in opposite directions, with energy of 511keV (annihilation radiation). In PET, detectors are arranged circularly around the subject to detect the annihilation radiation. At that stage, simultaneous measurement (co-incidence) by two detectors can be used to limit the direction of the radiation rays (no collimator is required). In addition, either before or after the data collection (emission scan) the external source is rotated around the body for transmission data collection (transmission scan), which is used to compensate for the absorption of annihilation radiation in body tissue (attenuation correction).

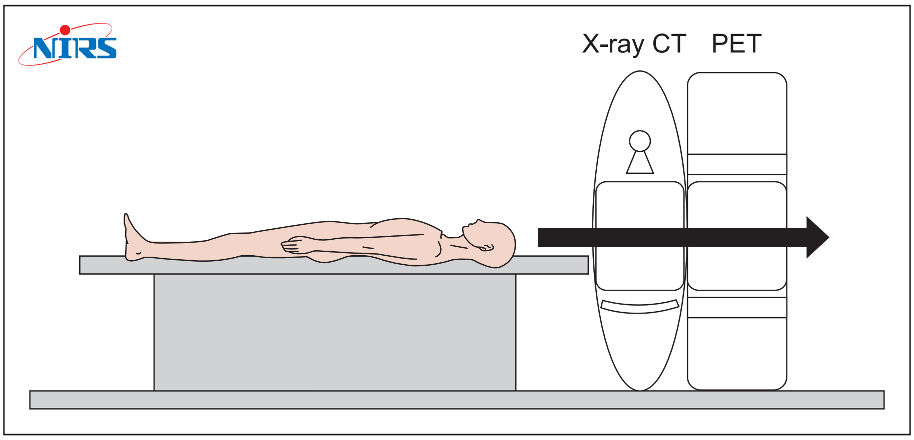


Fig. 5 PET/CT

X-ray CT and PET instruments are installed as single equipment. PET data acquisition is conducted after CT imaging. With PET/CT, it is possible to obtain accurate fusion images of the CT and PET images. In addition, attenuation correction can be performed by using CT data, not by using an external source.

Table 1 Representative Gamma Ray Nuclides

Nuclide	Physical Half life	Form of decay	Main gamma ray Energy (MeV)	Comments
Ga-67	3.26 d	EC	0.093 0.185 0.300	
Tc-99m	6.01 h	IT	0.141	
In-111	2.81 d	EC	0.171 0.245	
I-123	13.3 h	EC	0.159	
I-131	8.02 d	β-	0.364	Beta rays are also emitted
Tl-201	3.04 d	EC	0.135 0.167	

EC: Electron capture, IT: Isomeric transition, β^-: Beta decay

Table 2 Representative Positron Nuclides

Nuclide	Physical half life (minutes)	Form of decay	Average energy (MeV)
C-11	20.4	β^+, EC	0.386
N-13	9.97	β^+, EC	0.492
O-15	2.04	β^+, EC	0.735
F-18	109.8	β^+, EC	0.250

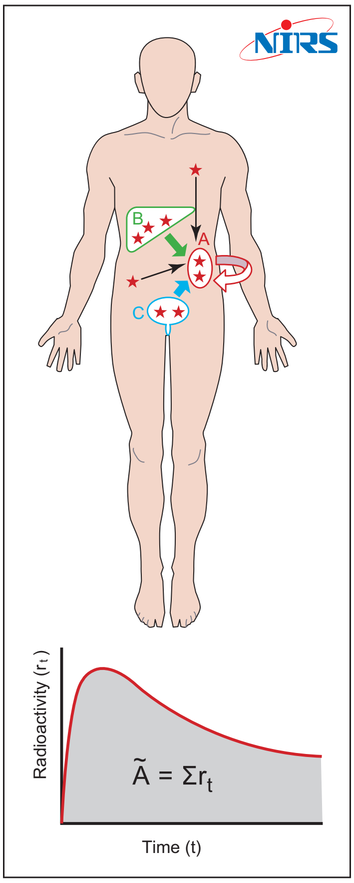


Fig. 6 Basic Concept of the Medical Internal Radiation Dose (MIRD) Method

Calculation of the internal radiation exposure dose from administered radiopharmaceuticals is conducted using the procedure devised by the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine.
For example, when considering the radiation exposure dose (absorbed dose) to organ A, in addition to the radiation exposure to organ A by cumulative radioactivity within it (organ A → organ A), radiation exposure to organ A from other organs B, C and so on, which are acting as sources (organ B → A, C → A...) , should be concidered. At that time, it is necessary to consider the types of radiation emitted from the radionuclides and the positional relationships between the organs. Thus the radiation exposure dose for any given organ is actually the total radiation exposure dose from the target organ itself plus that from other organs (in the entire body) as sources. When considering the exposure dose in the entire body, the calculation is "whole body → whole body" + "organ A → whole body"+ "organ B → whole body"....

The cumulative radioactivity to an organ is calculated by measuring the changes of radioactivity over time in the organ, to draw time-activity curve (TAC), in which the area-under the curve indicates the cumulative radioactivity.

Exercises

Question 1. Which of the following radionuclides is used for both diagnostic nuclear medicine and therapeutic nuclear medicine (internal radiation therapy)?

a. C-11 b. O-15 c. Tc-99m d. I-123 e. I-131

Question 2. Which of the following is an incorrect statement concerning the characteristics of diagnostic nuclear medicine?

a. The amount of radiopharmaceutical administered is small compared to CT contrast media.
b. The optimal timing for imaging differs depending on the radiopharmaceutical used.
c. With SPECT, gamma rays emitted from inside the body are detected from multiple directions and the tomographic images are reconstructed.
d. PET does not detect positrons, but pairs of annihilation radiation rays emitted when a positron is annihilated.
e. Radioactivity in the body from administration of a radiopharmaceutical reduces over time in accordance with the physical half-life.

Question 3. Which of the following is an incorrect statement concerning adverse effects and radiation exposure exposure in diagnostic nuclear medicine?

a. The probability of adverse effects due to administration of radiopharmaceuticals is low compared to CT contrast media.
b. Radiation exposure in diagnostic nuclear medicine is mainly internal exposure.
c. The MIRD method is used for radiation exposure dose estimation in diagnostic nuclear medicine.
d. When estimating radiation exposure dose in any given organ, it is necessary to consider the effect of radioactivity accumulated in other organs.
e. In diagnostic nuclear medicine, the amount of radiopharmaceutical administered to a child can be the same as for an adult.

Exercise answers and explanations

Answer to Question 1: e

- Radionuclides emitting gamma ray and positron are used for diagnostic nuclear medicine, while beta ray and alpha ray-emitting radionuclides are used for therapeutic nuclear medicine.
- C-11 and O-15 are positron-emitting radionuclides, while Tc-99m and I-123 are gamma ray-emitting radionuclides, so they are used for PET and for gamma camera imaging, respectively.
- I-131 emits both beta and gamma rays, so it can be used for both diagnostic and therapeutic nuclear medicine.

Answer to Question 2: e

a. Compared to the iodine contrast media used for CT, the dose of radiopharmaceutical in diagnostic nuclear medicine is smaller and no pharmacological effects occur. A correct statement.
b. Since the dynamics of radiopharmaceuticals differ according to the radiopharmaceutical used, the optimal timing for imaging is different for each. A correct statement.
c. For SPECT, one or more gamma cameras are rotated around the subject to detect gamma rays from many directions. Detected rays are used as projection data, from which tomographic images are reconstructed using a computer.
d. For PET, the pairs of annihilation radiation rays emitted in opposite directions when a positron is annihilated are measured simultaneously to reconstruct tomographic images. A correct statement.

e. Radioactivity from internally-administered radiopharmaceuticals declines in accordance with the effective half-life, which takes into account the physical half-life of radionuclides and the biological half-life from excretion of the radiopharmaceutical from the body.

Answer to Question 3: e

a. The dose of radiopharmaceutical administered is very small and the frequency of adverse effects is extremely low. A correct statement.
b. Radiation exposure in diagnostic nuclear medicine is mainly an internal exposure caused by the radiation emitted from a radiopharmaceutical administered within the body. However, external radiation exposure can arise during PET or PET/CT due to the transmission scans or CT imaging used therein. A correct answer
c. The internal exposure dose from a administered radiopharmaceutical is assessed using the MIRD method from the Society of Nuclear Medicine Medical Internal Radiation Dose (MIRD) Committee. A correct answer.
d. It is also necessary to consider exposure from radioactivity accumulated in other organs, acting as sources. A correct answer.
e. For children it is necessary to take care to optimize the administered dose to avoid an excessive dose, considering children are more radiosensitive than adults and have a longer remaining lifespan.

Teaching support materials for advanced students

References:

- *Saishin Kakuigaku* (Kinichi Hisada, supervising editor, Norihisa Tonami and Atsushi Kubo, editors), Kanehara and Co., Ltd., Tokyo, 1999
- Atsushi Kubo and Fumio Kinoshita: *Nuclear Medicine Notes*, Kanehara and Co., Ltd., Tokyo, 2009

Guidelines and Q&As (available to view and download from the Japanese Society of Nuclear Medicine website):

- Guidelines for the Appropriate Use of Radiopharmaceuticals
- Risk Management in Nuclear Medicine
- Nuclear Medicine Q&A, Nuclear Medicine Q&A for Nursing Staff, PET Q&A
- Safety guideline for FDG-PET examination
- Criteria for Discharge of Patients Administered with Radiopharmaceuticals (June 30, 1998, November 8, 2010)

Unit Name	4b.1 Principles, Practice and Adverse Effects in Radiotherapy
Items related to core curriculum	• Be able to explain the principles of radiotherapy and list the major methods of radiotherapy. • Be able to explain adverse effects and damage caused by radiotherapy.
General objectives	• Study the basic summary and application of radiotherapy.
Extended objectives	• Be able to explain the principles of radiotherapy and its necessary management and provide summaries and applications of the methods of therapy (external beam irradiation, brachytherapy, nonsealed radionuclide therapy). Be able to explain the early and late adverse effects caused by radiotherapy.
Points to understand	• Exposure due to radiotherapy and its necessary management • The risks and benefits of each irradiation method and the balance between them • Impact on the entire body and individual organs
Essential teaching points	• When applying radiotherapy, it is necessary to thoroughly consider the benefits and risks. • The importance of quality assurance and quality control in radiotherapy.
Keywords	Absorbed dose, photon beams, particle radiation, external irradiation, intensity-modulated radiotherapy (IMRT), stereotactic radiotherapy (SRS, SBRT), brachytherapy, nonsealed radionuclide therapy, radiation pneumonitis, radiation dermatitis, radiation mucositis
Reference tutorials	8, 9, 11, 12

Outline

4b.1.1 What is radiotherapy?

- Methods that use radiation to treat disease, mainly cancer (malignant tumor). Radiation, which causes damage to DNA etc. in the body through its excitation and ionization actions, is used. The level of radiation damage causes to DNA and other biological materials differs between tissues and organs. The level of damage to DNA etc. in biological tissue is called "radiosensitivity." Generally, cancer is more radiosensitive than normal tissue and that characteristic is used in treatment. Therefore, for radiotherapy to work, the tolerance dose of the normal tissue irradiated at the same time as the cancer must be higher than the tumor cure dose (the dose that kills cancer cells) (Table 1). Fractionated radiation, which divides a small dose between applications, is used to reduce the damage suffered by normal tissue. Under that method, the cancer suffers repeated damage and dies, but the normal tissue can repair its damage and recover.

4b.1.2 Factors that influence the effects of radiotherapy

- DNA damage by radiation is modified by chemical agents. Anticancer drugs are often radiation sensitizers and that is why chemo-radiation therapy, which employs chemotherapy at the same time as radiotherapy, is used on advanced cancers difficult to control with radiotherapy alone. Conversely, anticancer drugs may raise the radiosensitivity of normal tissue, making it more susceptible to adverse effects, so care is required in implementation. Hyperthermia, which applies heat of around 43°C to the tumor, has the effect of increasing sensitivity to radiotherapy.
- Radiosensitivity differs between types of tumor. Also, the impact on tissues and organs differs between methods of radiation. Compared to X-rays and other types of low-LET irradiation, heavy particle radiation and other types of high LET irradiation (see 2.2 Basics of Radiation etc. Measurement, Dose and Units) are highly effective against tumors thought to be radio-resistant. But, it is important to use them properly.

4b.1.3 Radiotherapy doses

- The unit used in absorbed dose is Gy (grays), which represents the amount of radiation energy absorbed per unit mass (see 2.2 Basics of Radiation etc., Dosimetry Quantities) • In radiotherapy, total doses such as 50~70Gy, which would be immediately fatal if applied to the whole body, are applied to lesion areas (see 3.2 The Effects of Radiation on Health). However, this is partial irradiation to the tumor area, therefore the impact is completely different (Fig. 1).

- The properties of cancer are such that there is no well-defined boundary between it and normal tissue, so it is always necessary to consider the possibility of adverse reactions to radiation in the surrounding normal tissue. Take into account the applicability of radiotherapy, the necessary range and dose of irradiation, the irradiation method and other factors. The precision of the dose and irradiated area are extremely important and the involvement of a medical physicist or other expert in the physical quality assurance and quality control (QA/QC) of radiotherapy is essential.

4b.1.4 Characteristics of each irradiation method

4b.1.4.1 External irradiation

- This method applies radiation such as photon beams (gamma rays and X-rays), electron rays and particle radiation (proton beams, heavy ion beams) from outside the body. In conventional external irradiation with X-rays, a linac (a medical linear accelerator) is used for fractionated radiation of around 50~70Gy in applications of 1.8~2.0Gy per fraction, five times a week, for five to seven weeks. The method of precisely determining the position of a small tumor and irradiating it one or few times with large doses is called stereotactic radiotherapy (SRS, SBRT). Radiation precision control is particularly important with this method. Intensity-modulated radiotherapy (IMRT) is one irradiation technique which concentrates the dose on the lesion area.

4b.1.4.2 Brachytherapy

- A small, sealed source (radioisotope) as the radiation source is inserted into a tissue incision or body cavity to provide irradiation in this method. The insertion of a temporarily inserted source into the body requires an operating room in a controlled area, or radiation isolation room. Nuclides with small external doses, such as iodine 125, are used as sources for permanent insertion. A patient inserting permanent source can leave the controlled area once it decreases below a certain level dose (discharge standard level).

4b.1.4.3 Nonsealed radionuclide therapy

- Radiopharmaceuticals (radioisotopes with affinity for the lesion area or its compounds) are administered intravenously or orally, then irradiated from within the body with particle radiation (mainly β rays). This has the advantage of enabling treatment of lesions regardless of their position or number. Radiation is emitted from within the body, making it necessary to apply the same management as for brachytherapy.

4b.1.5 Exposure due to radiotherapy, and its impact

- Performed properly, radiotherapy is not a treatment with many adverse effects, but it is always necessary to prepare a treatment plan with consideration of the tolerance dose of normal tissue. It is also necessary to watch for adverse effects in addition to therapeutic effects, both during and after therapy (Figs. 2, 3 and Table 2).

4b.1.5.1 Acute adverse effects

- In situations such as large irradiation field, there can be whole-body effects such as malaise, nausea and vomiting or bone-marrow suppression. Basically, effects occur within the irradiated area. Adverse effects that may occur include dermatitis and hair loss if the skin dose is high, mucositis in the mouth, pharynx and gastrointestinal tract, xerostomia if the salivary glands are irradiated, radiation pneumonitis in the lungs and cystitis in the pelvis.

4b.1.5.2 Late adverse effects

- Malnutrition of the irradiated tissue due to microvascular damage can be a trigger of tissue fibrosis and necrosis. These conditions are the cause of pulmonary fibrosis, intestinal obstruction, hemorrhagic cystitis, rectal ulcers and spinal nerve paralysis (Figs. 4, 5). Growth impairment can occur in children. In rarely, radiation induced malignancy can occur after a latent period of 15-20 years.

