Safe Handling of Radiation and Radioisotopes (Basics)

Safe handling I

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Kumamoto University
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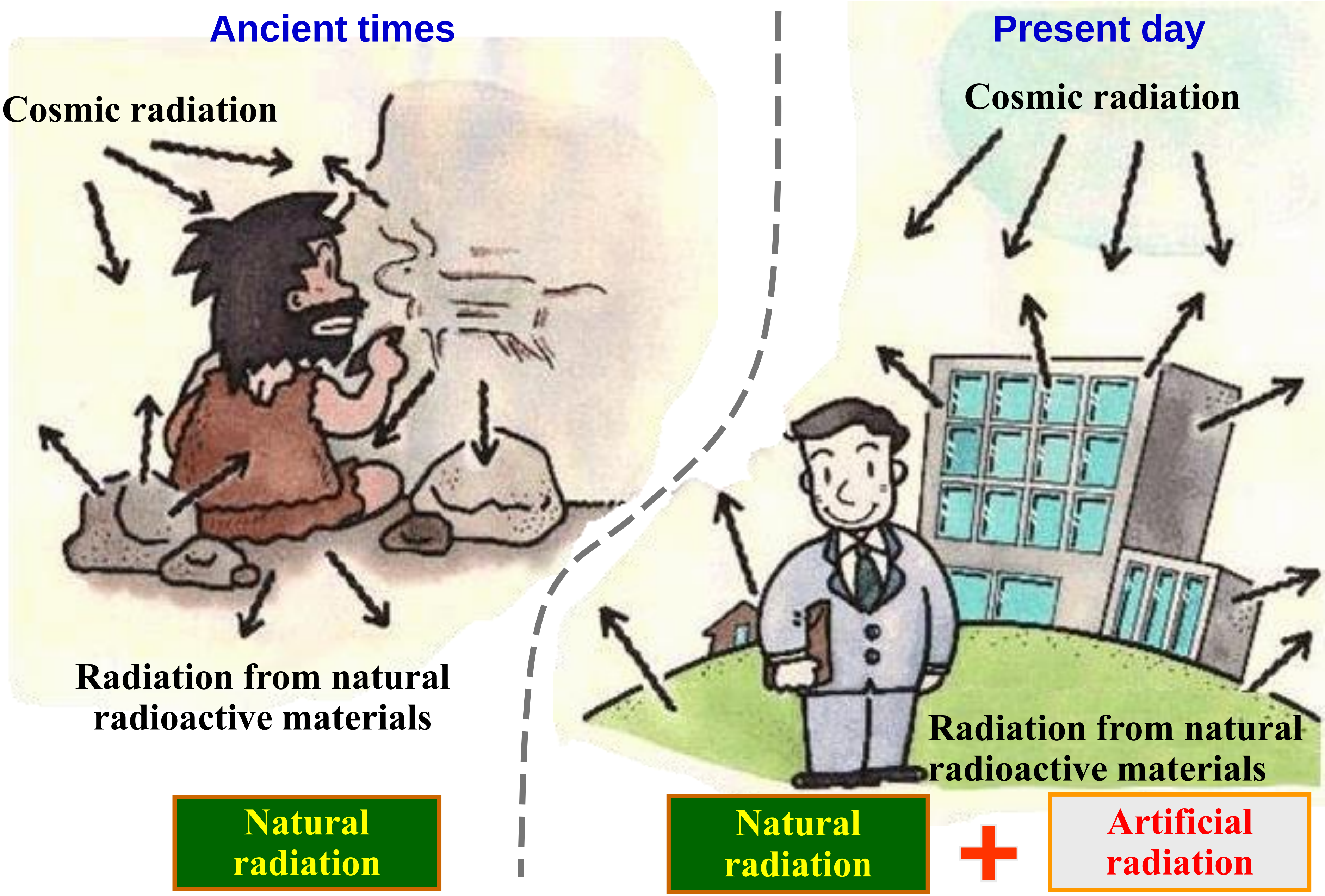
2023

Human evolution and radiation

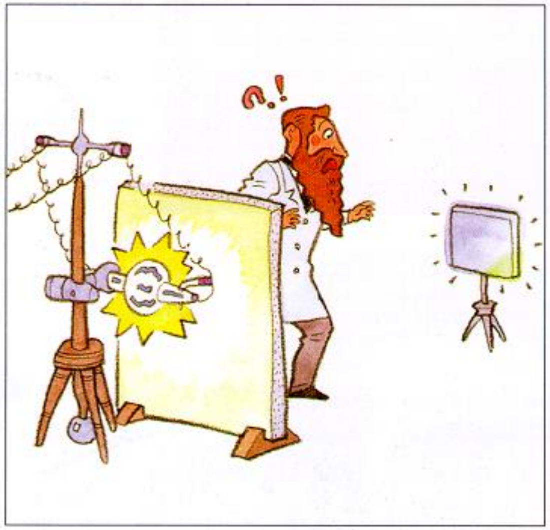
Since the beginning of time, all living things have been, and are still being, exposed to radiation.



Discovery of X-rays

1895 Dr. Röntgen discovered X-rays

Wilhelm C Röntgen
(Germany)



Vacuum discharge experiment

X-ray photograph of a human hand taken by Dr. Röntgen for the first time in the world

Started application to medicine

Discovery of radioisotopes and radioactivity

1896 Becquerel discovered that uranium ore emits radiation

Natural radiation

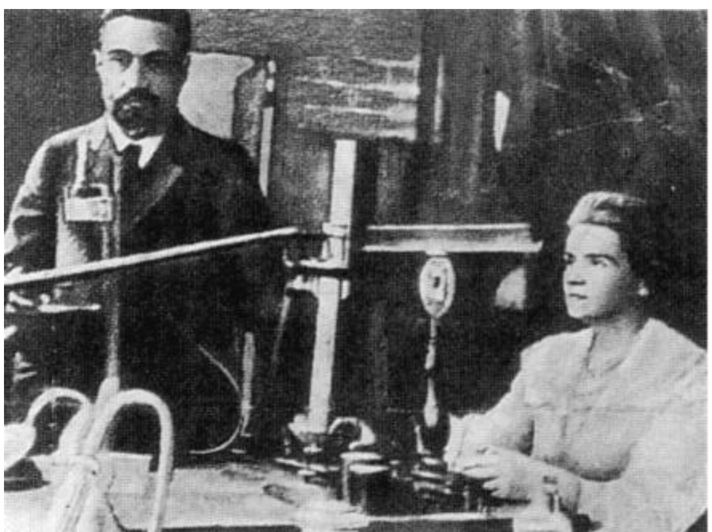
A. H. Becquerel
(France)

Metal cross

radioactivity

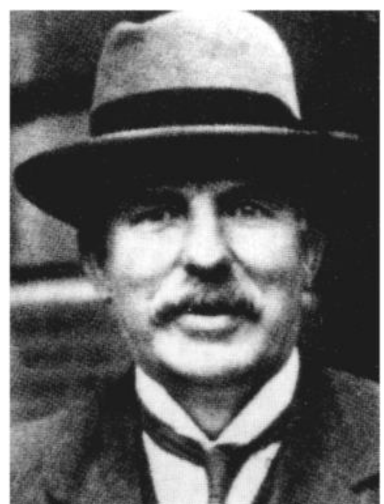
1898 Pierre and Marie Curie discovered radioisotopes

They named polonium and radium.



Pierre & Marie Curie
(France & Poland)

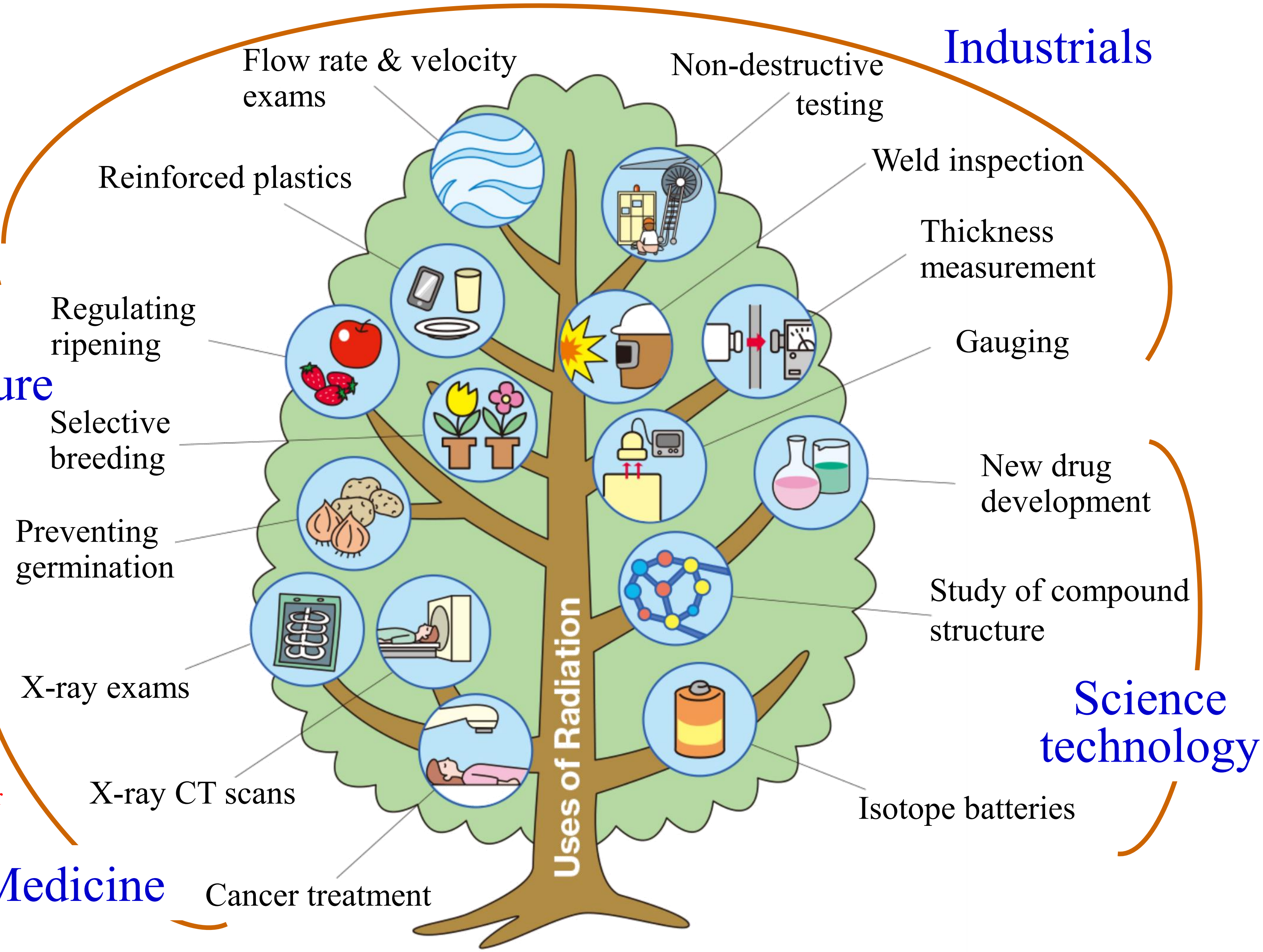
1902 Rutherford presented "disintegration theory of radioactivity"

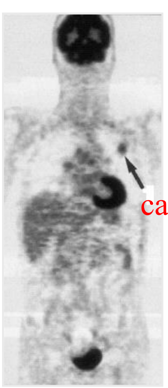


alpha and beta rays, emanating from radioactive nucleus

E. Rutherford
(England)

Use of radiation in various fields





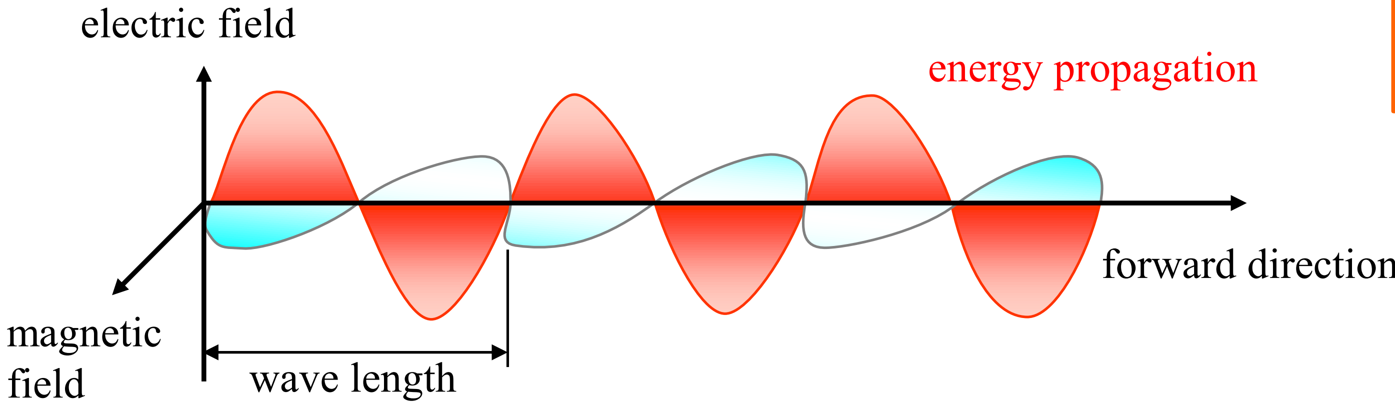
Nuclear medicine (FDG-PET)

Graphical Flip-chart of Nuclear & Energy Related Topics, Japan Atomic Energy Relations Organization, 2016

Types of radiation

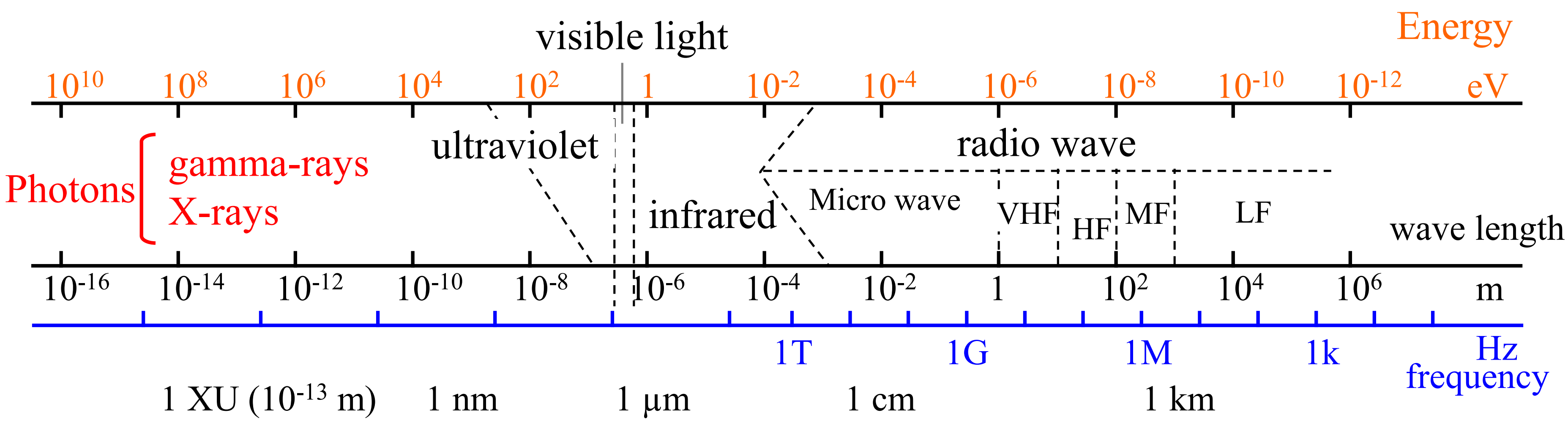
- Radiation
  - ionizing radiation
    - electromagnetic wave (indirectly ionizing radiation)
      - X-ray, synchrotron radiation
      - gamma ray, annihilation
    - particle beam
      - charged particle (directly ionizing radiation)
        - alpha ray
        - beta ray
        - electron beam
        - proton beam
        - deuteron
        - heavy ion
        - fission product
      - uncharged particle (indirectly ionizing radiation)
        - neutron beam
  - non-ionizing radiation
    - micro wave, infrared, visible light, ultraviolet ray

Electromagnetic Spectrum



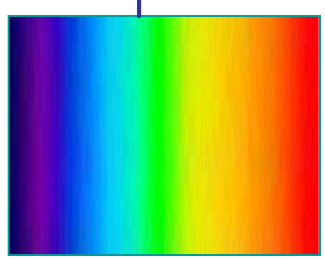
$$E = h \cdot \nu = \frac{hc}{\lambda}$$