Diagrams

Table 1 The tolerance dose of the normal tissue

Organ	TD5/5 volume 1/3	TD5/5 volume 2/3	TD5/5 volume 3/3	TD50/5 volume 1/3	TD50/5 volume 2/3	TD50/5 volume 3/3	Complication used as an indicator
Kidney	50	30	23	-	40	28	Chronic nephritis
Brain	60	50	45	75	65	60	Necrosis, infarction
Brain stem	60	53	50	-	-	65	Necrosis, infarction
Spine	5cm: 50	10cm: 50	20cm: 47	5cm: 70	10cm: 70	20cm: -	Paralysis, necrosis
Lungs	45	30	17.5	65	40	24.5	Pneumonitis
Heart	60	45	40	70	55	50	Pericarditis
Esophagus	60	58	55	72	70	68	Perforation
Stomach	60	55	50	70	67	65	Ulcer, perforaton
Small intestine	50	-	40	60	-	55	Obstruction, perforation
Large intestine	55	-	45	65	-	55	Obstruction, perforation
Rectum	Volume: $100cm^3$		60	Volume: $100cm^3$		80	Severe proctitis
Liver	50	35	30	55	45	40	Liver failure

TD5/5: The dose that has a 5% probability of causing the complication five years later (2Gy / fraction as the standard)
TD50/5: The dose that has a 50% probability of causing the complication five years later (2Gy / fraction as the standard)

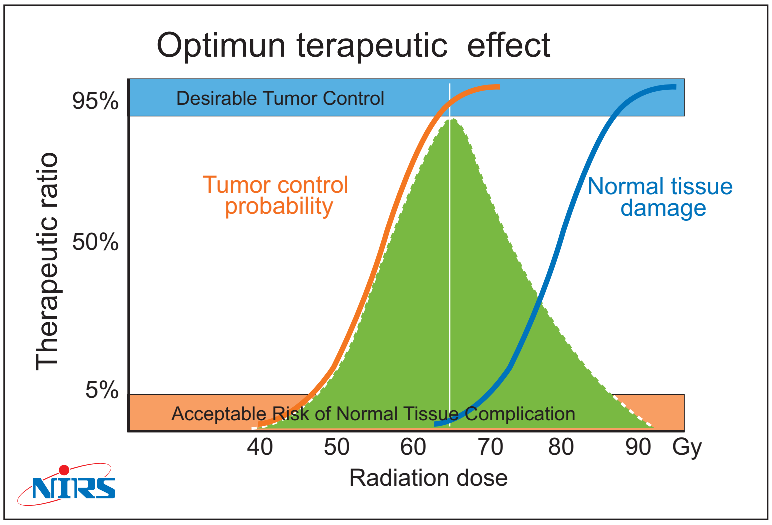


Fig. 1 Dose Effect Curve of Radiotherapy

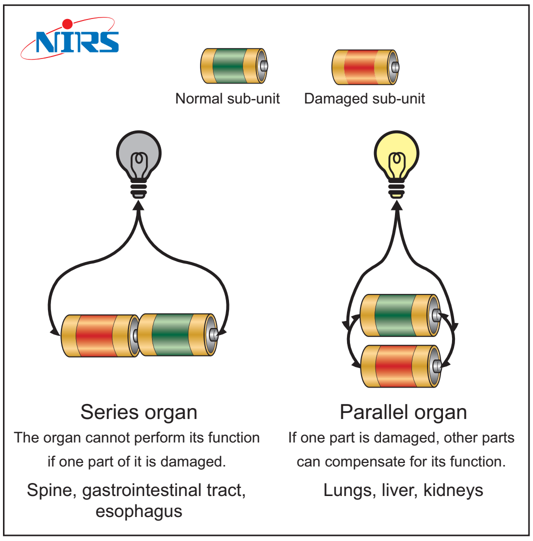


Fig. 2 Series Organ and Parallel Organ

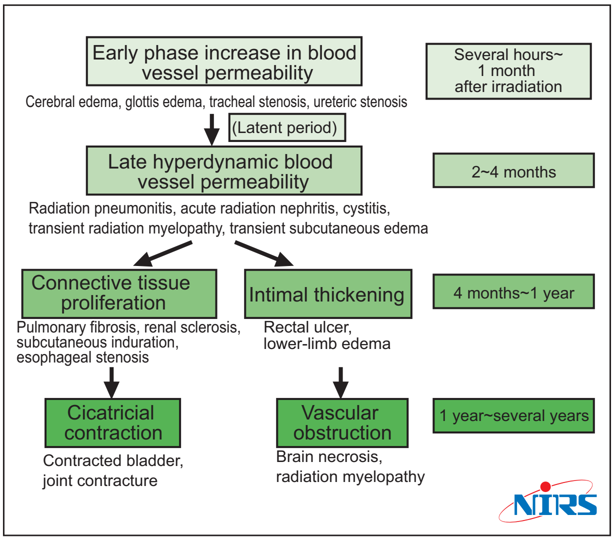


Fig. 3 Impact of Radiation Therapy

(Figures 2, 3 and Table 2 are modified from "Adverse Events in Normal Tissue" by Norio Mitsuhashi. Fig. 4 and Table 4 are modified from "Cancer Radiation Therapy," Shinoharashinsha Inc., Tokyo, 2010)

Table 2 Acute and Late adverse effects in radiotherapy

Organ	Acute adverse effects	Late adverse effects
Hematopoietic organs	Aplasia, pancytopenia	Fatty bone marrow, myelofibrosis, leukemia
Skin	Erythema, hair loss, blister, erosion, ulcer, pigmentation, depigmentation, capillary dilatation, hair loss	Pigmentation, depigmentation, capillary dilatation, hair loss contraction, scarring, ulcer
Oral mucosa	Hyperemia, edema, sores, furred tongue, ulcer	Fibrosis, scarring, ulcer
Eyes	Lacrimation, reduced tear secretion, dry eye	Cataract, retinopathy, corneal ulcer
Salivary gland	Amylase elevation, viscous saliva, dry mouth	Xerostomia, dysgeusia, caries, fibrosis
Lungs	Pneumonitis	Pulmonary fibrosis
Heart		Epicarditis, pericardial effusion
Esophagus	Esophagitis	Esophageal ulcer, perforation
Intestines	Diarrhea	Ulcer, stenosis, intestinal obstruction, rectum, cyst, vagina
Kidney	Nephritis	Atrophic kidney (renal sclerosis), malignant hypertension
Bladder	Cystitis, pollakiuria	Contracted bladder, pollakiuria
Brain, spine	Cerebral edema, brain hypertension	Brain necrosis, myelopathy, peripheral nerves
Muscle, soft tissue	Edema	Induration (fibrosis), circulatory disturbance (lymphatic edema)
Bones	Arrested growth	Bone necrosis, growth impairment

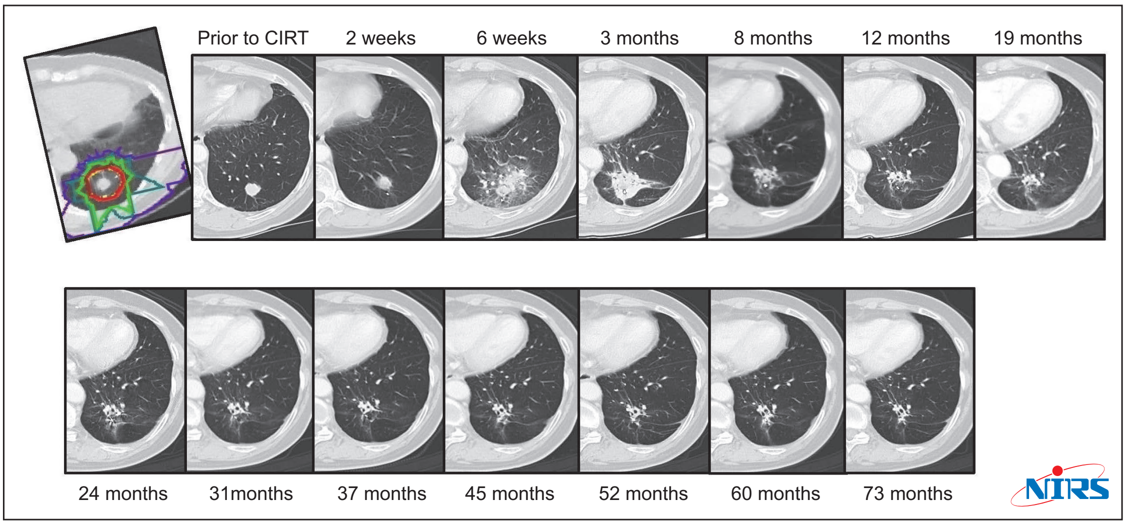


Fig. 4 Radiation pneumonitis associated with the treatment of lung cancer

Radiation pneumonitis occurred six weeks after irradiation, but the tumor disappeared 2 years later and five years later, only fibrosis in the lung was left.

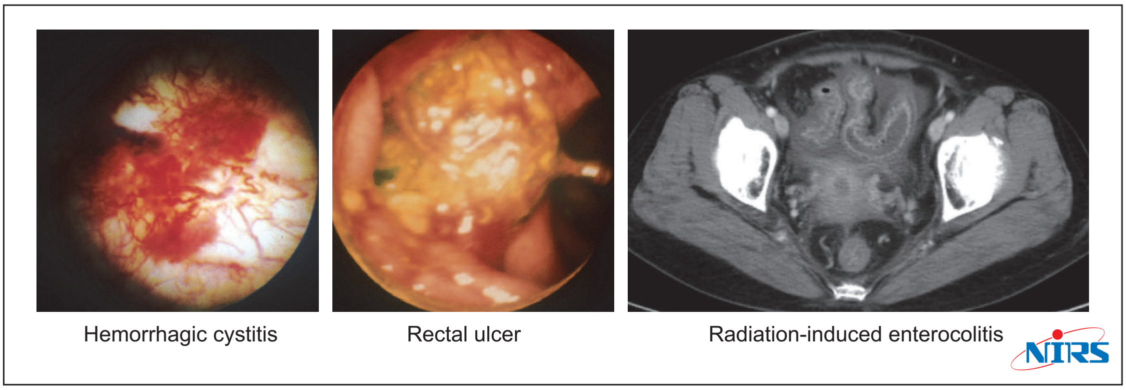


Fig. 5 Late reaction after radiotherapy of uterine cancer

Exercises

Question 1. Which organ has the lowest radiation tolerable?

a. Esophagus b. Kidney c. Liver d. Heart e. Brain

Question 2. Which cancer can often be completely cured by radiotherapy alone?

a. Stage III lung cancer b. Stage III prostate cancer c. Stage I breast cancer
d. Stage I stomach cancer e. Stage I larynx cancer

Question 3. Which complication is a contraindication for radiotherapy as a general rule?

a. Systemic lupus erythematosus b. Cardiac infarction c. Fatty liver
d. Intracerebral hemorrhage d. Diabetes

Exercise answers and explanations

Answer to Question 1: b

As Table 1 shows, the kidneys are the weakest. The brain and heart etc. are organs with relatively high tolerance doses.

Keywords: Radiosensitivity, radiation tolerance dose

Answer to Question 2: e

In advanced-stage lung cancer, the cure rate from radiotherapy alone is low and chem-radio therapy is standard. For limited-stage prostate cancer, external beam irradiation or iodine seed brachytherapy are generally used, with high cure rates, but in stage III, metastasis is common and the cure rate is raised by combined use of endocrine therapy. For early-stage breast cancer the general therapeutic method is breast-conserving surgery followed by postoperative breast irradiation, with the addition of drug treatment. Surgery is the basic treatment for gastric cancer and radiotherapy is generally not performed. In early larynx cancer, the first choice is radiotherapy, which can preserve the patient's voice and has a high cure rate.

Keywords: Radiotherapy, lung cancer, larynx cancer, prostate cancer, breast cancer, gastric cancer

Answer to Question 3: a

Adverse effects are more common in connective tissue diseases that reduce the radiation tolerance dose of normal tissue and systemic lupus erythematosus makes problems such as late fibrosis and necrosis more common. It may be necessary to consider diabetes as well, if it is poorly controlled over many years and leads to gangrene.

Keywords: Radiotherapy, contraindications

Teaching support materials for advanced students

- *Current Radiation Therapy 2010*, edited by Hiroshi Onishi, Kumiko Karasawa, and Katsuyuki Karasawa, Shinoharashinsha Inc., Tokyo, 2010
- *Current Radiation Therapy 2010 - Supplement*, edited by Hiroshi Onishi, Kumiko Karasawa, and Katsuyuki Karasawa, Shinoharashinsha Inc., Tokyo, 2010

5. Radiation Risks and Protection

Unit name	5.1 Radiation Risks and Protection
Items related to core curriculum	• Be able to describe radiation protection and safety management.
General objectives	• Study the basic concepts of radiation protection and understand the relationship between related law and safety management.
Extended objectives	• Be able to describe radiation protection and safety management.
Points to understand	• Basic objectives of radiation protection • Basic principles of radiation protection, optimization and diagnostic reference levels in particular • Overview of regulations that apply to radiation medicine
Essential teaching points	• Preventing deterministic effects and limiting the risks of stochastic effects • Justification, optimization and dose limits • Exposure categories: occupational exposure, medical exposure and public exposure • The Ordinance for the Enforcement of Law Medical Care Act, The Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc. and the Ordinance on the Prevention of Ionizing Radiation Hazards
Keywords	Radiation protection, the concepts behind safety management, approaches to understanding risk (justification of practice, consideration of benefit and risk), three types of exposure, optimization of protection, law
Reference tutorials	13, 14, 15, 16

Outline

5.1.1 The goal of radiation protection(Table 1)

According to recommendations by the International Commission on Radiological Protection (ICRP), the goal of radiation protection is to limit useful activities that can result in radiation exposure without imposing unreasonable restrictions.

In more concrete terms, the goal is to prevent deterministic effects and decrease the risk of stochastic effects as low as reasonably achievable through the management of exposure.

5.1.2 The basic principles of radiation protection (Table 2)

5.1.2.1 Justification: Benefits must exceed harm

Because exposure as part of medical treatment is intentional, the importance of justification is pointed out.

Justifications for the use of radiation in medicine can be considered in three levels.

(1) Medical use: For the use of radiation in medicine, benefits that greatly exceed harm are granted and these justifications are now regarded as a matter of course.

(2) Specific techniques with specific goals: This is easy to understand, for example, when considering the use of PET ([^{18}F]-FDG) for early diagnosis of cancer. This justification is an issue that is being dealt with by Japanese authorities and professional organizations in cooperation with relevant international organizations.

(3) Application on an individual patient basis: The goals of exposure are considered for individual patients and must be justified beforehand.

5.1.2.2 Optimization: The financial and social factors behind the potential for exposure, number of people exposed and the size of the dose must be considered and kept as low as reasonably achievable.

This is also called the ALARA principle, an acronym of “as low as reasonably achievable.”

In treatment, the goal is to apply the dose to the lesion—i.e., the irradiation itself; but diagnostically, the goal is to obtain information and irradiation itself is not the goal. Diagnostic reference levels are used to easily measure such quantities as standard dose and the amount of radiopharmaceuticals to give to patients for each test. Diagnostic reference levels are the means for checking situations in which the radiation or drug dosage is abnormally high. If the level is exceeded, it is examined whether it has been sufficiently optimized.

5.1.2.3 Dose limits: Do not exceed the predetermined dose limit.

It is inappropriate to apply the dose limit for medical exposure, going under the assumption that the patient's dose is justified. The reason is because if there is a dose limit, it will be impossible to obtain the necessary diagnostic information, or to carry out all medical treatment. The benefits and harm of medical exposure are produced in the same patient and there is no partiality.

5.1.3 Exposure categories

5.1.3.1 Occupational exposure

The concept of protection applied to occupational exposure as exposure to health care workers is basically the same for exposure in other occupations. However, the reality of individual doses received by health care workers is that the average dose is as high as in the area of nondestructive testing (Table 3). Most importantly, there are many workers in health care who receive doses exceeding 20 mSv. It is also pointed out there are nonuniform exposures.

5.1.3.2 Medical exposure

Aside from exposure received by patients, medical exposure includes exposure received careers, comforters and volunteers in biomedical research.

5.1.3.3 Public exposure

All exposure other than occupational exposure and medical exposure is public exposure.

5.1.4 Related laws and regulation

The basic law with respect to the usage of medical radiation is <u>the Ordinance for Enforcement of Law Medical Care Act</u> (Ministry of Health, Labor and Welfare, last revised Jan. 30, 2012), and the relevant section is Article 4 "Medical Radiation Protection" (from Section 24 to Section 30.27). This consists of regulations on notification, protections for X-ray devices, buildings and facilities with X-ray examination rooms, the obligations of administrators and limitations (Table 4). Under the Medical Care Act, there are seven types of radiation devices that require notification, and for four of these types, which consist of accelerators and sealed radiation sources, care must be taken when applying the <u>legislation</u>* (Ministry of Education, Culture, Sports, Science and Technology, last updated May 10, 2010). (*the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.)

As to dose limits, there are regulations regarding the dose rate of radiation-related facilities and the exposed dose of workers. On the matter of facilities, there are rules specifying dose rate and the concentration of radioactive material in the air, as well as on the concentration of radioactive material in exhaust fumes and waste water. The dose limit for radiation workers is explained in detail in 5.3 Occupational Exposure.

Care must be taken with the regulations set forth by <u>the Ordinance on the Prevention of Ionizing Radiation Hazards</u> (Ministry of Health, Labor and Welfare, last updated Dec. 22, 2011) from the viewpoint of occupational safety and health.

Diagrams

Table 1 The Categories of Radiation Effects and the Goals of Radiation Protection

Type of effect	Threshold dose	Increase in dose	Goal
Deterministic effect	Exists	More severe symptoms	Prevention
Stochastic effect	Supposed not to exist	Increase in frequency of occurrence	Limitation of risk

Table 2 Basic Principles of Radiation Protection

Justification	Confirming that benefits outweigh harm Three levels of justification: (1) Medical use, (2) Specific techniques, and (3) Application to the individual patient
Optimization	Exposed dose should be as low as reasonably achievable Application of diagnostic reference levels: confirmation of optimization if dose is exceeded
Dose limits	Dose limits are not applied to medical exposure.

Table 3 2010—Distribution of Actual Doses by Occupation (Numbers of People)

Yearly effective dose (mSv)	General Health	Dentistry	Veterinary	General Industry	Nondestructive	Research and Education	Total
Average dose (mSv)	0.43	0.05	0.04	0.05	0.43	0.02	0.29
Below detection limit	202.304	16.123	10.438	67.116	2.616	69.880	368.477
0.10–1.00	61.066	669	594	2.892	1.001	2.301	68.523
1.01–5.00	24.435	150	96	696	396	395	26.168
5.01–10.00	3.467	10	7	82	55	35	3.656
10.01–15.00	819	3	1	14	5	3	845
15.01–20.00	321	0	1	0	3	1	326
20.01–25.00	158	0	0	1	1	0	160
25.01–50.00	162	1	0	1	0	0	164
Over 50.00	29	2	0	1	0	0	32
Total	292.761	16.958	11.137	70.803	4.077	72.615	468.351

(Source: Council on Personal Dosimetry Service: Statistical Data in 2010)

Table 4 Medical Radiation at Medical Institutions

Items Requiring Reporting under the Ordinance for Enforcement of Law Medical Care Act	Application of the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.
X-ray devices	–
Medical high-energy radiation devices	○
Medical irradiation devices	○
Medical irradiation instruments	○
Medical equipment with radioisotopes	○
Medical radioisotopes	–
Medical radioisotopes for positron computerized tomography	–

Exercises

Question 1. Which of the following statements regarding the basic principles of radiation protection is incorrect?

a. The basic principle behind justification is to confirm the benefits of using radiation outweigh the harm.
b. There are three levels of justification in the medical use of radiation.
c. Under the principle of optimization, the radiation dose should be as low as reasonably achievable.
d. Diagnostic reference levels are used as an optimization standard for diagnosis.
e. Exposure received by radiation workers is medical exposure, so dose limits do not apply.