h : Planck constant
ν : frequency
c : light speed
λ : wave length



Radiation therapy

X-ray imaging

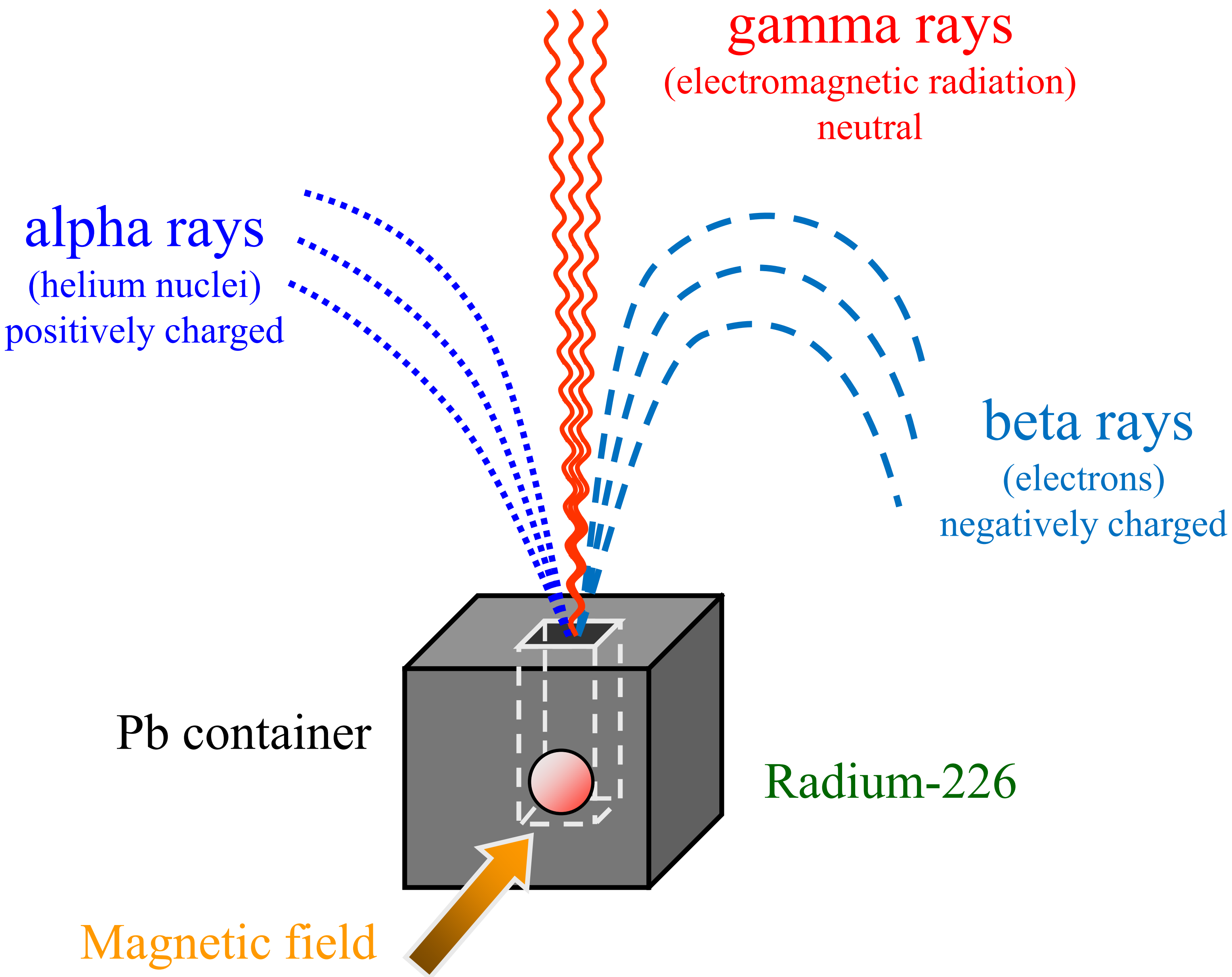


Light

Microwave

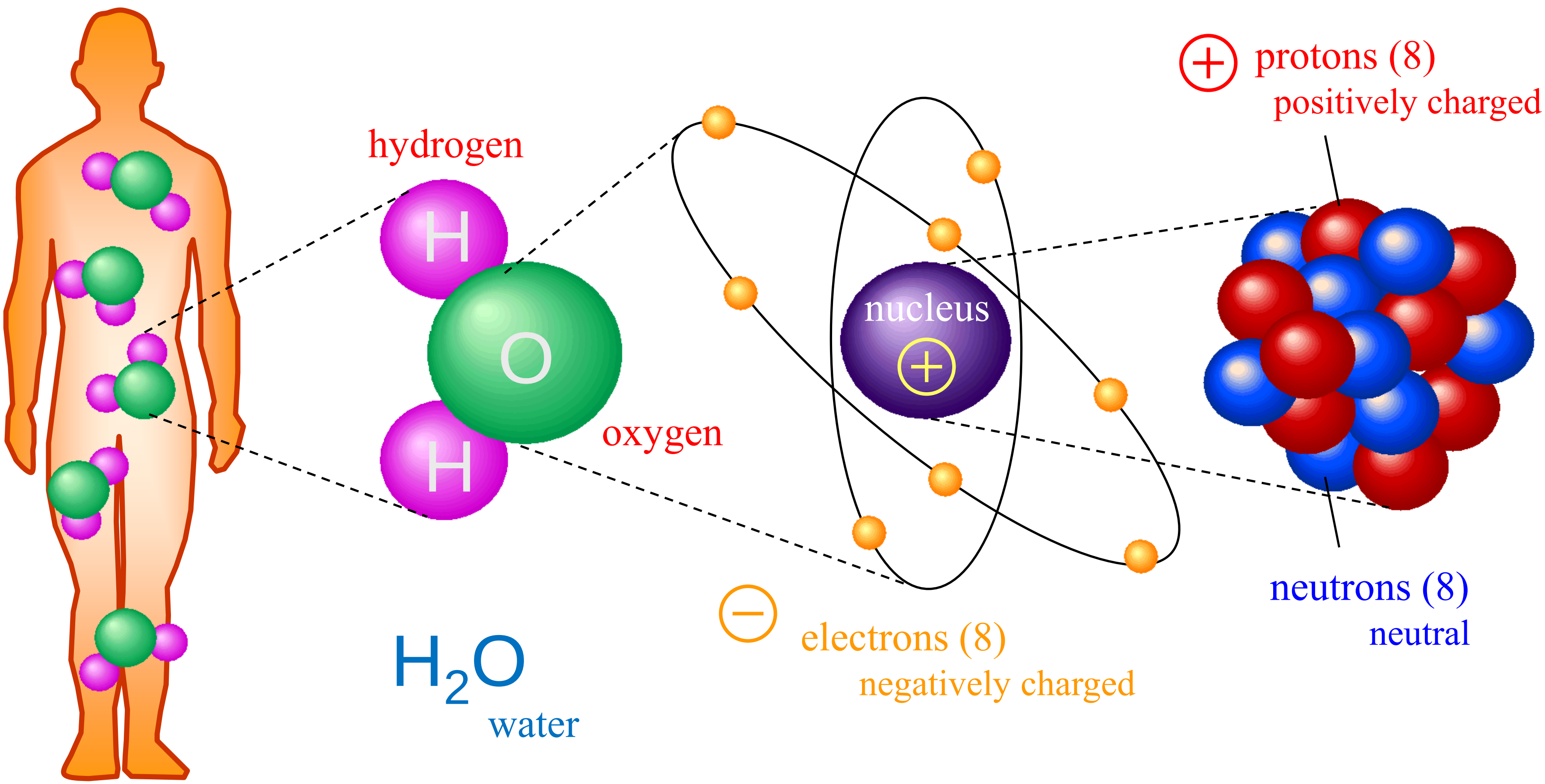
Television

Behavior of radiation in a magnetic field



Physics of Radiation and Radioisotopes

Structure of matter



Matter (human body)	Molecule	Atom	Nucleus
~ 1.7 m	~ 10^{-9} m	~ 10^{-10} m	~ 10^{-14} m

Atomic notation

Carbon

$$^{14}_{6}\mathrm{C}$$

Mass number (number of protons and neutrons) — 14

Atomic symbol — C

Atomic number (number of protons) — 6

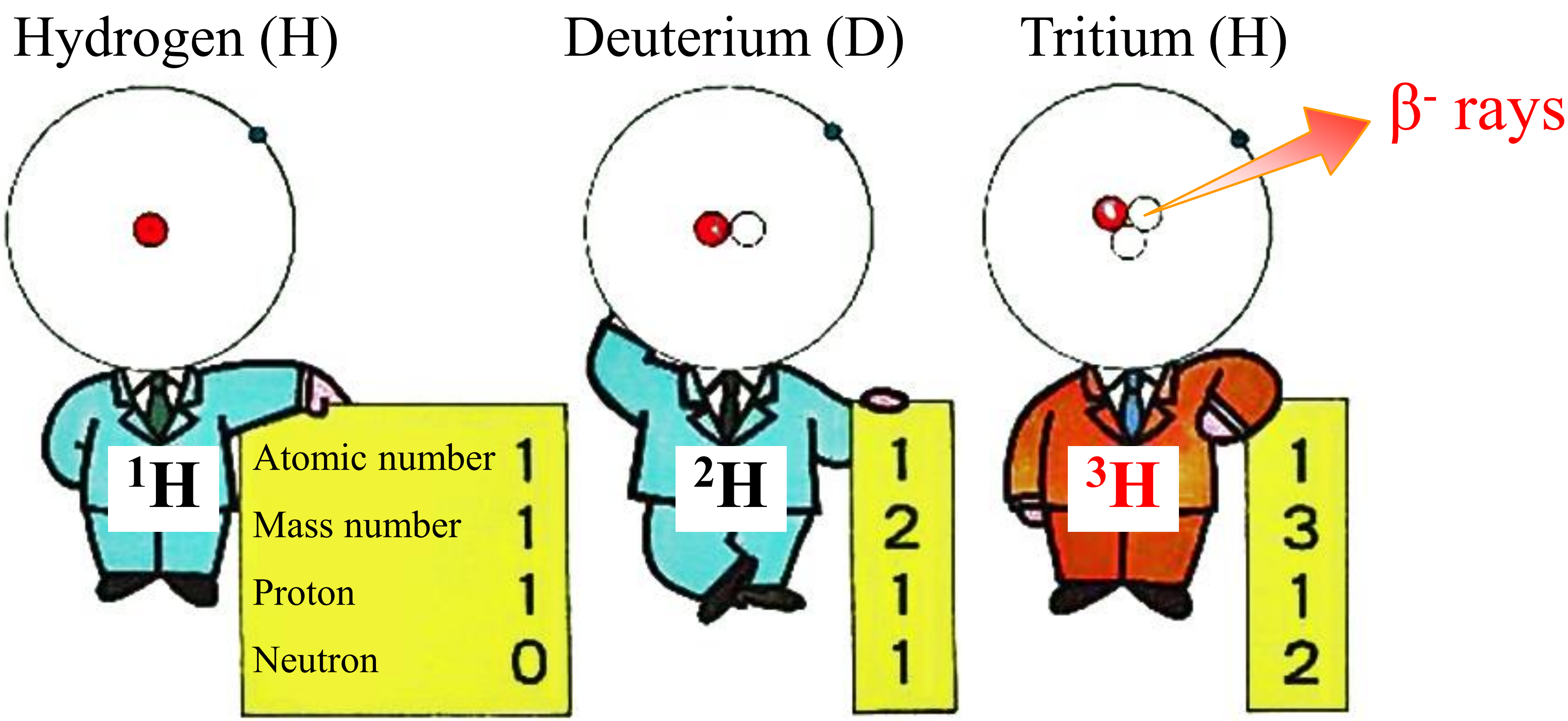
^{14}C, C-14, Carbon-14

Nuclide : type of atom or nucleus characterized by a specific number of protons and neutrons

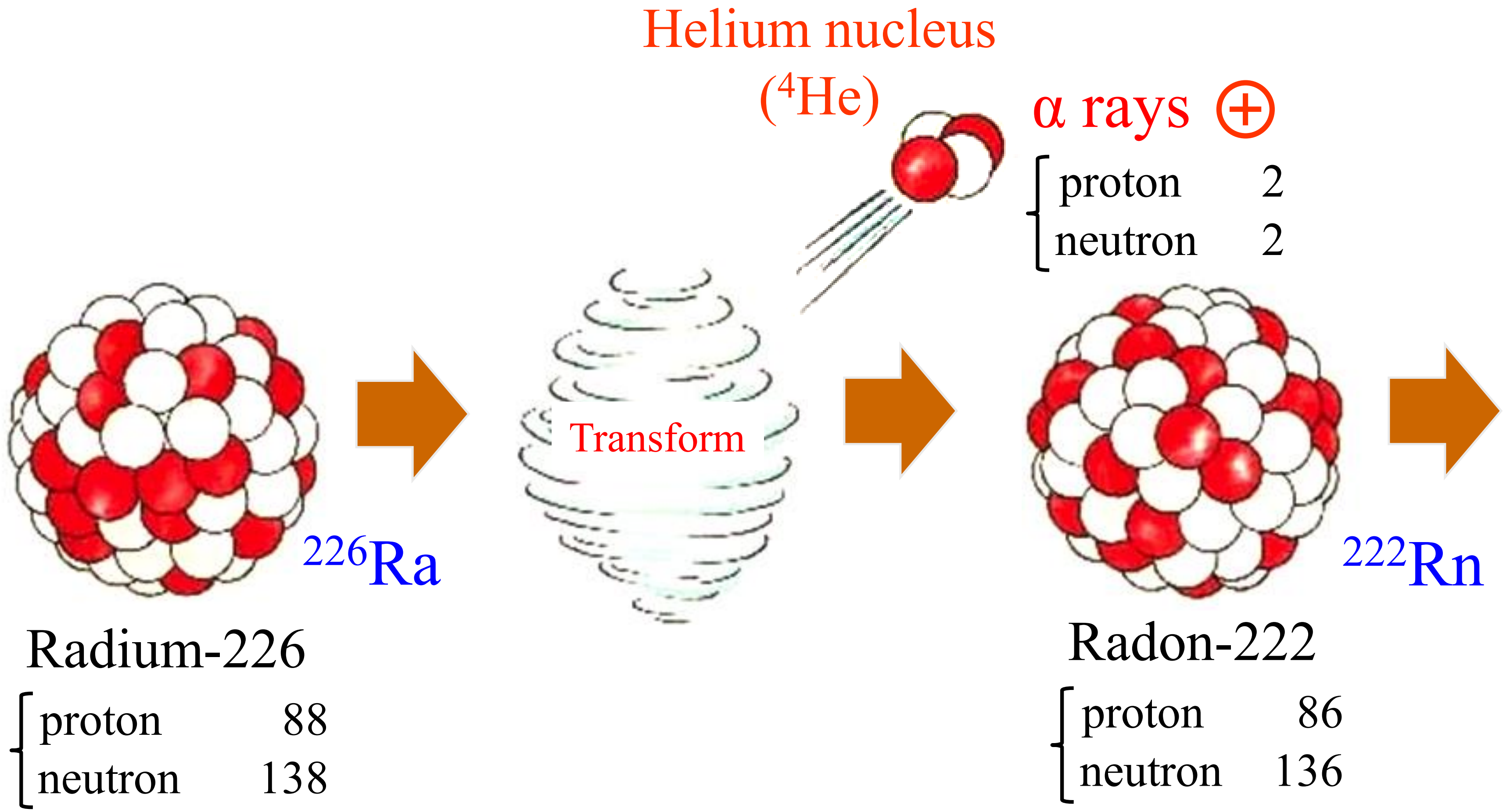
Isotope

Isotope - nuclide that have the same number of protons but differing numbers of neutrons (or mass number)

Radioisotope - isotope that has an unstable nucleus and emit radiation. In Japan, radioisotope is abbreviated as “RI”.