Question 2. Which of the following statements regarding the realities of exposure received by radiation worker is correct?

a. The number of people involved in radiation work is greatest in the area of research and education.
b. The average exposure dose received by medical radiation workers is as high as in the area of nondestructive testing.
c. Although the average exposure dose in the medical field is high, the areas of industry and research are about five times higher.
d. According to fiscal year 2010 statistics, only the medical field exceeded the dose limit of 50 mSv per year exceeded.
e. The ratio of individuals who receive exposure exceeding 20 mSv per year does not differ in all occupations.

Question 3. Which of the following statements regarding the regulations involving medical radiation is correct?

a. There are two primary relevant laws: the Ordinance for Enforcement of Law Medical Care Act and the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.
b. Article 4 of the Ordinance for Enforcement of Law Medical Care Act has provisions regarding reporting, protections for X-ray devices, buildings and facilities with X-ray examination rooms, the obligations of administrators and limitations.
c. X-ray devices, medical irradiation equipment and medical radioisotopes are only regulated by the Ordinance for Enforcement of Law Medical Care Act.
d. Dose limits regarding facilities are determined from the viewpoint of protecting radiation workers.
e. Because the Ordinance on the Prevention of Ionizing Radiation Hazards is the law that gives provisions on the safety of workers from the viewpoint of occupational safety and health, the Ordinance for Enforcement of Law Medical Care Act has no provisions regarding the location of external radiation doses with regard to controlled areas.

Exercise answers and explanations

Answer to Question 1: e

Exposure received by radiation workers is occupational exposure, so dose limits apply. It is for medical exposure that dose limits do not apply and medical exposure includes exposure received by careers, comforters and volunteers in biomedical research, in addition to the exposure received by patients.

Keywords: justification, optimization, dose limits, occupational exposure, medical exposure

Answer to Question 2: b

The medical field accounted for 68.5% of all occupationally exposed workers in 2010. The average dose per person was 0.43 mSv, and as a whole, radiation workers can be said to have received a high level of occupational exposure. This is at least ten times higher than the average doses in the area of general industry and research. The percentages exceeding 20 mSv per year, the yearly average of the five-year dose limit of 100 mSv, as well as the percentage exceeding the one-year dose limit of 50 mSv were also highest in the medical field.

Keywords: Distribution of effective dose by industry, dose limits

Answer to Question 3: b

There are three primary laws regarding medical radiation: the Ordinance for Enforcement of Law Medical Care Act, the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc. and the Ordinance on the Prevention of Ionizing Radiation Hazards. Article 4 of the Ordinance for Enforcement of Law Medical Care Act has provisions regarding notification, protections for X-ray devices, buildings and facilities with X-ray examination rooms, the obligations of administrators and limitations. Of the seven types of radiation equipment that require notification, medical high-energy radiation devices, medical irradiation devices, medical irradiation instruments and medical equipment with radioisotopes are also regulated by the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc. Limitations on facilities include regulations on concentrations of radioactive material in exhaust fumes and waste water, and these regulations are determined from the viewpoint of protecting the members of the public. Under the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc., there are also predefinitions regarding placement of such things as administrative areas or business area borders.

Keywords: Ordinance for Enforcement of Law Medical Care Act, The Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc., Ordinance on the Prevention of Ionizing Radiation Hazards

Teaching support materials for advanced students

ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection.

ICRP. Radiological Protection in Medicine (ICRP publication 105).

Unit name	5.2 Public Exposure
Items related to core curriculum	• Be able to describe radiation protection and safety management.
General objectives	• Understand the necessity of radiation protection against public exposure.
Extended objectives	• Be able to outline approaches to public exposure limits.
Points to understand	• Basic approaches to the necessity of public exposure management • Limits on public exposure
Essential teaching points	• Critical groups and representative persons as targets for assessing public exposure doses • Annual dose limit of public: 1 mSv
Keywords	Public exposure, critical group, representative person, necessity of dose limits, individual-related, source-related
Reference tutorials	4, 12, 13, 14

Outline

5.2.1 Public exposure

Public exposure includes all types of public exposure other than occupational exposure and medical exposure.

Exposure from natural radiation sources is also public exposure. Quite some time ago, exposure from natural radiation was regarded as outside the scope of radiation protection, but it has now come within the scope of protection for instances in which exposure (or routes of exposure) can be controlled even if the radiation source itself cannot be controlled.

In concrete terms, radiation protection measures are taken with regard to high-altitude flying in aircraft and naturally occurring radioactive materials (NORM).

The radiation dose received from natural radiation is, on average, 2.4 mSv per year. At 1.2 mSv, radon inhalation accounts for the largest portion of those doses, along with 0.4 mSv from cosmic rays, 0.5 mSv from terrestrial radiation and internal radiation of 0.3 mSv from foods (Fig.1).

Speaking of high-altitude flying, exposure at sea level is about 0.03 μSv/h, but 5 μSv/h at an altitude of 10,000 m.

5.2.2 Approaches to the management of public exposure

If a radiation source exists and radiation is used, this will cause surrounding members of the public to be exposed. It does not mean, however, that each individual member of the public is required personal monitoring or other direct management as a target of radiation protection.

This is why an approach has traditionally been taken that distinguishes public exposure by critical groups (small groups with identical lifestyle habits that receive higher doses than the rest of the population), and public dose limits have been applied to the average dose of critical groups.

For public dose evaluations, the necessity of dose evaluations that takes into consideration hypothetical probability distribution with regard to, for example, disposal of radioactive waste with long-lived nuclides, has emerged in recent years, and the concept of the representative person has replaced the concept of critical groups.

From Japan’s legal point of view, this is established by the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc. on the basis of Article 20 of the Atomic Energy Fundamentals Act, but its purpose is “to prevent damage from radiation and ensure the public safety,” and this is expressed from both the side of the user and that of ensuring safety for the nearby public.

5.2.3 Exposure limits

For public dose limits, the ICRP recommends an effective dose of 1 mSv per year.

Two approaches are applied in deciding on a public dose limit. One is the same approach as that used for occupational exposure and is based on risk assessment. An average exposure of 1 mSv per year over a lifetime is equivalent to a 1:10,000 risk level for one's yearly risk of death.

The other approach involves the varying levels of natural radiation. There are small effects on health even if the variation is not so small, and so this approach holds that the difference should not be disregarded.

Dose limits are quantities related to the individual. Individuals of interest receive exposure from a variety of radiation sources. It is the total dose received by the individual that is regulated as a dose limit (Fig.2).

On the other hand, justification and optimization are studied as quantities related to radiation sources. When introducing some use of radiation, the radiation source thus used subjects nearby members of the public to exposure. Optimization is the reasonable balancing of the total dose received from that radiation source (Fig.2).

Diagrams

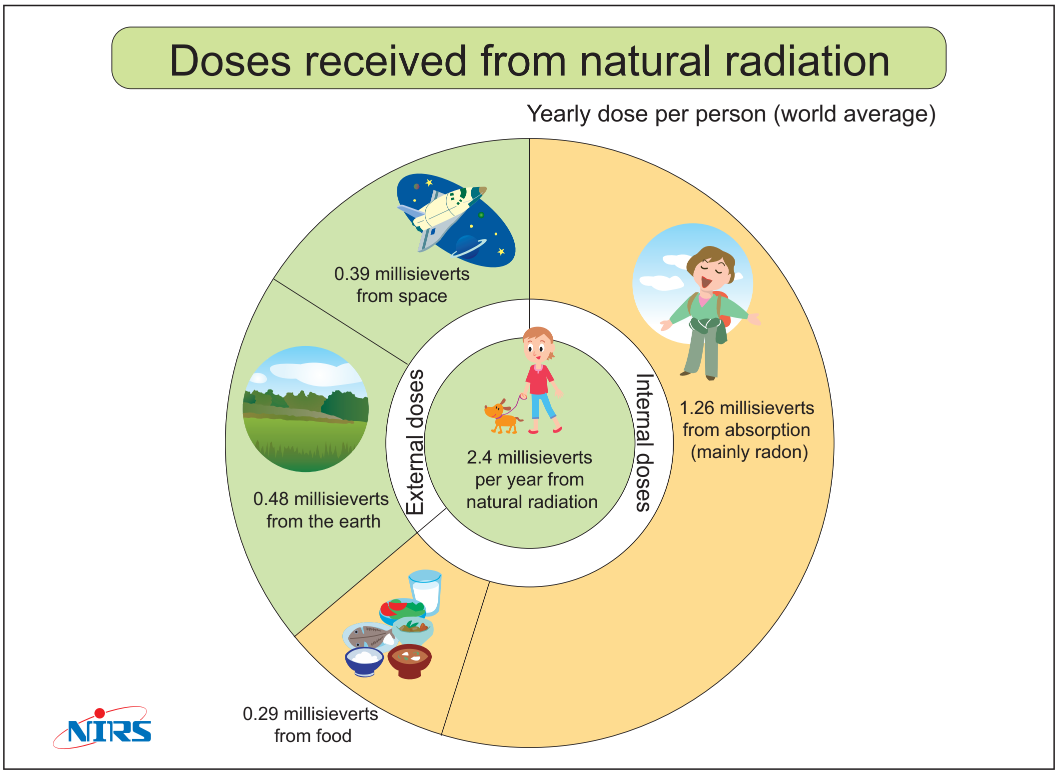


Fig. 1 Doses Received from Natural Radiation

(Source: modified according to Graphical Flip-chart of Nuclear & Energy Related Topics 2010, the federation of electric power companies of Japan)

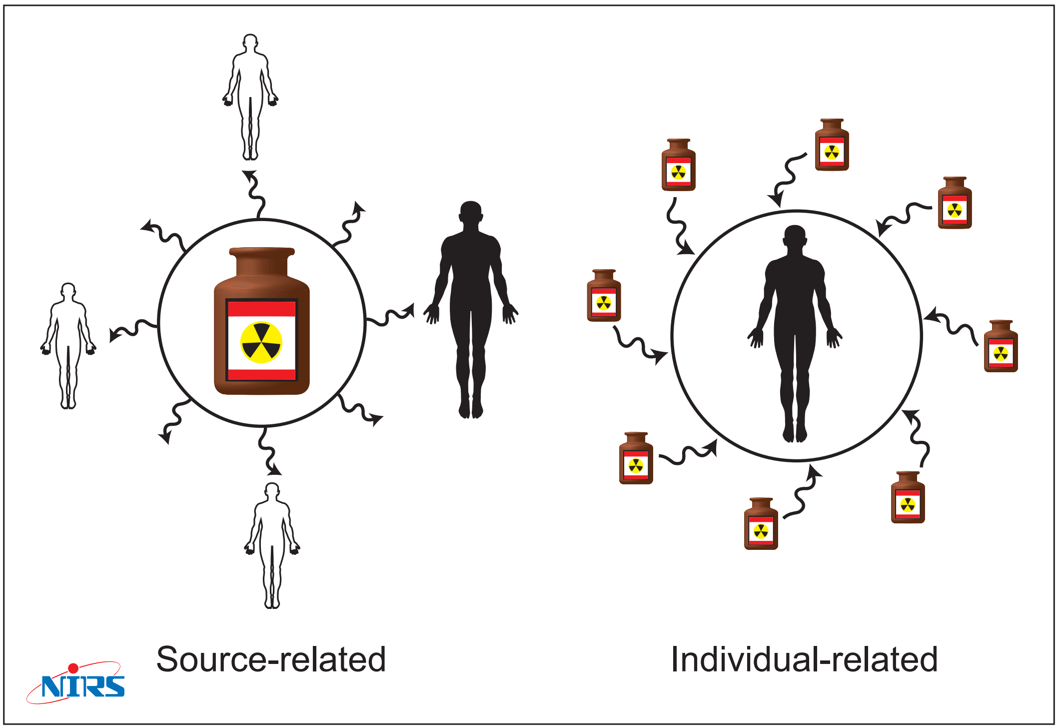


Fig. 2 Two Perspectives on Radiation Protection

(Source: ICRP Publication 103 (The 2007 Recommendations of the International Commission on Radiological Protection)

Exercises

Question 1. Which of the following statements regarding public exposure is incorrect?

a. Public exposure is exposure that includes medical exposure but excludes occupational exposure.
b. The scope of protection from public exposure includes exposure from natural radiation sources.
c. High-altitude flying in aircraft, radon and NORM are specific targets of protection from natural radiation.
d. The global average for natural radiation exposure is 2.4 mSv per year and inhalation of radon is the largest contributor of these exposures.
e. Flying at an altitude of 10,000 m in an aircraft gives an exposure level over 100 times the level on the ground.

Question 2. Which of the following statements regarding public exposure management is incorrect?

a. Monitoring and other individual management are not carried out for protection of members of the public.
b. Public dose limits apply to individuals who receive the highest exposure.
c. A critical group is a small group consisting of several dozen people with the same lifestyle habits who receive higher doses than the rest of the population.
d. A representative person is a hypothetical person considered to receive high exposure doses when parameters such as dietary habits and lifestyle are taken into account.
e. Japanese law provides for the safety of members of the public in surrounding areas to ensure public safety.

Question 3. Which of the following statements regarding public exposure limits is incorrect?

a. The public dose limit is 1 mSv per year.
b. Dose limits are one indicator for showing the boundary between danger and safety.
c. Continuous exposure to radiation at the dose limit over a lifetime will increase one's risk of death by one-10,000th.
d. The public dose limit is determined from the viewpoints of considering risk levels and variations in natural radiation levels.
e. Dose limits are categorized into individual-related quantity from the viewpoint of radiation protection concept.

Exercise answers and explanations

Answer to Question 1: a

"Public exposure" refers to all exposure aside from occupational exposure and medical exposure. Its scope also includes protection from exposure from natural radiation sources, with specific examples including high-altitude flying in aircraft, radon and NORM.
Keywords: natural radiation exposure, high-altitude flying, NORM, radon

Answer to Question 2: b

The public dose limit applies to critical groups and representative persons.
Keywords: dose limit, critical group, representative person, public safety

Answer to Question 3: b

Dose limits do not indicate the boundary between safety and danger. In the case of public dose limits, the limit is equivalent to a one-in-10,000 chance of death per year risk level and at the same time is determined from the viewpoint of the amount of variation in natural radiation.
Keywords: necessity of dose limits, individual-related, source-related

Teaching support materials for advanced students

ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection.

Unit name	5.3 Occupational Exposure
Items related to core curriculum	• Be able to understand radiation protection and safety management.
General objectives	• Understand the approaches to protection against occupational exposure and the requirements for radiation management.
Extended objectives	• Be able to summarize management methods for occupational exposure (occupations in general).
Points to understand	• Effective dose limits and equivalent dose limits • Individual monitoring (external and internal exposure) • Radiation health examinations, and education and training
Essential teaching points	• The risk level at an effective dose limit of 100 mSv per 5 years • Personal dosimeters for external exposure, external counting and bioassays for internal exposure • Frequency and details of radiation health examinations • Frequency and details of education and training
Keywords	Effective dose limits, equivalent dose limits, individual monitoring, health examinations, education and training
Reference tutorials	2, 14, 16

Outline

5.3.1 Dose limits for workers (Table 1)

Dose limits are set to achieve the radiation protection objectives of preventing deterministic effects and reducing stochastic effects to be as low as reasonably achievable.

Equivalent dose limits focus on preventing deterministic effects and are set with sufficient margin beyond the threshold of each organ and tissue.

Effective dose limits focus on limiting the risk of stochastic effects and, based on a lifetime dose of 1 Sv, are set at 100 mSv over five years for an employment period of 50 years and a management period of 5 years. This level is equivalent to a 0.001 chance of death per year.

These are set forth in more specific terms as follows:

Effective dose limits:

100 mSv per 5 years, 50 mSv per year

Women: 5 mSv per 3 months

Pregnant women: 1 mSv of internal exposure for the duration until birth

Equivalent dose limits:

Lens of the eye: 150 mSv per year

Skin: 500 mSv per year

Pregnant women: 2 mSv to the abdominal surface for the duration until birth

In instances involving urgent jobs whose purpose is to prevent radiation damage, the effective dose limit is 100 mSv and equivalent dose limits are 300 mSv for the lens of the eye and 1 Sv for the skin. The effective dose limit was raised to 250 mSv at one time only for work during emergencies related to Tokyo Electric Power's Fukushima Daiichi Nuclear Power Plant, but this does not apply to the Ordinance for Enforcement of Law Medical Care Act.

5.3.2 Management requirements

5.3.2.1 Individual monitoring

(1) External exposure: use of personal dosimeters

Exposure dose management for occupational exposure is implemented by wearing personal dosimeters (Fig. 1) when entering controlled areas. The dosimeters are worn on the torso—on the chest for men and on the abdomen for women. Exposure doses are measured and recorded every month (or every three months) from the dosimeters, with glass badges or OSL dosimeters as fundamental personal dosimeters.

An electronic pocket dosimeter (Fig. 2) is to be worn when entering a controlled area,whenever dose management for each entering a controlled area is required.

If part of the body is exposed to a higher dose than the torso—as when one's hand is inserted into an invisible radiation cone—an extra dosimeter should be worn on that body part (and a ring badge worn in the case of a finger).

If the exposure dose from the effect of scattered radiation is high, a lead apron should be worn to minimize exposure. In such instances, the chest and abdomen will be covered by the lead apron, but the head and neck cannot be covered, so two personal dosimeters must be worn—one outside the lead apron and the other inside—to evaluate exposure doses (nonuniform torso exposure).

(2) Internal exposure: external counting and bioassays

If there is a possibility radioactive substances have been taken into the body when handling radiopharmaceuticals (unsealed radioactive material) in nuclear medicine, for example, internal exposure dose management may be necessary.

External counting methods using whole-body counters (Fig. 3) are used in the case of nuclides that emit gamma rays and bioassay methods that utilize biological samples such as feces and urine are used in the case of nuclides that emit alpha and beta rays.

However, ordinary handling facilities are equipped with handling equipment and protective equipment to accommodate the handling volume. For radiation management, dose evaluations are often carried out based on the concentration of radioactive material in the air, with internal exposure a rare issue unless accidental intake occurs.

5.3.2.2 Health Examinations (Prescribed by the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.) (Table 2)

Radiation health examinations are performed on radiation workers who enter controlled areas (1) before entering a controlled area for the first time, and (2) afterward at regular periods not exceeding one year (at regular periods not exceeding six months under the Ordinance on the Prevention of Ionizing Radiation Hazards).

The methods and provisions on health examinations cover interviews and tests or examinations. Health examinations performed at regular periods not exceeding one year exclude interviews and are performed only if deemed necessary by a physician.

5.3.2.3 Education and training (Prescribed by the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.)

Education and training must be performed once (1) before entering a controlled area for the first time or before engaging in handling tasks (new training) and (2) afterward at regular periods not exceeding one year (retraining).

The provisions on education and training include (1) the effects of radiation on the human body (2) the safe handling of radioisotopes and radiation generators (3) legislation regarding the prevention of radiation damage due to radioisotopes and radiation generators and (4) rules on the prevention of radiation damage. Table 3 displays the number of hours of new training determined in each provision. Retraining is covered by the same provisions, but no hours are given.

Tables

Table 1 Dose Limits for Radiation Workers

Effective dose limits	(1)100 mSv per 5 years (2)50 mSv per year (3)For women, 5 mSv per 3 months (4)For pregnant women, 1 mSv of internal exposure during pregnancy*
Equivalent dose limits	(1)Lens of the eye: 150 mSv per year (2)Skin: 500 mSv per year (3)Abdominal surface of pregnant women: 2 mSv during pregnancy*

*The period from the time a manager is notified the woman is pregnant until giving birth

Fig. 1 Personal dosimeters (glass dosimeter and OSL dosimeter)

Fig. 2 Electronic pocket dosimeter

Fig. 3 Whole-body counter

Table 2 Health Examination Methods and Provisions

Interviews	(1)Radiation exposure history (2)For workers with an exposure history, covers circumstances including place of work, exposure dose, presence of radiation damage, and exposure to other radiation.
Tests and examinations	(1)Hemoglobin content of peripheral blood or hematocrit value, red blood cell count, white blood cell count and differential white blood cell count (2)Skin (3)Eyes (4)Other body part and provisions determined by the Minister of Education, Culture, Sports, Science and Technology

Table 3 Education and Training for Radiation

Education and training provisions	Radiation workers	Workers engaged in handling, who don't enter controlled areas
Effect of radiation on the human body	30 minutes	30 minutes
The safe handling of radioisotopes and radiation generators	4 hours	1 hour 30 minutes
Legislation regarding the prevention of radiation damage due to radioisotopes and radiation generators	1 hour	30 minutes
Rules on the prevention of radiation damage	30 minutes	30 minutes

Exercises

Question 1. Which of the following statements about dose limits for radiation workers is correct?

a. The effective dose limit is 50 mSv per year.
b. The reason effective dose limits for women are set in three-month intervals is that women have higher radiosensitivity than men.
c. The equivalent dose limit for the lens of the eye is 300 mSv per year.
d. The equivalent dose limit for skin is 1 Sv per year.
e. An effective dose limit for pregnant women is only set for internal exposure.

Question 2. Which of the following statements about personal monitoring is correct?

a. Individual external exposure monitoring is carried out by wearing personal dosimeters.
b. Personal dosimeters measure the effective dose of whole-body and the equivalent dose on the skin.
c. Because someone wearing a lead apron is shielded, a personal dosimeter is worn only underneath the apron.
d. Though there is a possibility of inserting one's hand into an invisible cone of radiation, only the measurement of whole-body exposure doses is important, so a personal dosimeter is worn only on the chest.
e. Internal exposure monitoring is carried out by measuring the concentration of radioactive material in the air in the workplace, in addition to external counting and bioassays.

Question 3. Which of the following statements about the requirements for the management of occupational exposure is correct?

a. The frequency of health examinations is to be once per period not exceeding one year, according to both the Ordinance on the Prevention of Ionizing Radiation Hazards and the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.
b. Tests performed during health examinations must be performed for all items without any omissions.
c. Education and training must be performed at regular periods not exceeding six months before and after entering a controlled area.
d. For education and training provisions, there is no difference between new training and retraining.
e. For education and training hours, there is no difference between new training and retraining.

Exercise answers and explanations

Answer to Question 1: e

Dose limits are set for both effective doses and equivalent doses. The basic limit is an effective dose of 100 mSv per five years and 50 mSv per year, as well as an equivalent dose of 150 mSv for the lens of the eye and 500 mSv for skin. In addition to this, in the case of women who has the ability to be pregnant, there are regulations that stipulate 5 mSv per three months to make exposure as uniform as possible to protect the embryo/fetus. For pregnant women, there is an equivalent dose limit of 1 mSv to the abdomen for the duration of the pregnancy and the limit for internal exposure is a committed effective dose of 2 mSv.

Keywords: effective dose limit, equivalent dose limit, possibly pregnant women, pregnant women

Answer to Question 2: a

Measurement results are practically indicated by a 1-cm dose equivalent and a 70-μm dose equivalent as operational quantities. Exposure is nonuniform when a lead apron is worn, so personal dosimeters must be worn both outside and inside the lead apron. Furthermore, if a finger is subject to greater exposure, a ring badge or something similar must be worn.

Keywords: personal dosimeter, 1-cm dose equivalent, 70-μm dose equivalent, uneven exposure, whole-body counter, bioassay, measurement of the concentration of radioactive material in the air

Answer to Question 3: d

The frequency of health examinations prescribed by law differs as follows: under the Ordinance on the Prevention of Ionizing Radiation Hazards, once per period not exceeding six months and under the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc., once per period not exceeding one year. Items for testing are given by both the Ordinance on the Prevention of Ionizing Radiation Hazards and the Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc. and may be omitted according to the judgment of a physician. The implementation frequency of education and training is set at once per period not exceeding one year following entrance into a controlled area. There is a desire to consolidate the implementation frequency and item requirements of health examinations and education and training, including instances in which items can be omitted.

Keywords: interview, tests and examinations, exposure history, omission, education and training items, effect on the human body, safe handling, regulations

Teaching support materials for advanced students

ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection.

Ordinance for Enforcement of Law Medical Care Act, The Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc., Ordinance on the Prevention of Ionizing Radiation Hazards

Unit name	5.4 Medical Exposure and Exposure at Hospitals
Items related to core curriculum	• Be able to explain radiation protection and safety management.
General objectives	• Learn the fundamentals of examination that uses radiation.
Extended objectives	• Be able to explain radiation protection and safety management.
Points to understand	• Medical exposure definitions and protection: no dose limits, diagnostic reference levels and dose constraints are applied. • Medical exposure doses: large differences between not only different modalities, but also doses for the same type of examination • Protection at medical facilities: medical exposure, occupational exposure, and public exposure
Essential teaching points	• Approaches to medical exposure definitions and protection in ICRP Publications 60 and 103 • The current state of medical exposure • Actual practices in medical exposure protection
Keywords	Justification of practices, risks and benefits, optimization of protection, exposure dose, diagnostic reference levels, quality control
Reference tutorials	4, 6, 14

Outline

5.4.1 Definition of medical exposure

The definition given by ICRP recommendations is that medical exposures include exposures received by radiation treatment patients, patients' carers and comforters, and volunteers in biomedical research.

5.4.2 Medical Exposure Protection Systems

Justification: Physicians and dentists make judgments in view of benefits and risks. The ICRP provides levels of justification in three stages.

Optimization: Carried out by physicians, dentists and radiological technologists. Takes into account diagnostic reference levels in the radiodiagnosis of patients. Dose constraints are applied to the exposure received by carers and comforters for the patient, and research volunteers.

Diagnostic reference levels are values that serve as non-binding standards. Each medical institution compares these values with the exposure doses received at that institution, and investigates lowering its doses if they are higher than the diagnostic reference levels. Diagnostic reference levels are adopted by taking the third quartile of dose distribution, i.e. the point at which 75% of institutions are lower than those values. These are not yet incorporated into radiation protection in Japan.

Dose constraints are predictive limit values for individual doses from radiation sources. The dose constraints for carers and comforters are given as 5 mSv per case for adults and 1 mSv for children. In the case of volunteers in biomedical research, dose constraints are judged in accordance with the research results (benefits to society) expected by the research ethics committee.

5.4.3 Medical exposure doses

A variety of dose indexes are used depending on the procedures of the radiation diagnoses and treatments (Fig. 1, Table 1).

For the purpose of radiation protection, equivalent doses and effective doses are used, but these cannot be directly measured or evaluated.

Indexes that make use of diagnostic reference levels involve doses that are physically measurable.

Doses in radiation treatment are indicated by absorbed doses (given in grays [Gy]). (Currently, sieverts [Sv] are not used.)

The dose range is extremely wide (Table 2).

Depending on the technique, doses cover a wide range, from the 0.01 mSv level for dentistry to the level of dozens of Gy for medical treatment. Even with the same technique, doses may widely differ depending on the medical facilities and equipment, radiography conditions and other factors. Proper examinations might not be implementable if the dose is too low.

5.4.4 The current state of medical exposure

Justification is judged according to the experience of the physician or dentist and guidelines are not necessarily always consulted.

Judgments like “use a CT for starters” without careful consideration should not be made. Third-level judgments should be made prudently.

Optimization is determined according to appropriate irradiation conditions and carried out in accordance with quality management of the radiology equipment.

The minimum dose needed for suitable image quality is ensured. The radiation field is focused as narrowly as possible. Examination time is shortened as much as possible.

It is particularly important to set conditions that account for different ages and physiques, including children.

Attention must be paid to the fact that deterioration of the equipment can result in higher doses.

5.4.5 Exposure at medical facilities

Occupational exposure: exposure of occupationally exposed workers must be properly managed.

Management is done by means of environmental monitoring of the radiation facilities and through personal monitoring, carried out using personal dosimeters.

Exposure will nearly always fall below the dose limit, but there have been reports of small numbers of workers exceeding the limits (with IVR, for example).

Public exposure: dose limits are generally secured by means of facility management.

The limit is set and managed such that radiation does not exceed 250 μSv per three months (1 mSv total per year) at the site boundaries.

(However, this is the net value originating from the facility, which excludes background radiation.)

Other: exposure received inside hospitals

Exposure due to portable radiography done within the hospital. Special rules set the limits at 1.3 mSv per three months inside hospitals.

5.4.6 Exposure Outside Medical Facilities

Medical exposure: Radiation from patients who have undergone imaging or treatment of radiopharmaceuticals in nuclear medicine and patients who have taken in radionuclides can be a source of radiation to which carers and comforters may be exposed, but the dose constraint will not be exceeded if handled properly. Discharge standards for patients to take radiopharmaceuticals have been set with regard to strontium-90, iodine-131 and yttrium-90. Policies have been set with regard to gold-198 grains and iodine-125 seeds for the discharge of patients who have had medical irradiation sources permanently inserted.

Public exposure: Exposure can occur due to radiation emitted by aforementioned nuclear medicine patients and patients undergoing treatment in nuclear medicine.

They can become a source of radiation to the public. But, even allowing for that, these are trace amounts and are not a problem if handled properly.

5.4.7 Other

Everyone should be aware that an exposure dose of less than 100 mGy is no grounds for an abortion (ICRP Publication 84).

Diagrams

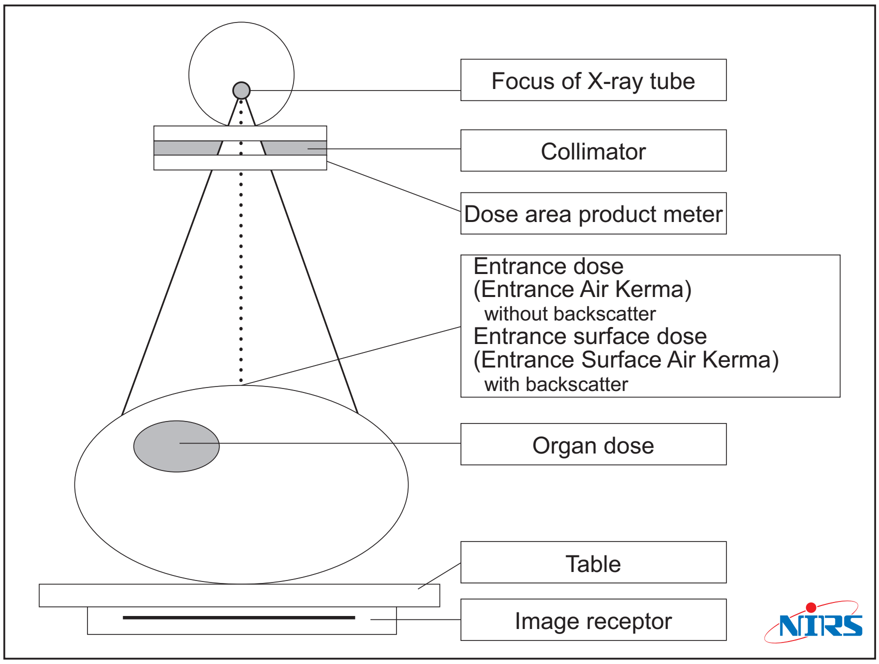


Fig. 1 Geometry and Dose during Radiology

Table 1 Various Exposure Indexes

Target	Name	Unit	Meaning
X-ray diagnosis	ESD (Entrance Surface Dose)	mGy	Air absorbed dose (or air kerma) at the point of incidence of X-rays into the patient's body
X-ray CT	CTDI (CT Dose Index)	mGy	Dose in the center of a PMMA Phantom with a torso diameter 32 cm and head diameter of 16 cm (several types exist, including CTDIw, which takes into account weighted dose values of surrounding sections)
"	DLP (Dose Length Product)	mGy/cm²	Value multiplying the CTDI by the length of the scanning range
Fluoroscopy	DAP (Dose Area Product)	mGy/cm²	Measurement value of dose area product meter attached to X-ray emitter of X-ray tube (value multiplying emitter dose by irradiation area)
Nuclear medicine	Equivalent dose and effective dose	mSv	Equivalent dose and effective dose of internal radiation calculated using the MIRD method

Table 2 Tests, Diagnostic Reference Levels and Exposure Doses

Test type	Diagnostic reference level			Exposure dose	
	IAEA guidance level	Japan Association of Radiological Technologists guidelines	Dose type	Doses	Dose type
Chest	0.4 mGy	0.3 mGy	Entrance surface dose	About 0.06 mSv	Effective dose
Upper GI		Direct 100 mGy, indirect 50 mGy	Entrance surface dose	About 3 mSv	Effective dose
CT	Head 50 mGy, abdomen 25 mGy	65 mGy to head, 20 mGy	CTDI	About 5–30 mSv	Effective dose
Nuclear medicine	Radiopharmaceutical value	Radiopharmaceutical value	Administered radioactivity	About 0.5–15 mSv	Effective dose
PET	"	"	Administered radioactivity	About 2–10 mSv	Effective dose
Mammography	3 mGy	2 mGy	Mammary gland dose	About 2 mGy	Mammary gland dose
Fluoroscopy	Normal 25 mGy/min (high level 100 mGy/min)	Exposure dose rate 25 mGy/min	Entrance surface dose rate	Differs by technique	
Dental imaging				About 2–10 μSv	Effective dose

Exercises

Question 1. Which of the following statements regarding the optimization of medical exposure is correct?

a. Diagnostic reference levels apply to the exposure received by volunteers in biomedical research.
b. Dose constraints apply to the radiodiagnosis of patients.
c. Dose constraints apply to exposure received by patients' carers and comforters.
d. Dose constraints apply to the total value of all exposure.
e. Diagnostic reference levels are represented by effective doses.

Question 2. Which of the following rough exposure dose levels received by radiodiagnosis patients is correct?

a. Effective dose of about 5–30 mSv for X-ray CT scans.
b. Effective dose of about 1–3 mSv for chest X-ray.
c. Effective dose of about 10–30 mSv for nuclear medicine diagnosis.
d. Effective dose of about 500–700 mSv for radiation treatment.
e. Effective dose of about 2–5 mSv for IVR.