Emission of alpha (α) rays (α decay)

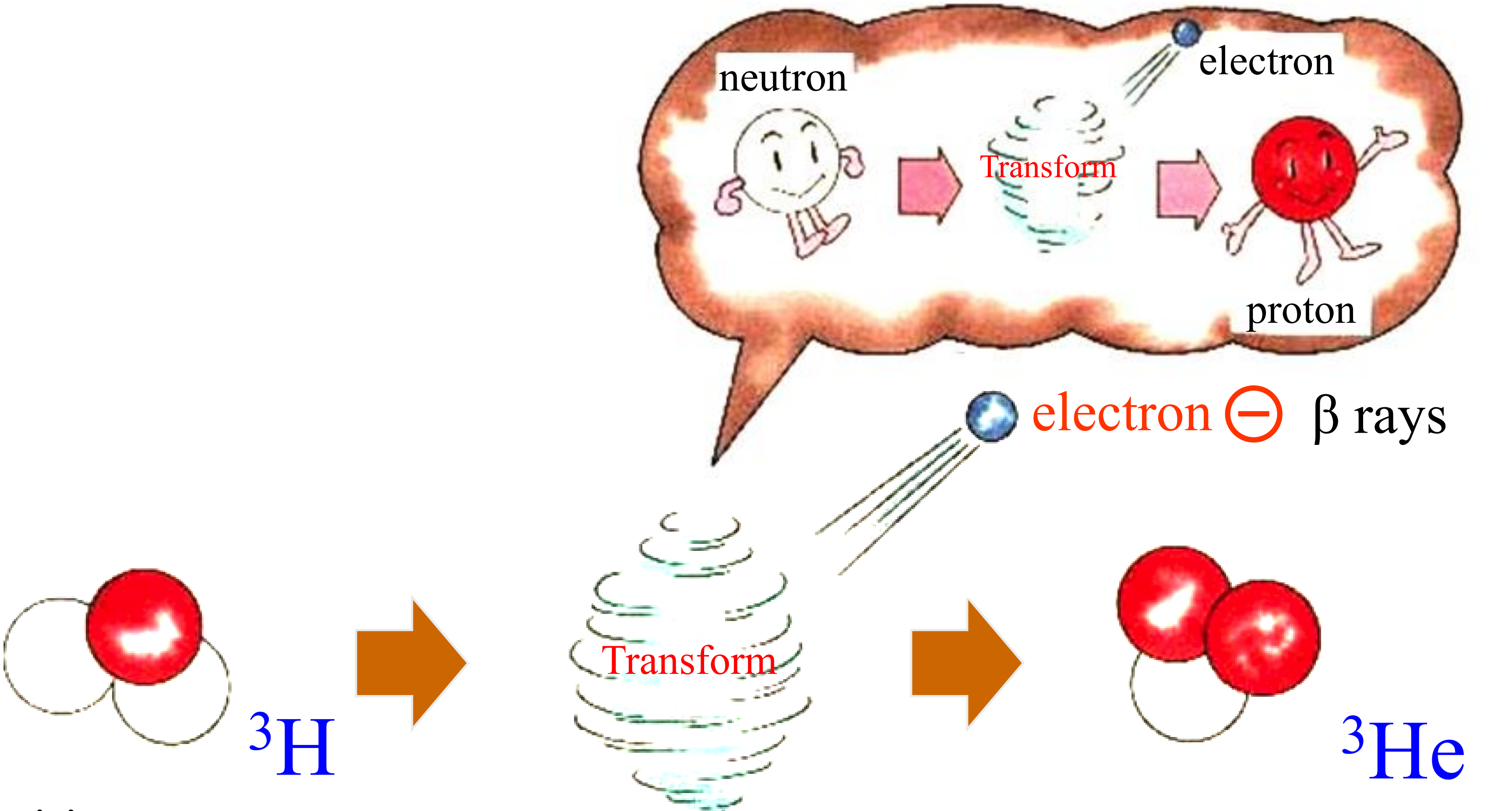


Decay (Disintegration) - It is to change into another nuclide by itself while emitting radiation. Such ability or intensity is called radioactivity.

Amount of radioactivity - unit (Bq, Becquerel)

the number of decay events per second

Emission of beta (β) rays (β decay)

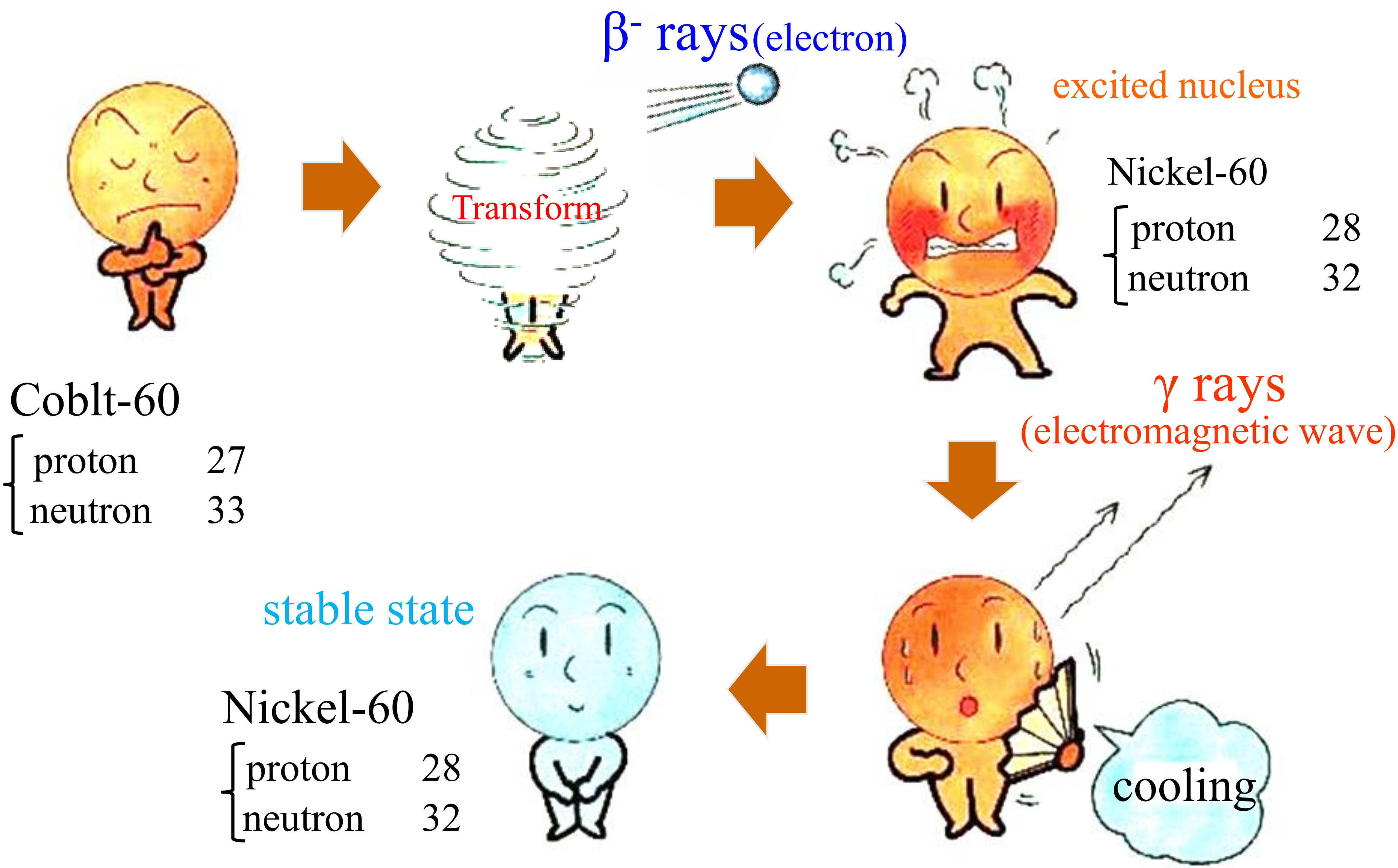


Tritium
- proton 1
- neutron 2

Helium-3 stable
- proton 2
- neutron 1

Positively charged positrons (β^+ rays) can also be emitted.