Question 3. Which of the following statements regarding exposure at medical facilities is correct?

a. Exposure received by patients is managed through personal monitoring and environmental monitoring.
b. Radiation is managed so as not to exceed 5 mSv per year at the boundaries of the medical facility.
c. There are special rules limiting radiation to 5 mSv per three months inside hospitals.
d. The standard for discharging patients who are on radiopharmaceuticals is set for technetium-99m.
e. CT scans at diagnostic reference levels do not exceed a dose of 100 mGy for fetuses.

Exercise answers and explanations

Answer to Question 1: c

a. Dose constraints apply.
b. Diagnostic levels apply.
c. The correct answer.
d. Dose constraints apply to radiation sources individually. Dose limits apply to the total value.
e. Diagnostic reference levels are represented by measurable doses.

Diagnostic reference levels apply to the diagnosis of patients (X-ray imaging, nuclear medicine imaging, IVR, etc.). Diagnostic reference levels have no dose constraints and are evaluated and applied according to measurable doses. Dose constraints are considered in protection quantities (mSv).

Answer to Question 2: a

a. The correct answer.
b. About 0.06 mSv.
c. About 0.5–15 mSv.
d. Several dozen Gy to the affected area. Generally not represented by an effective dose.
e. May reach gray-order levels at the irradiated skin surface.

It is desirable to understand the dose levels for each radiation treatment technique. Pay attention to the facts that great differences are seen in doses across a range of techniques, doses for the same technique may vary across a wide range and there is uncertainty about the measured (estimated) values themselves.

Answer to Question 3: e

a. This is true for occupational exposure received by occupationally exposed workers, rather than exposure by patients.
b. The limit at the facility boundaries is 250 μSv per three months (1 mSv per year).
c. The limit in hospitals is 1.3 mSv per three months (5 mSv per year).
d. Standards are set for strontium-90, iodine-131, and yttrium-90.
e. The correct answer. Refer to CTDI values.

One should understand management standards and the standards for discharging patients of nuclear medicine (the basis for calculation). Exposure received by a fetus during pregnancy is an extremely important issue. Proper responses should be taken according to the exposure dose levels for each type of radiation treatment.

Teaching support materials for advanced students

ICRP. *ICRP Publication 103:* The 2007 Recommendations of the International Commission on Radiological Protection.

UNSCEAR. UNSCEAR 1988 Report to the General Assembly, with Annexes: Sources, Effects and Risks of Ionizing Radiation. Japanese Ed. vol 1, “Radiation Sources” (National Institute of Radiological Sciences).

6. Preparedness and Response

Unit name	6.1 Preparedness and Response
Items related to core curriculum	• Be able to give an overview of the causes of radiation hazards and responses to them, etc. • Be able to explain the necessity of establishing a medical care system and on-site triage in the event of disasters. • Be able to differentiate early acute conditions and participate in primary treatments.
General objectives	• Learn the fundamentals of preparedness and response.
Extended objectives	• Be able to give an overview of a series of responses in the event of exposure.
Points to understand	• Radiation exposure accidents of interest • Types of exposure, methods for dose estimation and characteristics of hazards • Requirements, points to remember and actual situations • Typical drugs for internal decontamination • Understand that preparedness and response represents applied medicine.
Essential teaching points	• Know about disaster prevention guidelines.
Keywords	External exposure, internal exposure, contamination, dose estimation, decontamination, curing, area, protection, iodine tablet, Prussian blue, DTPA (diethylenetriaminepentaacetic acid)
Reference tutorials	15, 16

Outline

6.1.1 Exposure accidents (Fig. 1)

Accidents with irradiation devices, accidents with sealed radiation source devices, criticality accident, nuclear terrorism, and radiation terrorism

Incidence: highest for accidents with radiation devices and lowest for criticality accidents (adapted from the REAC/TS 1944-2009).

6.1.2 Classification of exposure (Fig. 2)

Acute or chronic (time)

Systemic or local (distribution)

External or internal (pathway)

(Note 1: Pathways for internal exposure: physiological openings [eye, nose, mouth, anus, vagina, and urinary tract], and pathological opening [wound])

6.1.3 Methods to assess an exposure dose

6.1.3.1 Method to assess (estimate) doses for internal exposure (Figs. 3, 4, and 5)

Direct measurement outside the body (mainly gamma radiation): whole body counter (WBC), pulmonary and thyroid monitors

Bioassay (indirect measurement, not only gamma radiation but also alpha and beta rays): samples are collected from physiological and nonphysiological (pathological) openings, as well as from excretory substances (urine, feces, and vomit).

Estimation from the concentration of radioactive substances in the air.

1/effective half-life: 1/physical half-life (radioactivity reduction for individual types of nucleus) + 1/biological half-life (rate of elimination from the body)

(Note 2: the software MONDAL is used on the results from measurements outside the body and from bioassay to practically estimate the doses of internal exposure.

6.1.3.2 Method to assess (estimate) the doses of external exposure:

No radioactive substance is found inside the body (except for exposure to neutrons). Therefore, this assessment is based on estimations using data on exposure conditions. (Fig. 6)

Information about radiation source: nuclide and intensity of radioactivity

Exposure conditions: exposure distance and duration, interruption status

6.1.3.3 Other methods to assess the doses (Fig. 7)

Biological dose assessment: lymphocyte count, abnormal chromosome (dicentric chromosome and ring chromosome).

Clinical symptoms (refer to the ARS section)

6.1.3.4 Summary of dose assessment (Table 1)

Dose for internal exposure should be represented as committed effective dose.

Effective dose = dose for external exposure+dose for internal exposure (committed effective dose)

(Note 3: committed equivalent dose: a dose at which an organ is exposed to radiation after ingestion of a radioactive substance. The dose should be calculated for 50 years in adults and in children until they are 70 years old.)

(Note 4: committed effective dose: a dose representing an effect on the whole body, which is calculated by combining the committed equivalent doses for all organs and the tissue weighting factor allowing for a difference in effect on individual organs.)

6.1.4 Requirements in activities for preparedness and response (Figs. 8 and 9)

Materials/equipment 1: personal dosimeter, measurement device, materials for simplified decontamination, rope and signs used for area control, materials/equipment for curing in facilities, protective clothing, and protector (disposable cap, mask, shoe cover, gloves, Tyvek suit).

Materials/equipment 2: secondary and tertiary radiation emergency hospitals have facilities for body decontamination, wastewater tanks and materials for sampling.

6.1.5 Points to remember and practices in activities for preparedness and response:

General rule that priority should be placed on medical care: the highest priority is placed on evaluation and stabilization of the whole body.

Prevention of secondary disasters: prevention of contamination spread, safety of rescuers (three rules of protection, prevention according to pathways for internal exposure).

Recognition of exposure and contamination conditions (refer to previous section).

Building a team responsible for medical care and sharing of roles is necessary (refer to team medicine).

Decontamination of contaminated body surface: decontamination should be conducted in the following order: i.e., clothing, wounded area, physiological openings and normal skin. To the extent possible, patients should conduct decontamination on their own.

6.1.6 Treatment for internal exposure (Fig. 10)

Objective: to reduce and prevent absorption and internal deposition of radioactive substances.

Criterion for administration: committed effective dose can be used as a reference. However, no criterion is established.

Administration timing: earlier administration is effective.

Different types of nucleus: optional

(1) Iodine tablets: used upon internal exposure to radioactive iodine (accumulation in the thyroid): the tablets should be taken once, in principle, in individuals younger than 40 years old. If the tablets are taken more frequently, in principle, the individual must be under refuge. Timing for oral administration (several hours before exposure for prevention and as soon as possible after exposure)

(2) Prussian blue: used for removal of cesium from the body: Cesium has a similar disposition to potassium: orally administered at a daily dose of 3 – 10 g for at least three weeks, no criterion for treatment discontinuation is established. Timing of oral administration (as soon as possible after exposure)

(3) DTPA: transuranic metals (plutonium, americium, and uranium) are chelated and then expelled in the urine: intravenous injection once daily, no criterion for treatment discontinuation is established.

6.1.7 Exposure preparedness and response/particularities of patients:

Patients have no symptomatic symptoms at the moment of exposure (no sensation).
Onset of symptoms may require longer time (later onset): presumption of prognosis is difficult.
Internal radiation exposure is prolonged for as long as radioactive substance exists within the body.
Anxiety and harmful rumors are likely to occur.
Fundamental knowledge of radiation is necessary.
Advice from specialized agencies may be necessary.

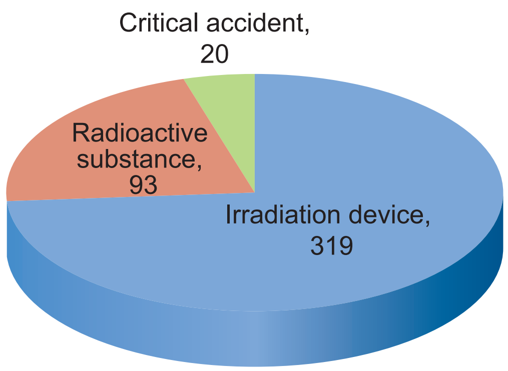
6.1.8 Differences from general medicine

Healthcare professionals must be protected from radiation.
Contaminated materials must be managed.
Therapeutic strategies must be determined based on dose estimation.
Cooperation must be obtained from radiological assessors.

6.1.9 **Summary** (Fig. 11)

Flow chart

Diagrams



Irradiation device			319
	Sealed radiation source	210	
	X-ray unit	83	
	Accelerator	25	
	Radar battery	1	
Radioactive substance			93
	Therapeutic diagnosis	38	
	Transuranic element	28	
	Fission products	11	
	Tritium	2	
	Radium contamination	1	
	Others	13	
Critical accident			20
	Critical facility	8	
	Accelerator	6	
	Chemical reaction	6	
		Total	432

Source: REAC/TS Registry

Fig. 1 Incidences of Radiation Accidents

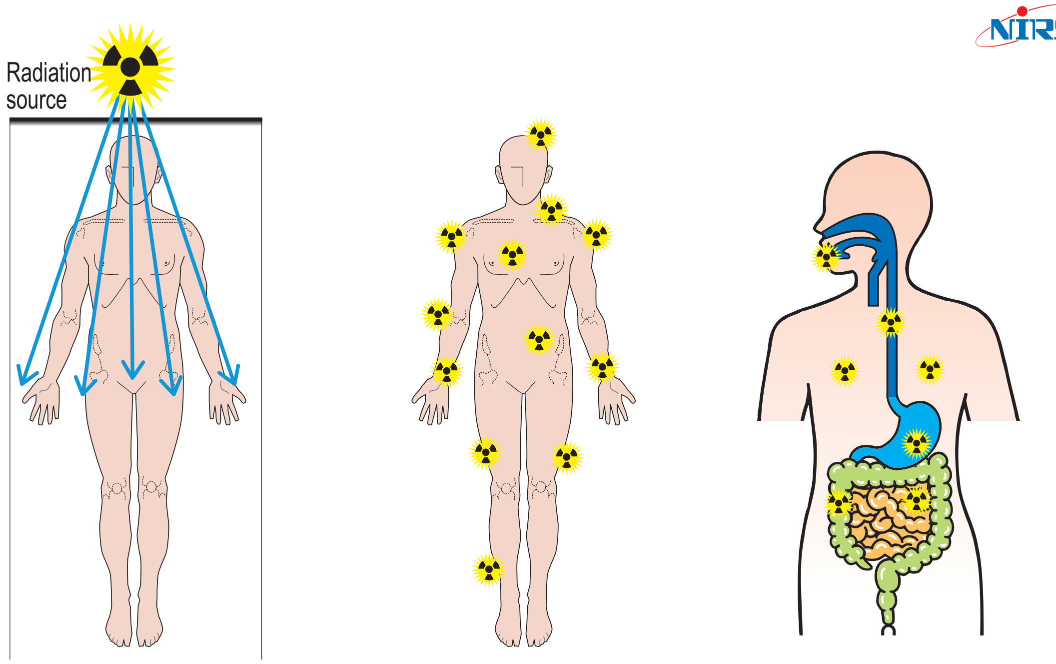


Fig. 2 Differences among Contamination Outside, Inside and on the Surface of the Body