Emission of gamma (γ) rays



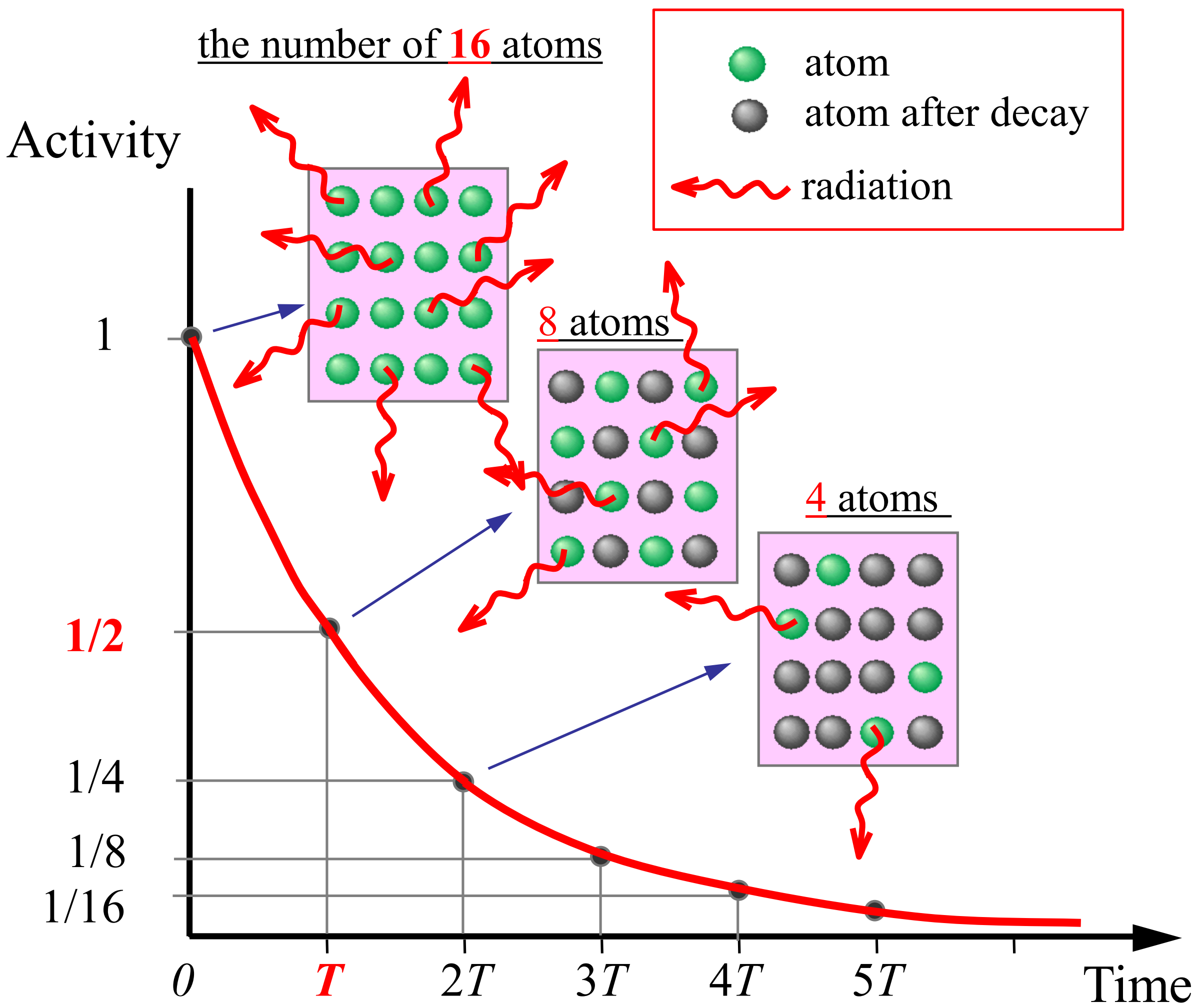
When an atomic nucleus is in an excited state after decay,
it emits gamma rays (photons).

Radioactive decay (half-life, *T*)

- Radioactivity decreases as an exponential form with a constant decay rate
- Half-life is the time required for a quantity to reduce to half of its initial radioactive value
- A radioisotope has a inherent half-life

$$A = A_0 \exp(-\lambda t) = A_0 (1/2)^{t/T}$$

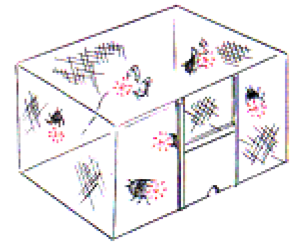
λ : constant decay rate $= \ln 2 / T = 0.693 / T$



^{3}H	12.3 years
^{14}C	5730 years
^{32}P	14.3 days
^{51}Cr	27.7 days
^{99m}Tc	6.02 hours
^{125}I	60.2 days
^{131}I	8.0 days
^{134}Cs	2.1 years
^{137}Cs	30.1years
^{238}U	4.5 billion years
^{40}K	1.28 billion years

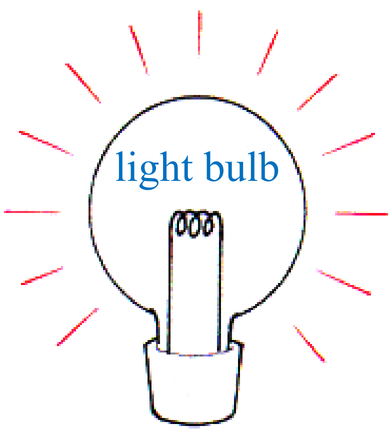
Difference between "Radiation" and "Radioactivity"

The two words are very similar and easily confused in Japanese



firefly - isotope
firefly light - radiation

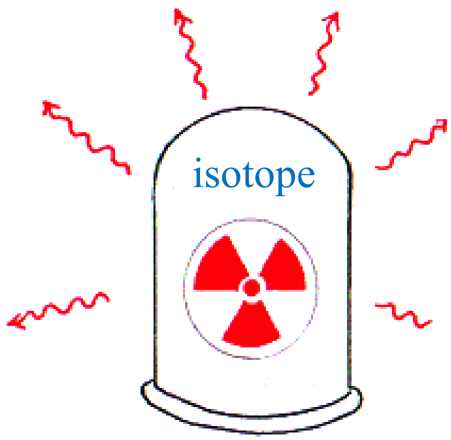
Light rays



100 watts

ability to glow
(lumen)

Radiation

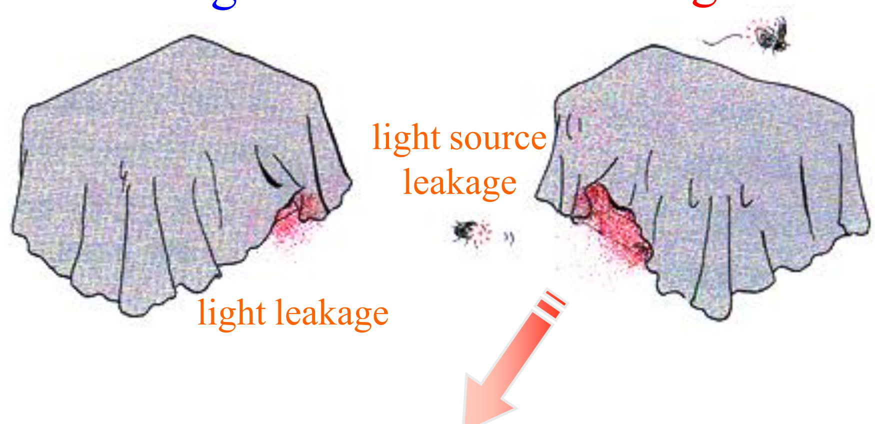


100 Bq

radioactivity
(Becquerel)

Radiation leakage

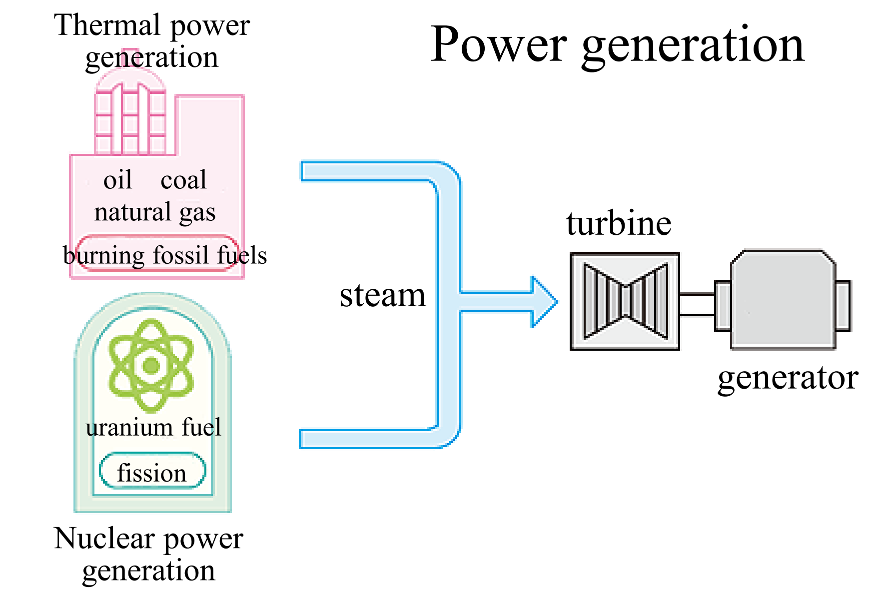
Radioactivity leakage



Radioactive material is leaking

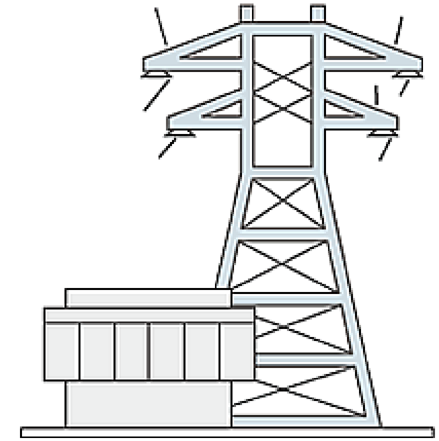
Mechanism of nuclear power generation

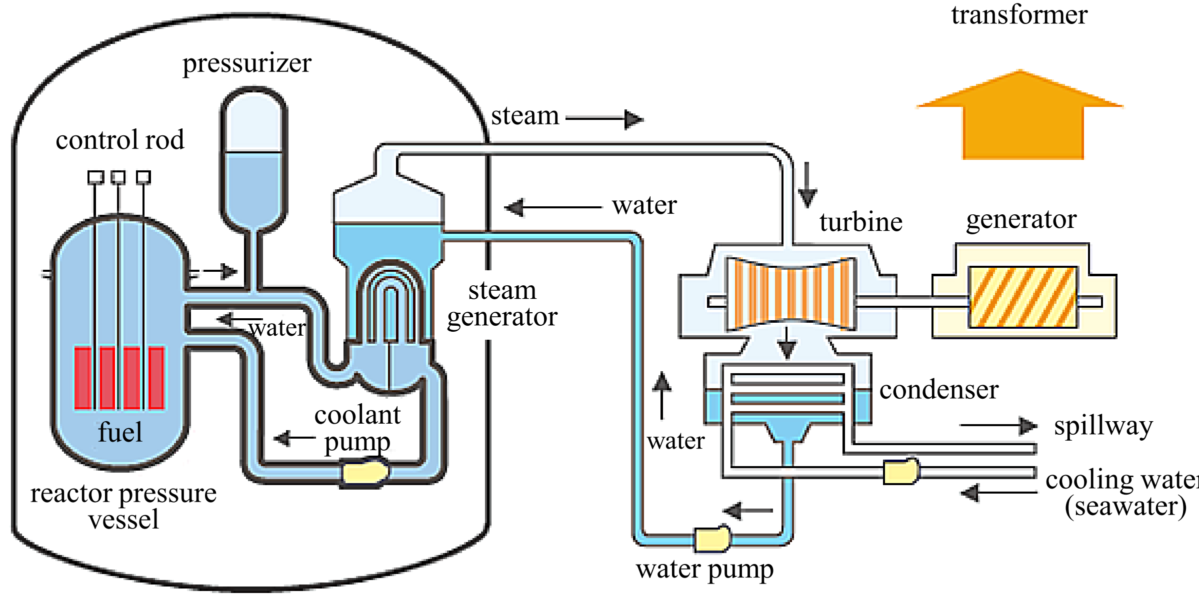
Power generation



Pressurized water reactor (PWR)

Steam is generated by a steam generator using high-temperature, high-pressure water produced in a nuclear reactor.