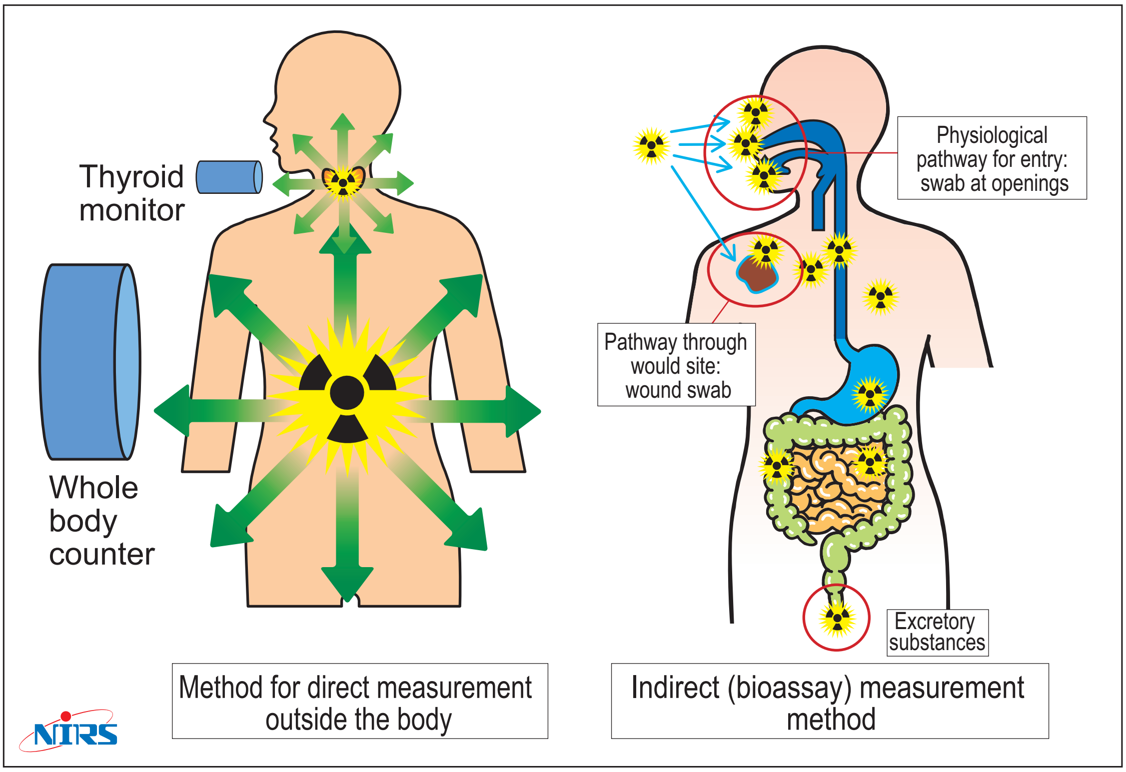


Fig. 3 Dose Estimation for Internal Exposure

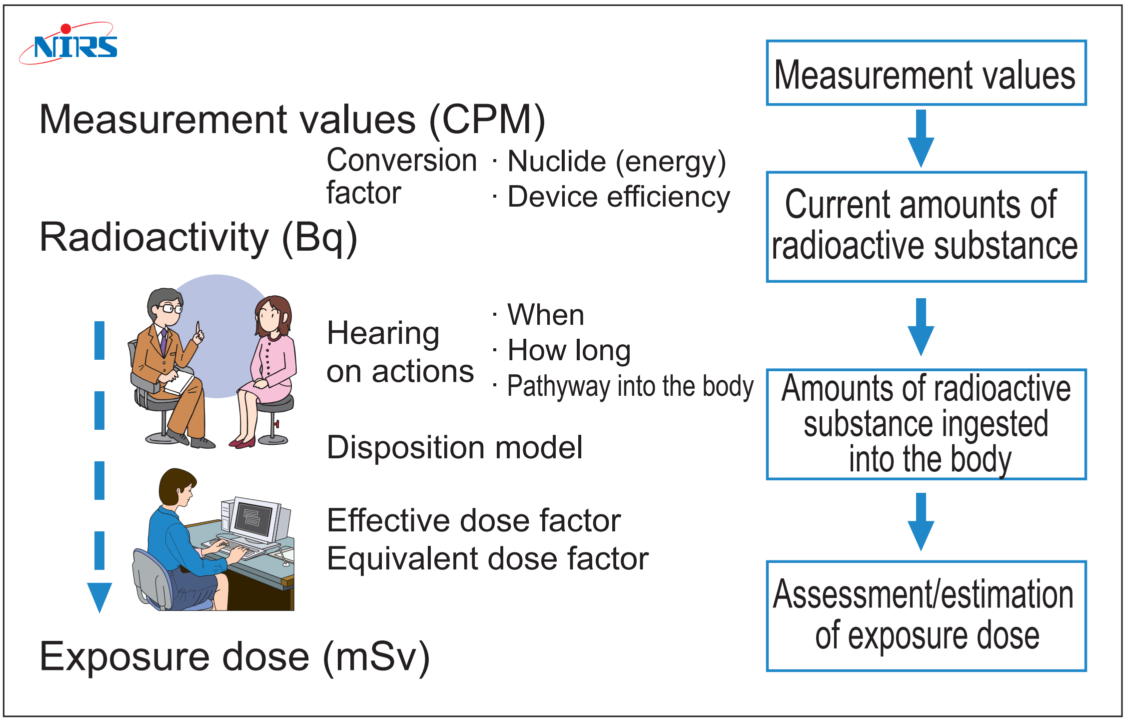


Fig. 4 Determination of Exposure Dose Based on Measurement Values

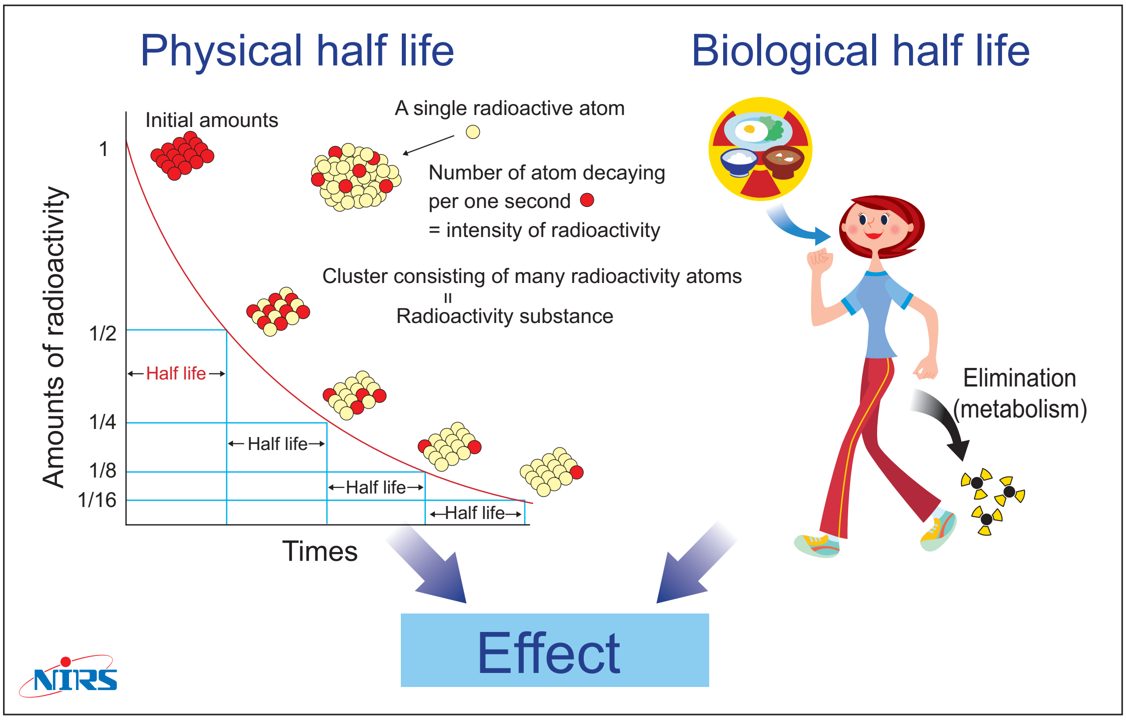


Fig. 5 Effective Half Life

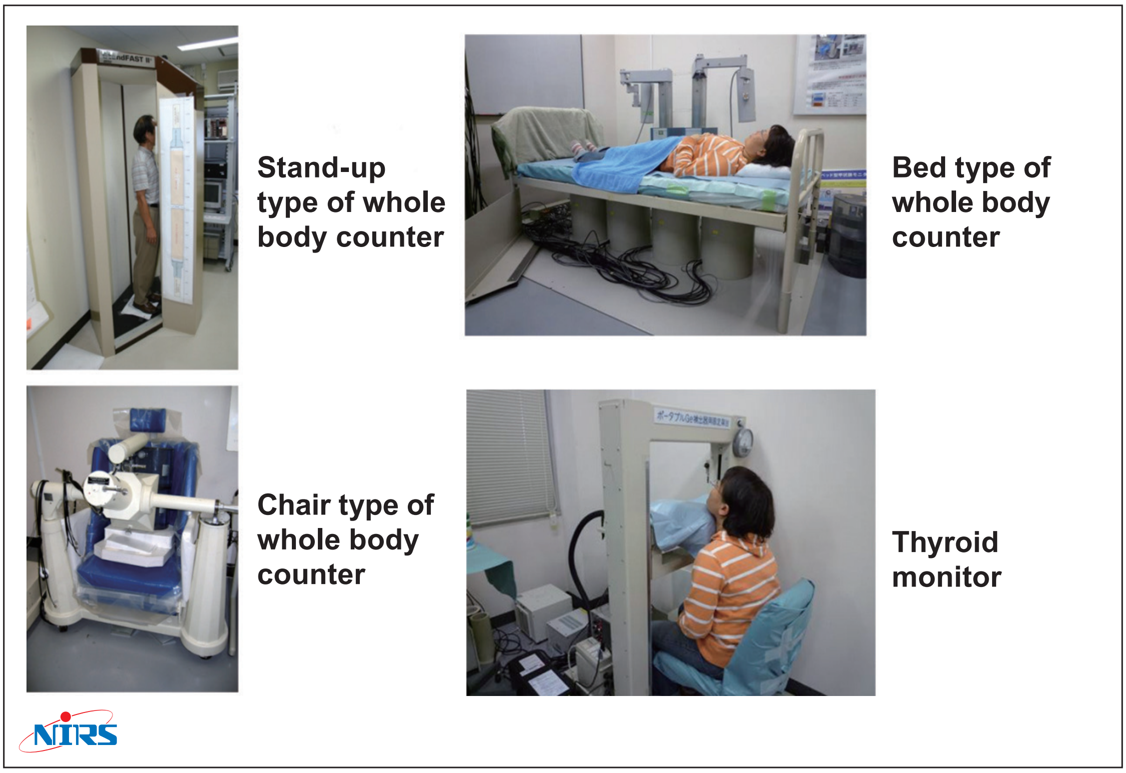
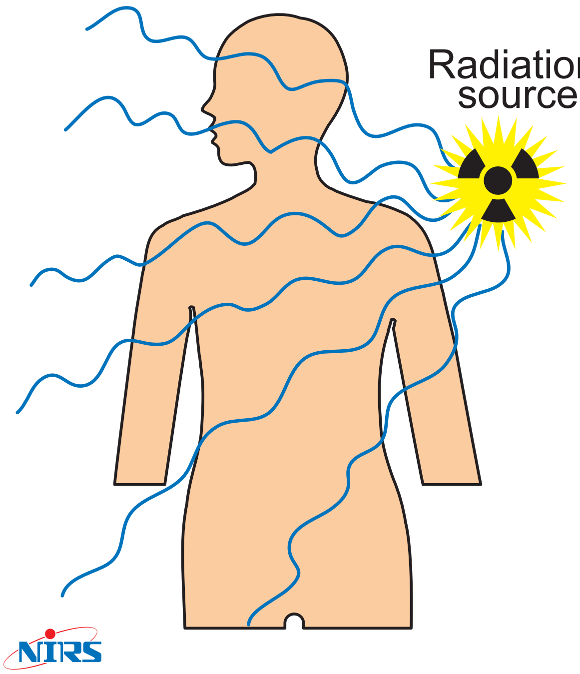


Fig. 6 Different Types of Monitors



In this case, no radioactivity substance exists inside the body of the individual. Therefore the exposure dose is estimated by collecting data on exposure conditions.

Data to be collected

1) Information on radiation source
   Nuclide
   Intensity of radioactivity
2) Exposure conditions
   Distance
   Duration
   Shielding condition
   Posture, etc.
   (if possible, reproduction)

Fig. 7 Examination for Dose Estimation in External Exposure

Table 1 Dose Estimation Based on Clinical Symptoms and Biological Evaluation

	Findings	Duration	Dosage (Gy)
Clincal symptoms	Nausea and vomiting	48 hours	~1
	Erythema	Several hours to several days	~3
	Loss of hair	2 to 3 weeks	~3
Hematologic values	Lymphocyte count < 1000/mm^3	24 to 72 hours	~0.5
Chromosome analysis	Abnormal chromosome (Decentric, ring etc.)	Several hours (it takes several days to obtain the results.)	~0.2

(Source: IAEA/WHO Safety Report Series No.2, 1998, applied)

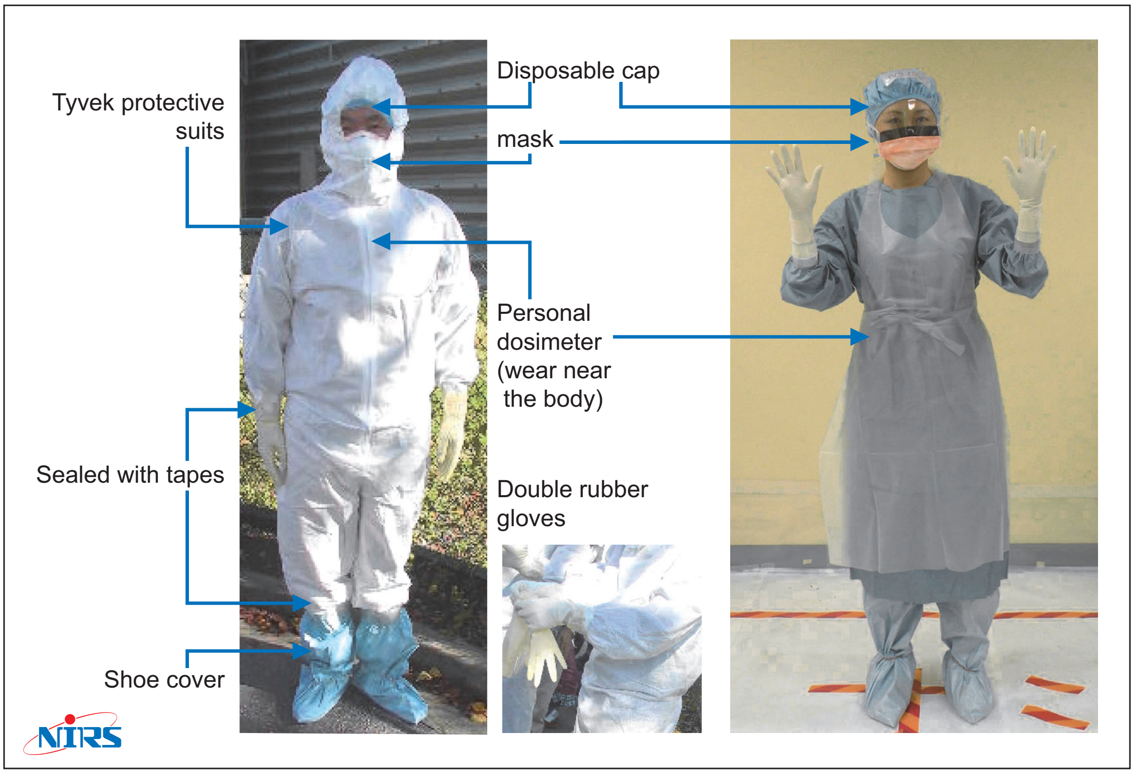


Fig. 8 Protective Clothing
(persons responsible for decontamination and healthcare professionals)

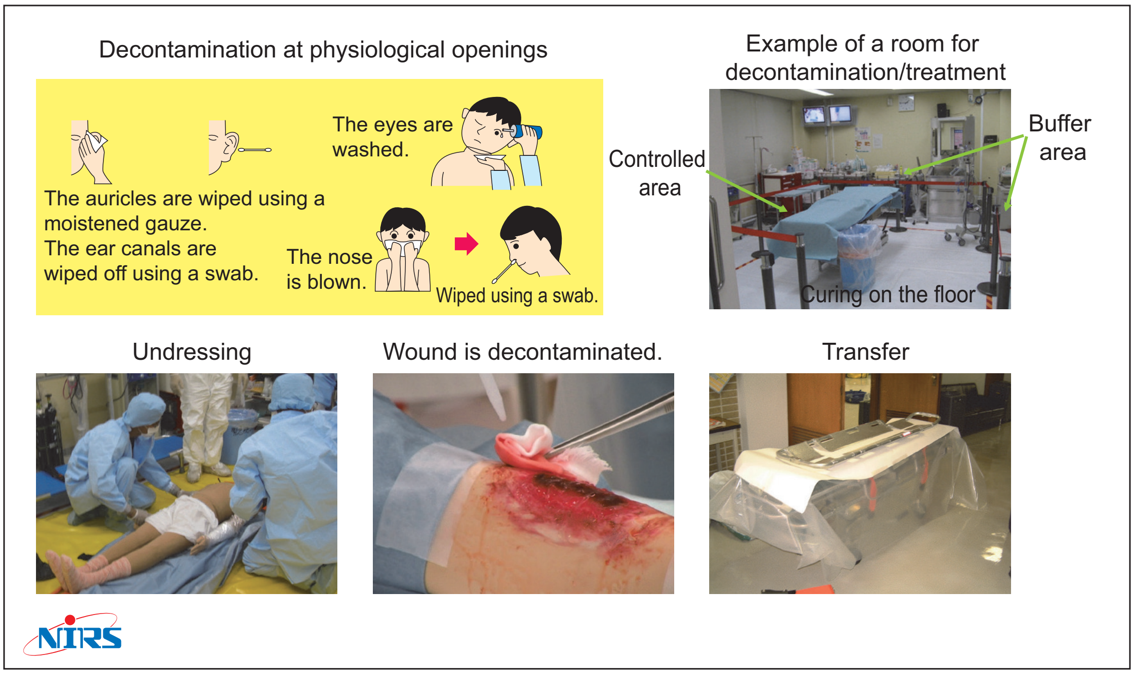


Fig. 9 Examples of Decontamination and Curing

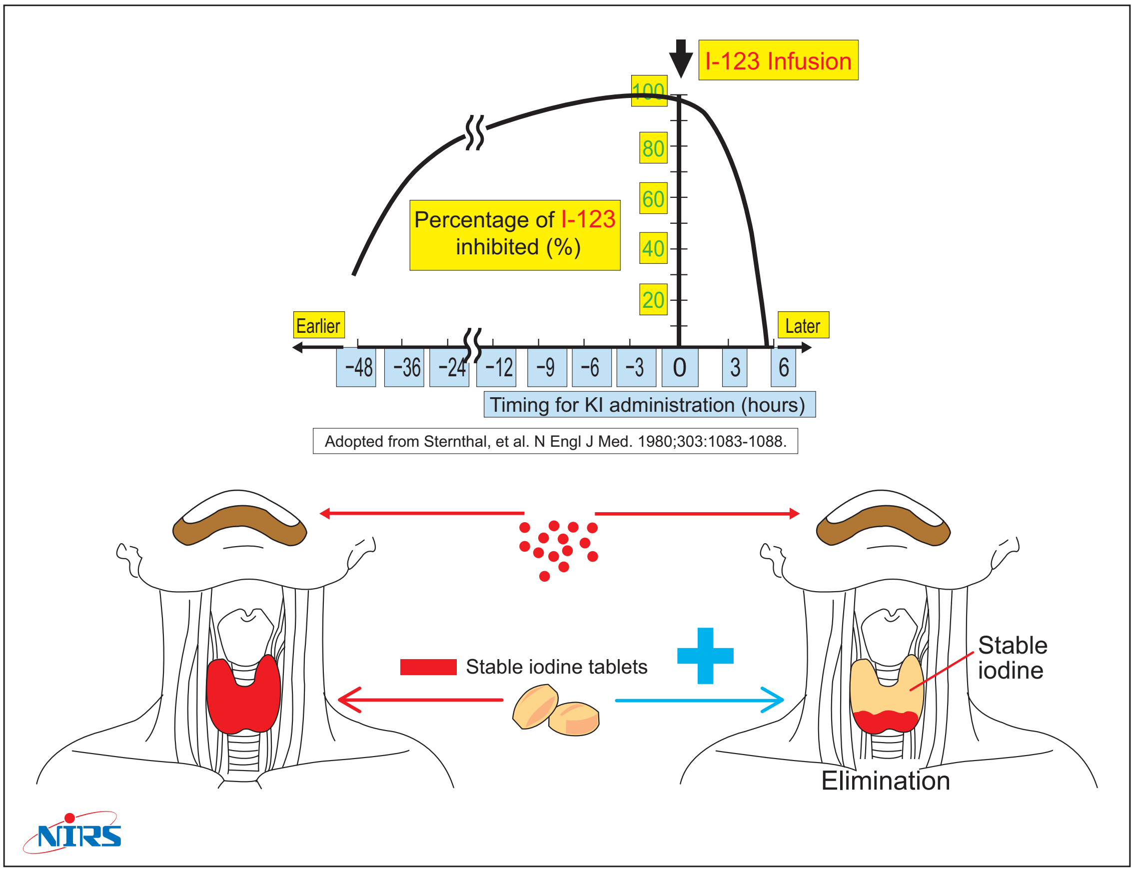


Fig. 10 Administration Timing and Mechanism for Iodine Tablets

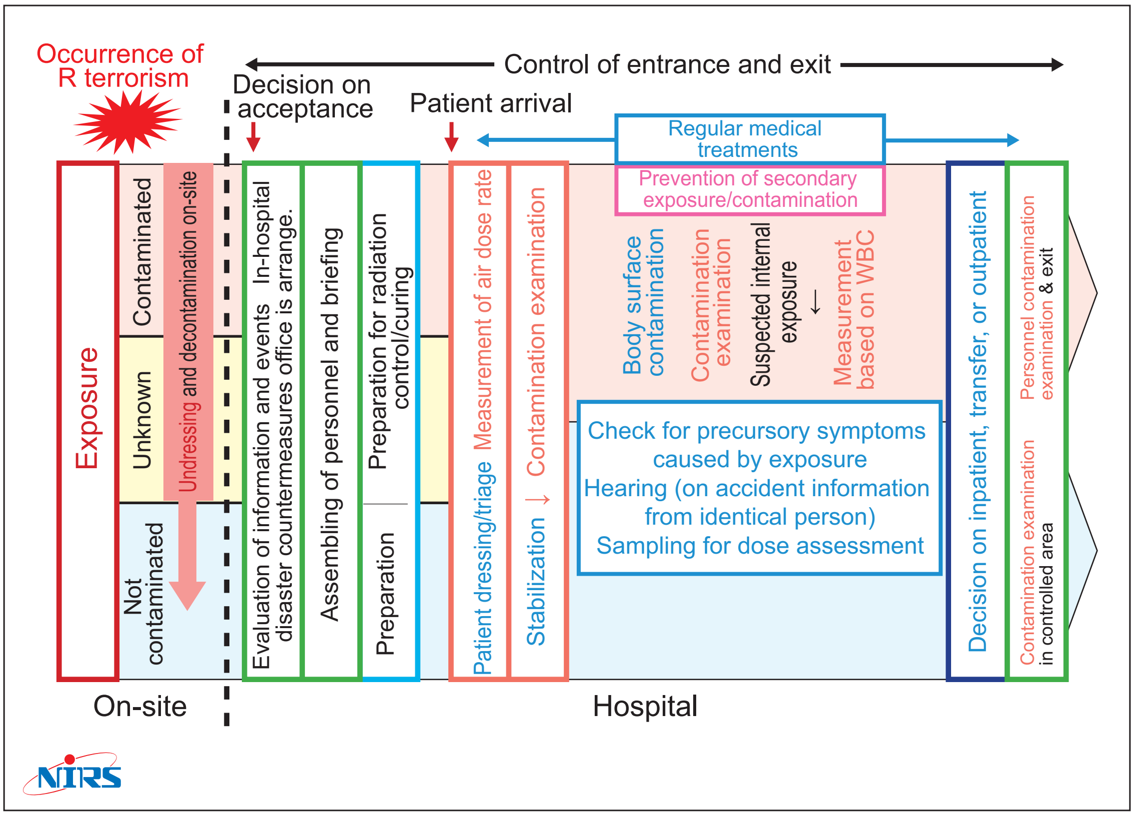


Fig. 11 Flow Chart for Responses to Exposed Patients

Exercises

Question 1. When a patient exposed to radiation due to faulty operation of irradiation equipment is transferred to a hospital, which of the following is the correct response?