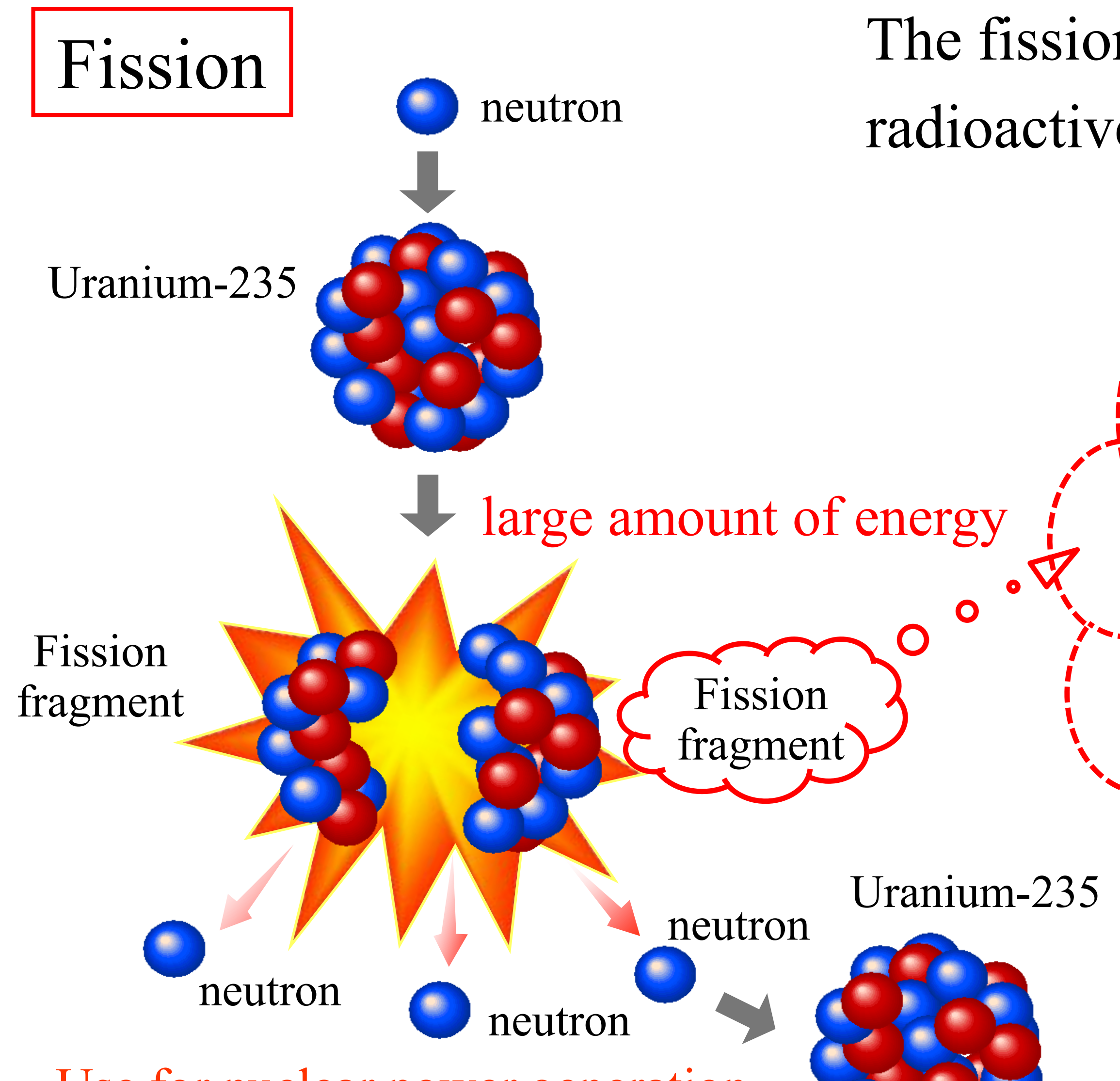
In 2010, nuclear power accounted for about 30% of Japan's total electricity.

Source: Nuclear Consensus 2012

In March 2023,
Kansai Electric Power 5 units,
Kyushu Electric Power 3 units in operation
(about 6% of total electricity in FY2021)

Fission and fission products

The fission of Uranium-235 produces radioactive "fission products".



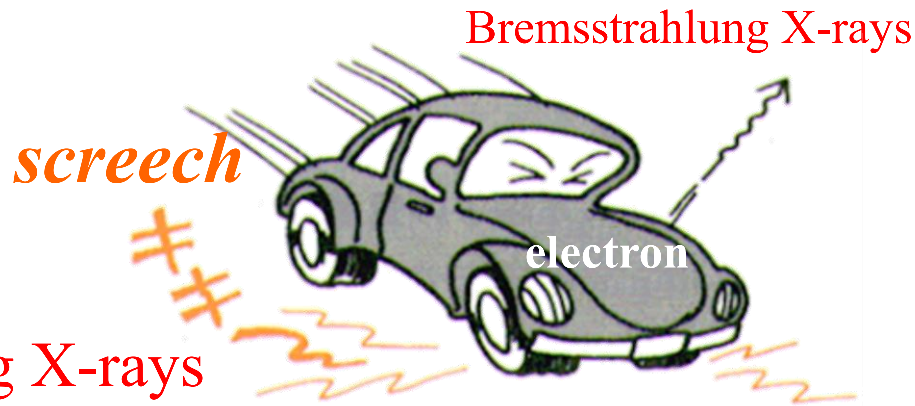
Use for nuclear power generation and atomic bomb

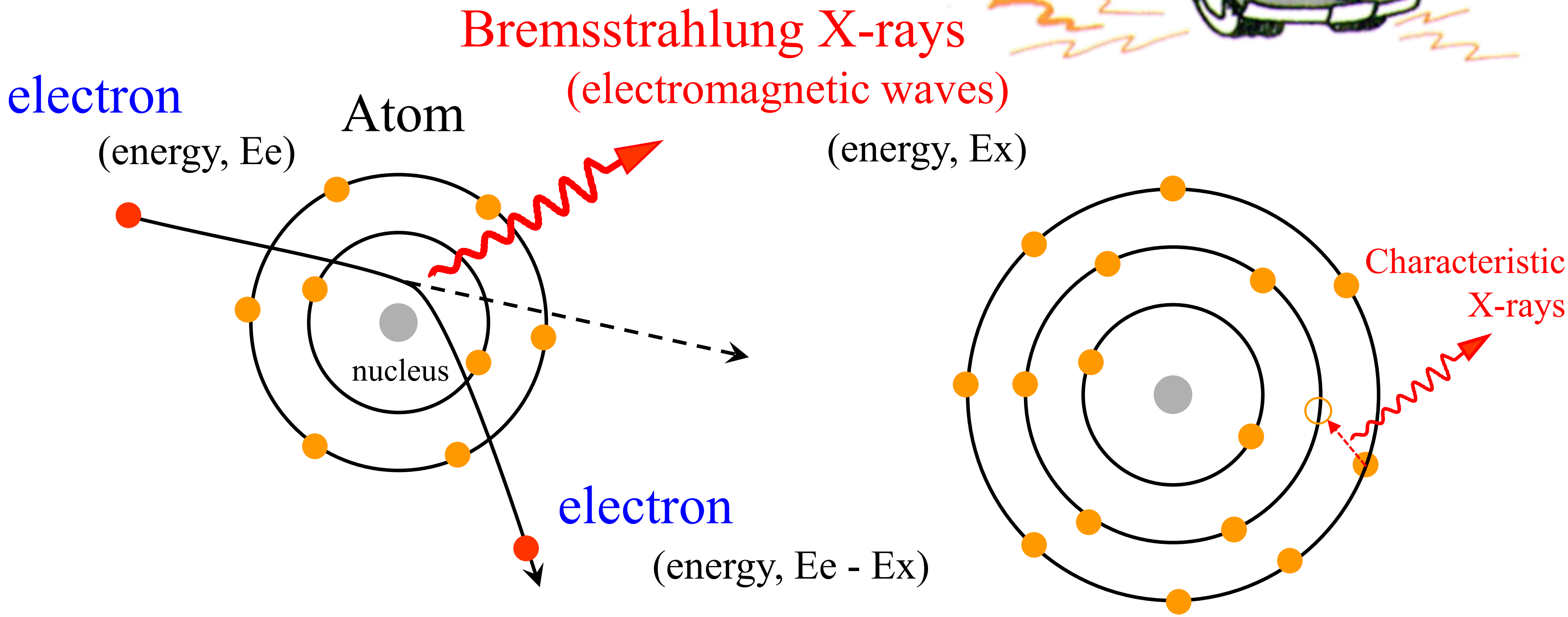
- Strontium (Sr)-90
- Iodine (I)-131
- Cesium (Cs)-134
- Cesium (Cs)-137