a. Wear a Tyvek suit
b. Attach a personal dosimeter
c. Cure in a treatment room
d. Nose smear
e. Collect blood

Question 2. A 30-year-old man was involved in a nuclear reactor accident while working at a nuclear reactor. Upon consulting a doctor immediately after the accident, 500 mSv of radioactive iodine I-131 was detected on a thyroid monitor. Which of the following is <u>incorrect</u>?

a. Measurement using a whole body counter
b. Administration of Prussian blue
c. Administration of iodine tablets
d. Nose smear
e. Skin cleansing

Question 3. A whole body counter mainly measures which of the following?

a. Alpha-rays
b. X-rays
c. Gamma-rays
d. Beta rays
e. Neutrons

Exercise answers and explanations

Answer to Question 1: e

This question addresses the difference between external and internal exposure. External exposure is not associated with contamination and the patient has no radioactive substances. Therefore, the Tyvek suit, personal dosimeter, nose smear and curing are unnecessary. Blood should be collected for dose estimation (white blood cell count, abnormal chromosome).

Answer to Question 2: b

This question comprehensively addresses the conditions for drug selection, medication and examination of internal exposure after an individual has been exposed to radiation. One of the conditions for measurement of internal exposure is the absence of contamination on the body surface. Therefore, contamination on the body surface should be removed using, for example, skin cleanser. Then, internal exposure should be assessed using, for example, a whole body counter. As the thyroid was found to contain a dose equivalent to 500 mSv, it exceeds the criterion for administration of iodine tablets (100 mSv). A nose smear is used to examine for internal exposure. (as of March, 2012)

Answer to Question 3: c

This question addresses basic knowledge. The question addresses application of whole body counters, which are increasingly drawing attention.

Teaching support materials for advanced students

Kinkyu Hibaku Iryo Text (Acute medical management of radiation accident victims), supervised by Yoshiro Aoki, Kazuhiko Maekawa. Tokyo: Iryo-kagakusya, 2004.
Genshiryoku bosai kiso yougo-syu (glossary of basic terms for nuclear accident prevention) by the Nuclear Safety Technology Center

Unit name	6.2 Radiation Emergency Medical Response System in Japan
Items related to core curriculum	• Be able to explain the system of emergency medicine and home healthcare in communities. • Be able to explain the necessity of establishing a medical care system and on-site triage in the event of disasters.
General objectives	• Radiation emergency medical response system
Extended objectives	• Be able to give an overview of the radiation emergency medical response system in Japan.
Points to understand	• Radiation emergency medical response system in Japan
Essential teaching points	• Radiation emergency medical response system
Keywords	Primary, secondary, and tertiary radiation emergency hospitals
Reference tutorials	15, 16

Outline

6.2.1 Laws etc., related to nuclear disaster measures

Nuclear disaster measures in Japan are summarized in the Basic Disaster Prevention Plan made by the Central Disaster Prevention Council based on the Disaster Countermeasures Basic Act.

The nuclear disaster measures edition of the Basic Disaster Prevention Plan was revised to include processing, storage, disposal facilities and transport, in addition to the conventional nuclear power plant and reprocessing facilities following the criticality accident in the JCO uranium-processing plant in September 1999.

Taking into account lessons learned from the criticality accident at the JCO uranium-processing plant, the necessity became evident of sharing information among the national and local government nuclear disaster headquarters and taking measures to liaise and, thereby, smoothly implement countermeasures when nuclear disasters occur. This led to the establishment of the Act on Special Measures Concerning Nuclear Emergency Preparedness in June 2000.

6.2.2 Radiation emergency medical response system

Based on the experiences of medical responses to the criticality accident at the JCO uranium-processing plant, the Nuclear Safety Commission of Japan approved the Medical Guideline for Radiation Emergencies in June 2001 to make the radiation emergency medical response system more effective.

In Japan as of April 2012, only 19 prefectures have established radiation emergency medical response system, these being the one hosting nuclear facilities, or adjacent prefectures. These prefectures have designated primary and secondary radiation emergency hospitals in regions near nuclear facilities, and these hospitals are focused on training and exercises to respond to nuclear disaster as well as to improve facilities and materials.

Japan's radiation emergency medical response system splits the 19 prefectures into two regional blocks, East and West, with the National Institute of Radiological Sciences (NIRS) and Hiroshima University designated as tertiary radiation emergency hospitals.

NIRS has constructed the radiation emergency medical response network council, chromosome network council and physical dose assessment network council to cooperate with external specialists in matters related to radiation emergency medical response. These networks will enable enhancement of radiation emergency medicine through information exchange, cooperation in research and regular human interaction.

In response to the Tokyo Electric Power Company Fukushima Daiichi nuclear plant accident in March 2011, the addition of prefectures adjacent to those with nuclear facilities is under considerations.

6.2.3 Role of radiation emergency hospitals

Primary radiation emergency hospital: provides initial medical treatment to patients with or without contamination who are transferred from regions near nuclear facilities, including responding to accidents or sickness covered by general emergency medical care.

Secondary radiation emergency hospital: provides dosimetry, decontamination and specialized medical treatment, if necessary on an inpatient basis, to patients who cannot be handled at primary radiation emergency hospitals.

Tertiary radiation emergency hospital: provides specific dose assessment in cooperation with the relevant facilities that work together in terms of dose assessment, radiation protection and medical practices, etc. These hospitals also practice radiation emergency medical response in cooperation with primary and secondary radiation emergency hospitals.

Diagrams

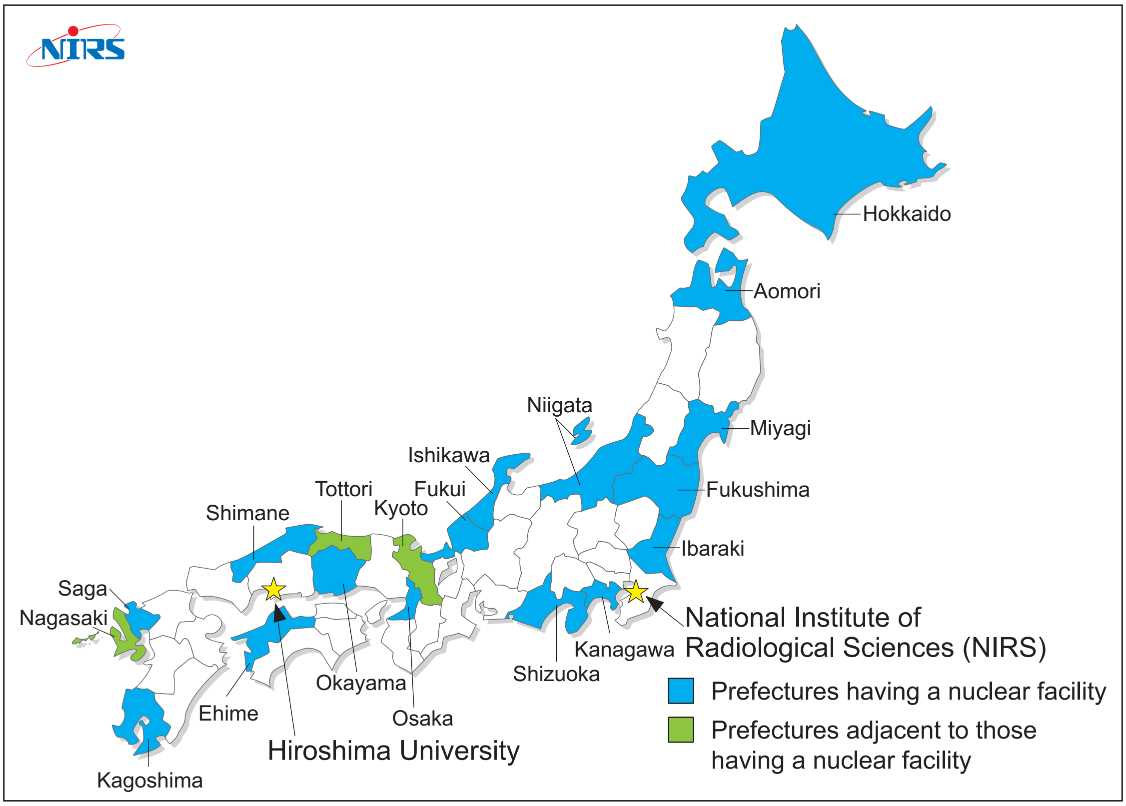


Fig. 1 Prefectures with Nuclear Facilities and Adjacent Prefectures (as of March, 2012)

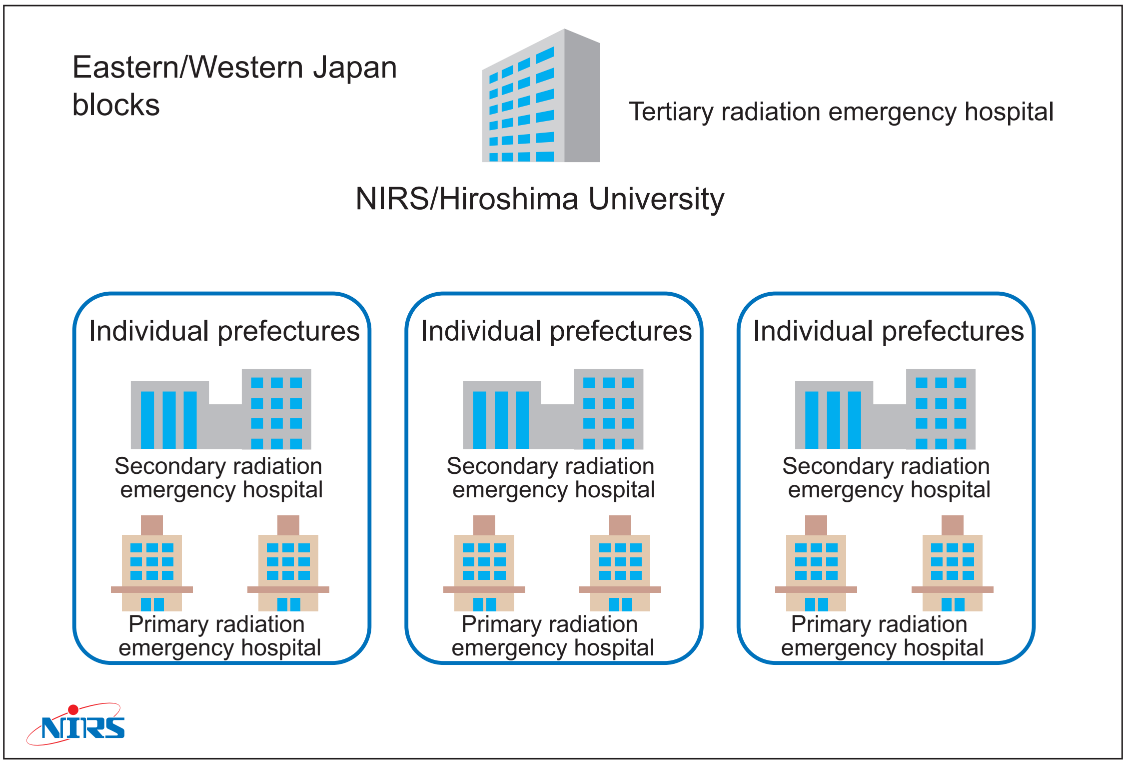


Fig. 2 Radiation Emergency Medical Response System

Exercises

Question 1. Which of the following is not the role of a radiation emergency hospital?

a. Emergency medical care
b. Examination for body surface contamination
c. Decontamination
d. Measurement using a whole-body counter
e. Environment monitoring

Question 2. Which of the following is correct for a system for radiation emergency preparedness and response?

a. Set up in all prefectures.
b. Does not respond to accidents at reprocessing facilities.
c. Secondary radiation emergency hospitals do not provide in-patient treatment.
d. Quaternary radiation emergency hospitals provide advanced assessments of radiation doses.
e. The National Institute of Radiological Sciences (NIRS) and Hiroshima University are designated as local tertiary radiation emergency hospitals.

Exercise answers and explanations

Answer to Question 1: e

However trauma and acute disease life-threatening, radiation exposure and contamination do not lead to immediate death. Therefore, the highest priority in radiation emergency medicine is placed on medical practices such as emergency medical treatment rather than contamination survey or decontamination. Additionally, radiation emergency hospitals set and manage whole body counters for dose assessment of internal exposure.

Answer to Question 2: e

As of April 2012, the system for radiation emergency medical response has been set up only in 19 prefectures, which are those with nuclear facilities or adjacent prefectures. The system covers not only accidents at nuclear power plants but also reprocessing, processing, storage, and disposal facilities, as well as transport. Furthermore, as local tertiary radiation emergency hospitals, the National Institute of Radiological Sciences (NIRS) and Hiroshima University are designated to provide more specific dose assessments, etc.

Teaching support materials for advanced students

Nuclear Safety Commission of Japan: *Medical Guidelines for Radiation Emergencies* by the Nuclear Safety Commission of Japan working group specializing in nuclear installations, June 2001 (partially revised in October 2008)

Unit name	6.3 Team Medical Care
Items related to core curriculum	• Be able to explain the necessity of establishing a medical care system and on-site triage in the event of disaster.
General objectives	• Radiation emergency medical response system
Extended objectives	• Be able to give an overview of the importance of team medical care in emergency preparedness and response.
Points to understand	• Cooperation between doctors and co-medical staff
Essential teaching points	• Importance of radiological assessor in the activities in radiation emergency medicine and of team medical care
Keywords	Radiological assessor, dose assessment
Reference tutorials	15, 16

Outline

6.3.1

Medical care cannot be accomplished by physicians alone. Doctors need to cooperate with various types of co-medical staff. Such cooperation is needed in radiation emergency medical response to ensure its smooth and rapid progress. Specialized knowledge and skills regarding radiation and radioactive substances are needed in particular in radiation emergency preparedness and response, therefore advice and support on protection from radiation, health physics and dose assessments from experts are essential. A radiological assessor plays an important role in the actual activities involved in radiation emergency medical response. In addition, treatment of contaminated patients requires more medical workers than usual medical treatment and treatment areas are divided into hot and cold zones to prevent the spread of contamination.

6.3.2 Staff actively involved in radiation emergency medical response and their roles

(1) Doctors: 1) Provide treatment to patients based on advice, etc., from experts. 2) Ensure the safety of medical staff. 3) Order necessary examinations (including dose assessments for external exposure, identification of nuclides involved in contamination and dose assessments for internal exposure). 4) Prepare medical records.

(2) Nurses: 1) Prepare necessary materials/equipment. 2) Assist in treatment. 3) Prepare nursing records.

(3) Medical radiologic technicians or radiological assessors: 1) Control exposure among medical staff. 2) Examine contamination, documentation and dose assessments of patients. 3) Manage/analyze biologic samples. 4) Manage radioactive waste. 5) Manage radiation controlled areas.

(4) Medical technicians: 1) Clinical laboratory tests. 2) Manage biologic samples.

(5) Pharmacists: 1) Provide, dispense and manage medicines in hospitals, etc. 2) Cooperate with doctors in medicine administration.

(6) Management coordinators: 1) Manage/process information. 2) Public relations. 3) Procure necessary materials/equipment.

6.3.3 Radiological assessors

A radiological assessor is an expert who considers the effects of radioactive substances on human and conducts safe and efficient management of these substances in the establishments dealing with radioactive substances. The radiological assessor has expertise in radiobiology, physics, chemistry and laws and regulations. Therefore, in the setting of radiation emergency preparedness and response, the assessor works together for to examine physical contamination, decontamination, measurement of exposure doses in patients and to prevent the spread of contamination and contamination survey in medical facilities, transport vehicles and materials/equipment.

6.3.4 Radiation emergency medicine and dose assessment

In radiation emergency medicine, dose assessment is important in diagnosis of radiation esposure, deciding on therapeutic strategies and prognostic evaluation, which requires specialized skills, techniques and knowledge. Experts in physical and biological dose assessments are not always posted at radiation emergency medical institutions and hospitals, therefore there are cases where dose assessment needs to be outsourced to experts from other institutions. Dose assessment for external exposure requires such items as values obtained from personal dosimeters, exposure conditions (time point and duration) and information on chromosome analysis. Dose assessment for internal exposure, meanwhile, requires information on ingestion or inhalation conditions of radioactive substances and samples including urine and feces. Staffs involved in radiation emergency medicine are also responsible for providing information to dose assessment experts, indicating a necessity for mutual collaboration.

Diagrams

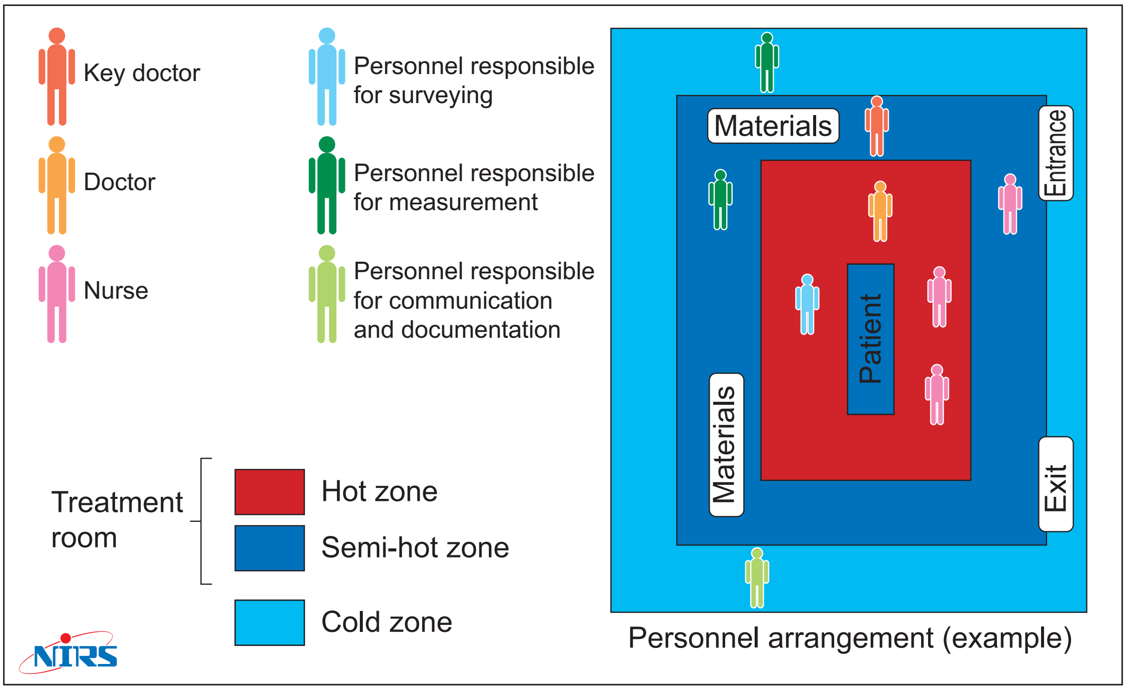


Fig. 1 Example of Personnel Positioning in a Treatment Room

Exercises

Question 1. Which of the following is not the role of physicians in radiation emergency medicine?

a. Deciding on therapeutic strategies
b. Radiation dose assessment
c. Information sharing with associated staff
d. Decontamination of transfer equipment (for example, ambulances)
e. Decontamination and treatment of patients

Exercise answers and explanations

Answer to Question 1: d

Dose assessment requires specialized knowledge and skills. Therefore, advice from experts. This makes information sharing and cooperation within a team vital.

Teaching support materials for advanced students

Nuclear Safety Commission of Japan: *Medical Guidelines for Radiation Emergencies* by the Nuclear Safety Commission of Japan working group specializing in nuclear installations, June 2001 (partially revised in October 2008)

Appendix

Examples of Tutorial Exercises

1. Worry about hot spring

1-1

Tanja is a woman in her 80s who likes hot springs. She heard that radium hot springs were good for her health and bathed there every month. But, she recently heard that radium is a radioactive substance and became worried. Does radium have ill effects on the body? What explanations should be given to Tanja?

Points for instruction

(1) Understand radium isotopes.
(2) Understand radioactive isotopes in nature.

1-2

What's the difference between radium produced in an accident and radium in hot springs? Are other types of naturally occurring radiation a cause for concern?

Points for instruction

(1) Understand the types and doses of natural radiation.
(2) Understand their effects.

Related unit	2.1 What are Radiation and Radioactive Materials?

2 Radiation exposure during clinical training

2-1

While undergoing training at a hospital, William saw a radiologist with a radiation-measuring device attached to him. How can he explain what it is to a classmate who will rotate department of radiology?

Points for instruction

(1) Understand measurement of medical radiation.

2-2

The classmate asked whether patients or nurses also needed to attach the device, and who needs it, when? Explain.

Points for instruction

(1) Understand exposure control among those involved in radiation medicine.

Related units	2.2 Measurement, Dose and Units 5.3 Occupational Exposure

3 Explanation of radiothrapy

3-1

During training at a hospital, you were responsible for a patient Mr. Aoki, who was undergoing chemo-radiotherapy treatment for lung cancer. Mr. Aoki asked if radiation burns off the disease like a laser or if it also damages healthy cells. How will you explain to Mr. Aoki the physical effects of radiotherapy?

Points for instruction

(1) Understand the biological action of radiation.
(2) Understand the difference in radiation sensitivity among tissues.

Related unit	3.1 Radiation Biology

4. Anxiety about breastfeeding

4-1

Maria is breastfeeding. She had a cough, so had a check-up that involved a chest X-ray. The radiogram showed no abnormalities, but she's worried about radiation in her breast milk. Does radiation have such an effect? How can you explain this to Maria?

Points for instruction

(1) Understand the difference between radiation and radioactive materials.
(2) Understand the effects of chest X-rays.

4-2

X-rays showed there was no effect on breast milk. But are other types of radiation-based examinations in hospitals not a cause for concern?

Points for instruction

(1) Understand examinations using radioactive materials.
(2) Understand the effects of these.

Related units	3.2	Effects of Radiation on Health
	5.2	Public Exposure
	5.4	Medical Exposure and Exposure at Hospitals

5. Honeymoon baby

5-1

You are an obstetrician. A newlywed patient called Ann traveled abroad and used a home pregnancy test to confirm she was pregnant. She went through an airport X-ray, is now worried that radiation may have affected her fetus and asks whether she should have an abortion. Ann is on the verge of tears through anxiety and misunderstanding. Does such an X-ray examination have an effect? What's the best explanation to give to Akemi?

Points for instruction

(1) Know about airport X-ray dose and effects.
(2) Understand the effects of radiation and its doses.

5-2

Airport X-rays have no effect on fetuses. But what about other types of X-rays at hospitals?

Points for instruction

(1) Understand medical exposure and dose.
(2) Understand the effects of these.

Related unit	3.2	Effects of Radiation on Health

6. Long-awaited pregnancy

6-1

You are a general practitioner specializing in internal medicine, and took over running your father's clinic. Your patient, Carol, is 40 and your elementary school classmate. She consulted you because of vomiting and loss of appetite and sought a thorough examination. An abdominal endoscopy and abdominal ultrasonography revealed no abnormalities. You monitored her condition for two weeks under medication but she showed no improvements. She underwent a pelvic CT scan, which indicated no lesions were potentially causing her condition, and you decided to observe her. Carol later visited your office to report that she was pregnant after she had consulted with a gynecologist upon missing her period. She guessed she had undergone a CT in the ninth week of pregnancy. Carol had been unable to conceive in 12 years of marriage, so neither you, nor her, thought she could have children. You feel responsible. Is it all right for Carol to continue her pregnancy? Is there a possibility of effects on the fetus?

Points for instruction

(1) Understand about dose associated with CT examination and effects on a fetus.
(2) Understand about radiation and effects of the dose and radiation quality on a fetus.

Related units	3.2 4a.1 5.4	Effects of Radiation on Health Principles, Practice and Side Effects in Radiodiagnosis Medical Exposure and Exposure at Hospitals

7.Sympton of an angina patient

7-1

You are a doctor, specializing in cardiovascular internal medicine, and working at a university hospital. A patient, 65-year-old Mr. Li, has angina and severe stenosis in several parts of the anterior descending coronary artery. After some procedures over several years, including catheterization of the heart and PTCD, he developed sore-like symptoms in the skin of his anterior chest wall, corresponding to the area around the heart. Is there a possibility this symptom is treatment related? How can you establish a cause for this symptom?

Points for instruction

(1) Examine the IVR dose and effects on normal tissues.
(2) Understand methods of estimating radiation dose.

Related unit	3.2	Effects of Radiation on Health

8. Heavy smoker

8-1

Terry, 82, a heavy smoker and grandfather of your close friend, Jean, regularly visits a local internal medicine clinic for treatment of emphysema and angina. A regular chest X-P revealed a 1.5-cm abnormal mass in his right superior lobe of lung. Jean consulted you, asking about the type of examinations that should be given in the future.

Points for instruction

(1) Understand diagnosis techniques for suspected lung cancer.

8-2

The result of a thorough examination at a university hospital led to a diagnosis of IA stage peripheral lung carcinoma. What treatment do you recommend?

Points for instruction

(1) Understand medical treatments for non-small-cell lung cancer.

Related units	4a.1 4a.2 4b.1	Principles, Practice and Adverse Effects in Radiodiagnosis Principles, Practice and Adverse Effects in Diagnostic Nuclear Medicine Principles, Practice and Adverse Effects in Radiotherapy

9. Abnormal mass of her breast

9-1

Your close friend, Diana, was instructed to receive a detailed examination of her right breast based on the results of a company health check involving an echography and mammogram. She has no palpable lump in the breast and works healthily without showing any symptoms. What examinations should she undertake from now?

Points for instruction

(1) Understand diagnosis techniques for suspected breast cancer.

9-2

Diagnostic imaging showed a mass localized partially in the mammary gland, and a biopsy revealed ductal cancer in situ. What treatment methods do you recommend?

Points for instruction

(1) Understand medical treatments for early-stage breast cancer.

Related units	4a.1 Principles, Practice and Adverse Effects in Radiodiagnosis 4a.2 Principles, Practice and Adverse Effects in Diagnostic Nuclear Medicine 4b.1 Principles, Practice and Adverse Effects in Radiotherapy

10. Breastfeeding after scintigraphy

10-1

Your cousin Sally is breastfeeding following childbirth. However, she was told she needs to undergo an examination because of reduced renal function after delivery. As she was instructed to stop breastfeeding after a renal scintigraphy, she called you to ask why she would be told this. How should you explain the reason?

Points for instruction

(1) Understand examination methods using radiation isotopes.

10-2

Sally asked if an X-ray of the kidney after an injection of contrast medium would have any effect on breastfeeding. How should you explain?

Points for instruction

(1) Understand the difference between radiation and radioactive materials.

Related units	3.2 Effects of Radiation on Health 4a.1 Principles, Practice and Adverse Effects in Radiodiagnosis 4a.2 Principles, Practice and Adverse Effects in Diagnostic Nuclear Medicine

11. Abnormal genital bleeding

11-1

Your grand-aunt, Sandra, is 90-years-old, lives alone and is comparatively healthy. However, when she had abnormal genital bleeding and consulted with her gynecologist, she was told there was a suspicion of cancer and recommended to have a checkup at a large hospital. What examinations should Sandra undergo in the future?

Points for instruction

(1) Understand diagnosis technique for suspected uterine cancer.

11-2

The results of a thorough examination revealed cervical cancer. Diagnostic imaging showed a mass localized in the uterine cervix, without metastasis. A biopsy showed squamous cancer. What examinations should be conducted in the future?

Points for instruction

(1) Understand treatment methods for cervical cancer.

Related unit	4b.1 Principles, Practice and Adverse Effects in Radiotherapy

12. Father's medical examination

12-1

Your 75-year-old father, Mike, was recommended to consult a doctor due to a PSA value of 15 ng/mL on his check-up. He shows no symptoms of urinary tract problems, such as frequent urination. What examinations should be conducted in the future?

Points for instruction

(1) Understand treatment methods for prostate cancer.

12-2	
A thorough examination revealed prostate cancer. Diagnostic imaging showed a mass localized partially in the prostate. A biopsy revealed he had a Gleason score of 7. What treatments should be conducted in the future?	
Points for instruction (1) Understand treatment methods for prostate cancer.	
Related units	4a.1 Principles, Practice and Adverse Effects in Radiodiagnosis 4a.2 Principles, Practice and Adverse Effects in Diagnostic Nuclear Medicine 4b.1 Principles, Practice and Adverse Effects in Radiotherapy 5.2 Public Exposure

13. Mischievous boy

13-1	
A 13-year-old body visited an outpatient department complaining of symptoms like burns on both hands. He had mild diarrhea and could not recall having held anything hot. About one week earlier, he had found a metal bar of an unfamiliar shape in a pocket of his father's jacket. He thought it was a tool, handled it briefly and then put it in a kitchen drawer. His father had brought this metal bar home about one month earlier. At that time, his father injured his right leg. Though it had only been a mild injury, the father's condition suddenly worsened and he died two weeks ago. This boy lives with his mother and grandmother. (1) What questions should be asked to the boy who visited the hospital? How can an examination plan be created? How should diagnostic procedures be followed? (2) What needs to be considered apart from diagnosis and treatment? What measures should be taken? (3) The incident was reported in a newpaper and neighbors asked questions such as "Does this mean we can't have children?" and "Will this cause genetic diseases in offspring?" What do you think about answers for each of those questions? (4) The boy had a mean systemic exposure dose of 4.2 Gy. If he survives, what problems will occur in the medium- and long-term?	
Points for instruction (1) Understand the nature of radiation and acute radiation syndrome. (2) Understand the importance of mental health care. (3) Understand deterministic and stochastic effects. (4) Understand late-onset effects.	
Related units	3.2 Effects of Radiation on Health 5.1 Radiation Risks and Protection 5.2 Public Exposure

14. Cheerful boy

14-1
Han is a healthy, 3-year-old boy. While playing with friends, he fell off the stairs on a slide in a park near his home, bruising his right elbow after hitting some concrete. He cannot extend his right arm because of the pain. His mother took him to consult an orthopedic department and was instructed to have him undergo an X-P examination of the arm because of a suspected bone fracture. He cannot remain motionless alone. What should be done?
Points for instruction (1) Understand the validity of medical exposure. (2) Understand the risks of radiation.

14-2

His mother is pregnant. Who should look after Daiki? What can be done to reduce exposure for the care-giver?

Points for instruction

(1) Understand the concept of medical, occupational and public exposure.
(2) Understand actual radiation protection.

Related units	3.2 Effects of Radiation on Health 4a.1 Principles, Practice and Adverse Effects in Radiodiagnosis 5.1 Radiation Risks and Protection 5.2 Public Exposure 5.3 Occupational Exposure 5.4 Medical Exposure and Exposure at Hospitals

15. Nuclear power plant accident

15-1

You are an obstetrician in Tokyo. Today is March 16, 2011. It is the fifth day since the Great East Japan Earthquake occurred. Reports on an accident at a nuclear power plant are causing great anxiety among citizens. Radiation levels are also rising in Tokyo. Eri, one of your patients, is the 6th month of pregnancy and has a 3-year-old child. She consulted with you about getting out of danger at an early time. What effects will occur? How should she handle this situation?

Points for instruction

(1) As a doctor, consider how you should respond to a radiation exposure accident.
(2) Understand the difference in effects caused by radiation exposure accidents according to exposure patterns and radiation dosage.

Related units	3.2 Effects of Radiation on Health 5.1 Radiation Risks and Protection 6.1 Preparedness and Response 6.2 Radiation Emergency Medical Response System in Japan 6.3 Team Medical Care

16. Industrial physician

16-1

You are a company doctor working for Number One Construction Co. At about 8 p.m., you receive notification on your mobile phone that a work refitting a plant dealing with radiation has been exposed and a request is made for instructions on how to proceed. What should happen first?

16-2

Who should you contact?

Points for instruction

(1) As a doctor, consider how you should respond to a radiation exposure accident.
(2) Understand the difference in effects caused by radiation exposure accidents according to exposure patterns and radiation dosage.
(3) Understand methods for communicating.

Related units	3.2 Effects of Radiation on Health 5.1 Radiation Risks and Protection 5.3 Occupational Exposure 6.1 Preparedness and Response 6.2 Radiation Emergency Medical Response System in Japan 6.3 Team Medical Care

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This document provides systematic educational references based on the items relevant to radiation exposure, radiation protection and radiation medicine in the Model Core Curriculum for Medical Education in Japan. This document can be utilized not only in the setting of medical education but also as a reference for self-learning of medical students.

We expect widespread use of this document will enhance basic education among medical students in the fields of radiation protection and radiation medicine to improve such things as radiation medical treatment in Japan.

Since contents of this document are based on the information as of March 2012, we intend to revise it according to the results of policy deliberation in the Japanese Government etc..

We thank all those who cooperated in preparing this document.

April 2012
National Institute of Radiological Sciences

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