etc

emit radiation

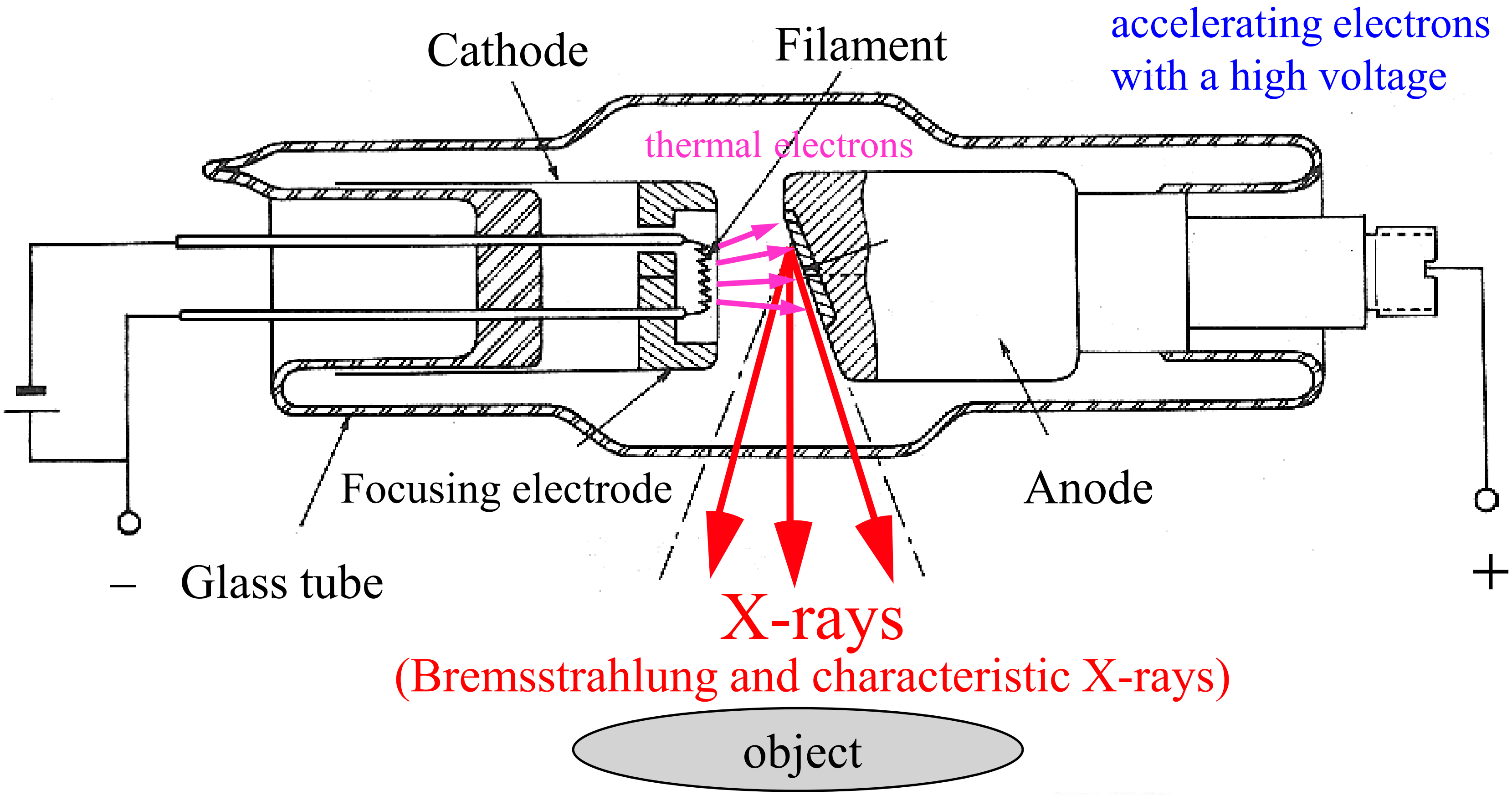
X-ray (bremsstrahlung) generation

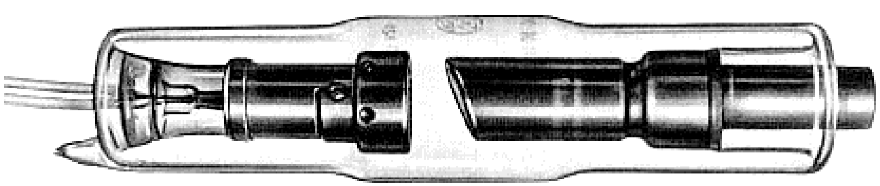




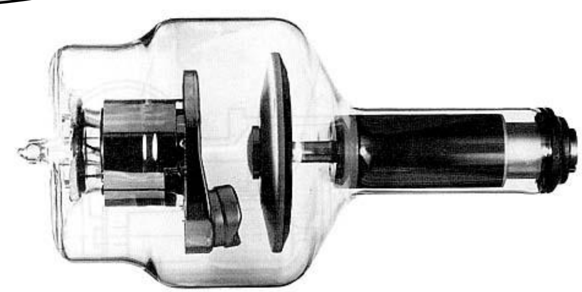
When electrons flying at high speed near a nucleus are braked by the nucleus strong positive electric force, X-rays called bremsstrahlung are generated. In addition, there are also characteristic X-rays.

Structure of X-ray tube



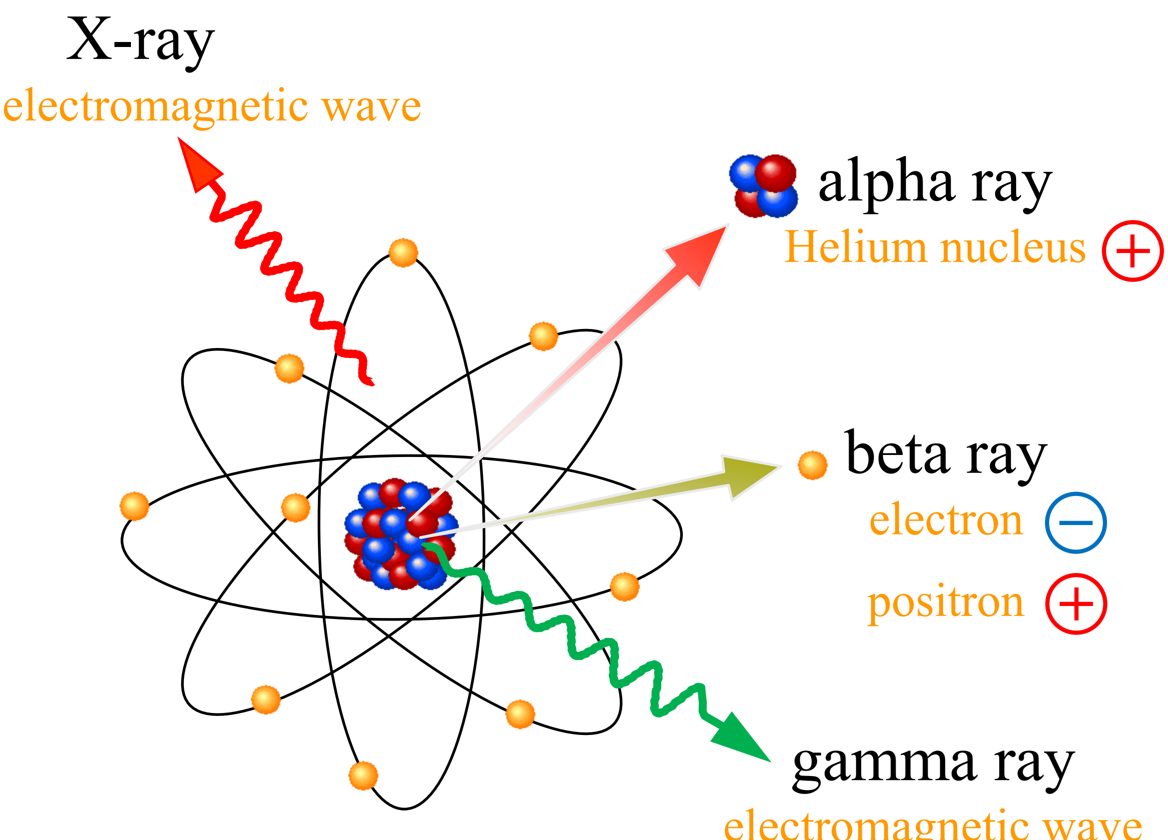


fixed anode X-ray tube



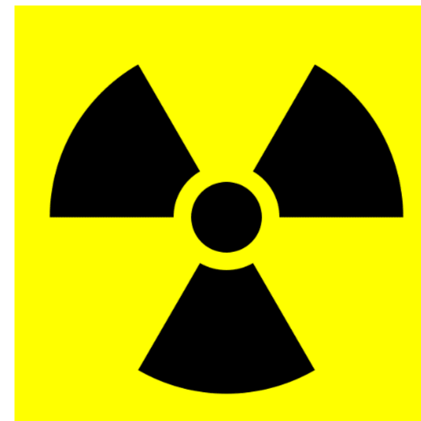
rotating anode X-ray tube

Generation of radiation



Atom

Radioactive sign



One of hazard symbols

It is said that the central circle is a radiation source and the three blades, a trefoil, represent radiation - alpha, beta and gamma rays.

Radiation generator (accelerator)

Generation of electron beams, proton beams, heavy proton beams, neutron beams, etc.

- Cyclotron
- Synchrotron
- Synchrocyclotron
- Linear accelerator (LINAC)

Radiation therapy

- Van de Graaff accelerator
- Cockcroft Walton accelerator

Spring-8 Synchrotron radiation

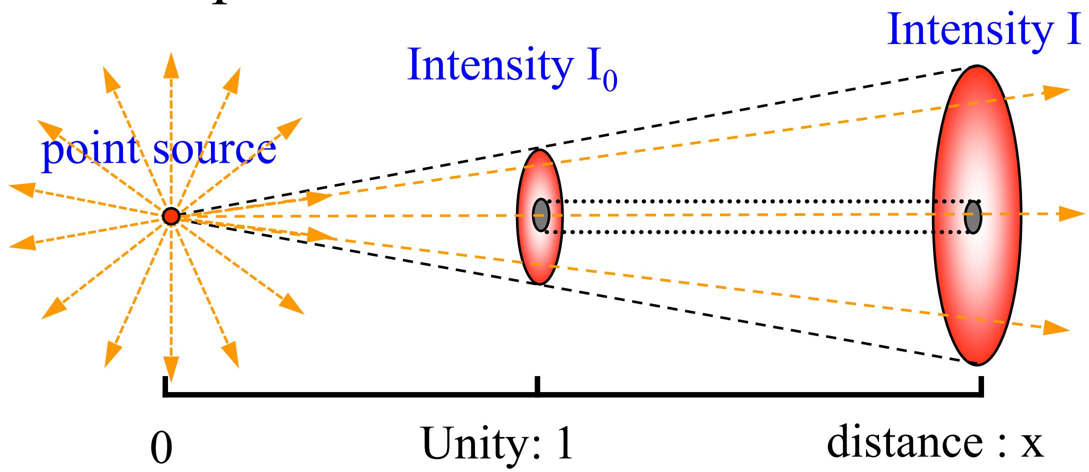
A small cyclotron capable of producing short half-life radioisotopes for PET study (self shielding type)

Sumitomo Heavy Industries (CYPRIS-HM12S)

A common examination to discover cancer is ^{18}F FDG-PET scan

Property of radiation

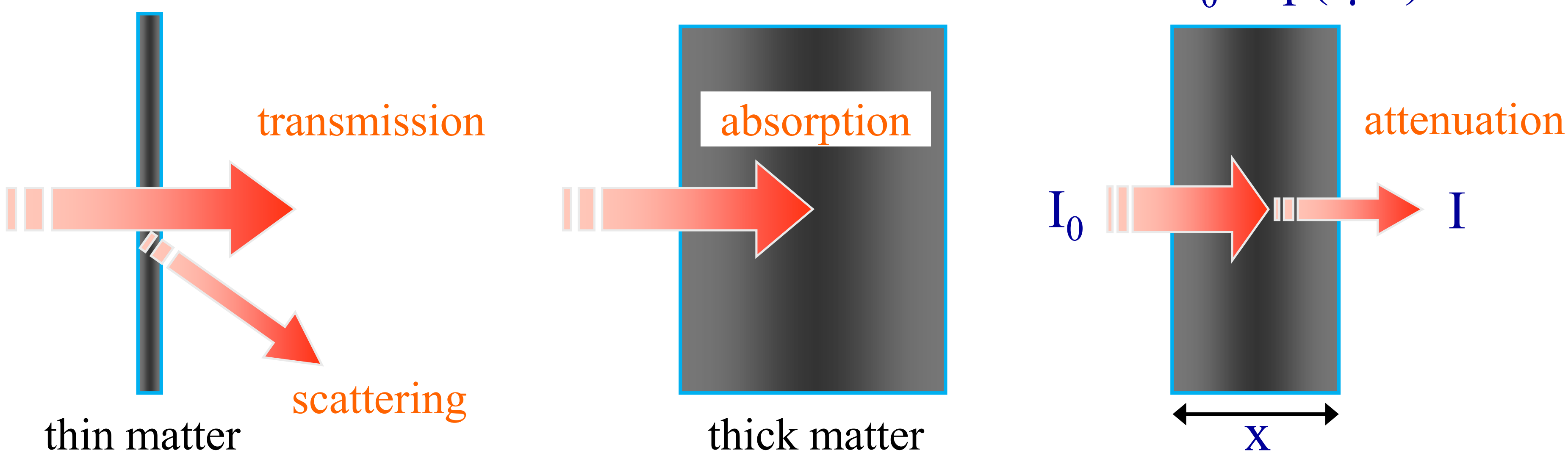
1) Distance-inverse square law



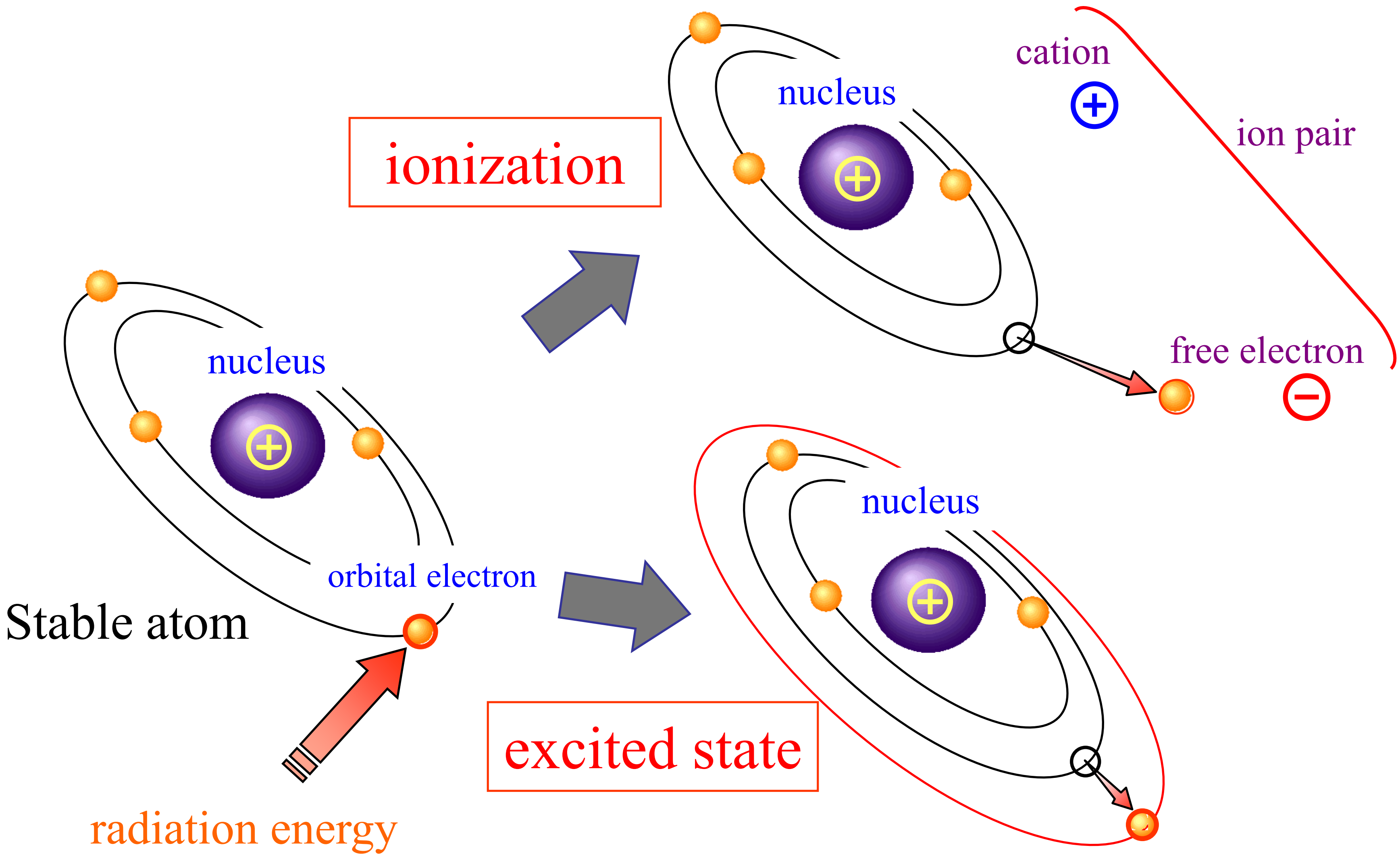
$$I = \frac{I_0}{x^2}$$

2) Interaction with matter

$$I = I_0 \exp(-\mu x)$$

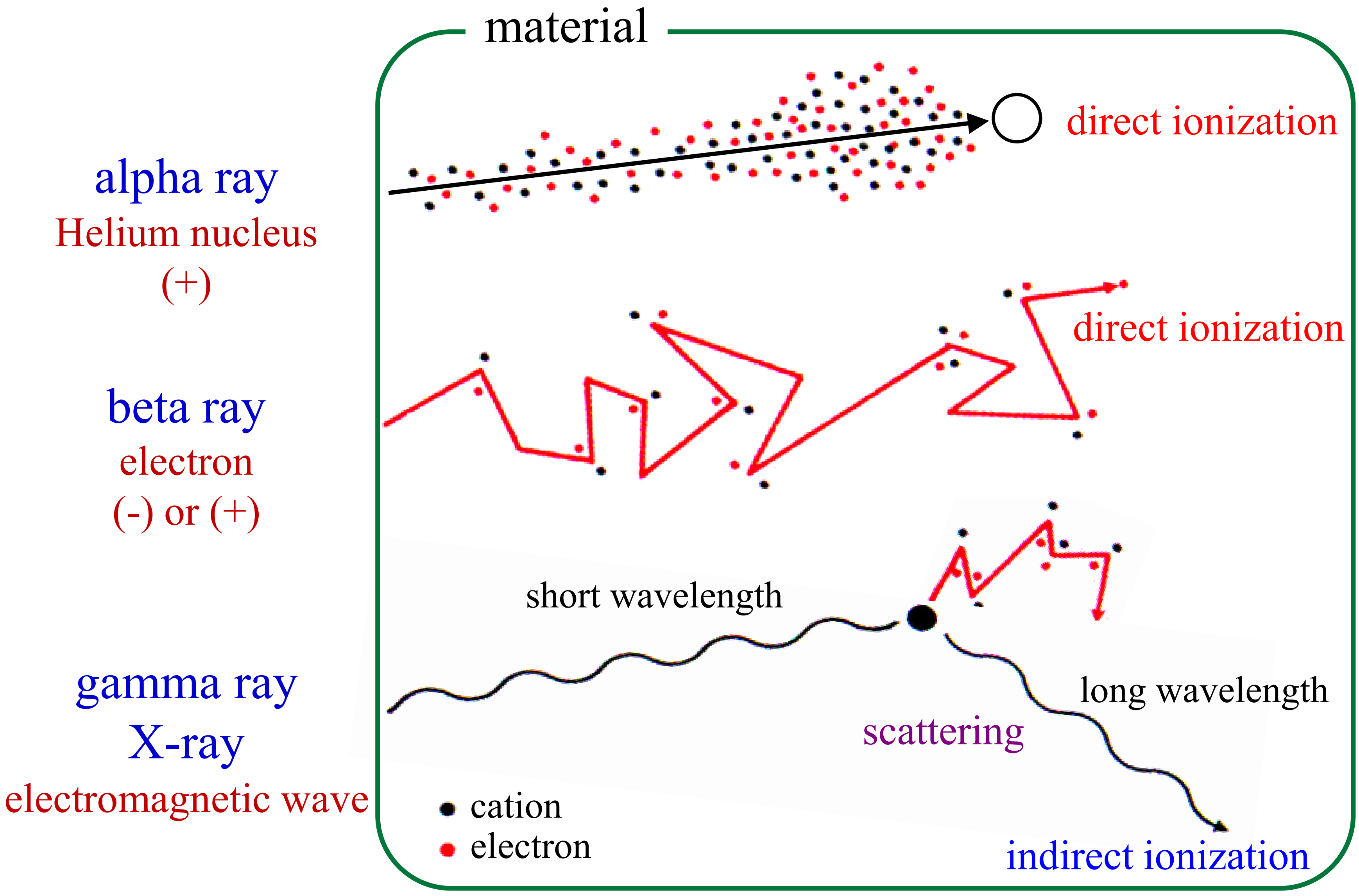


Ionizing radiation



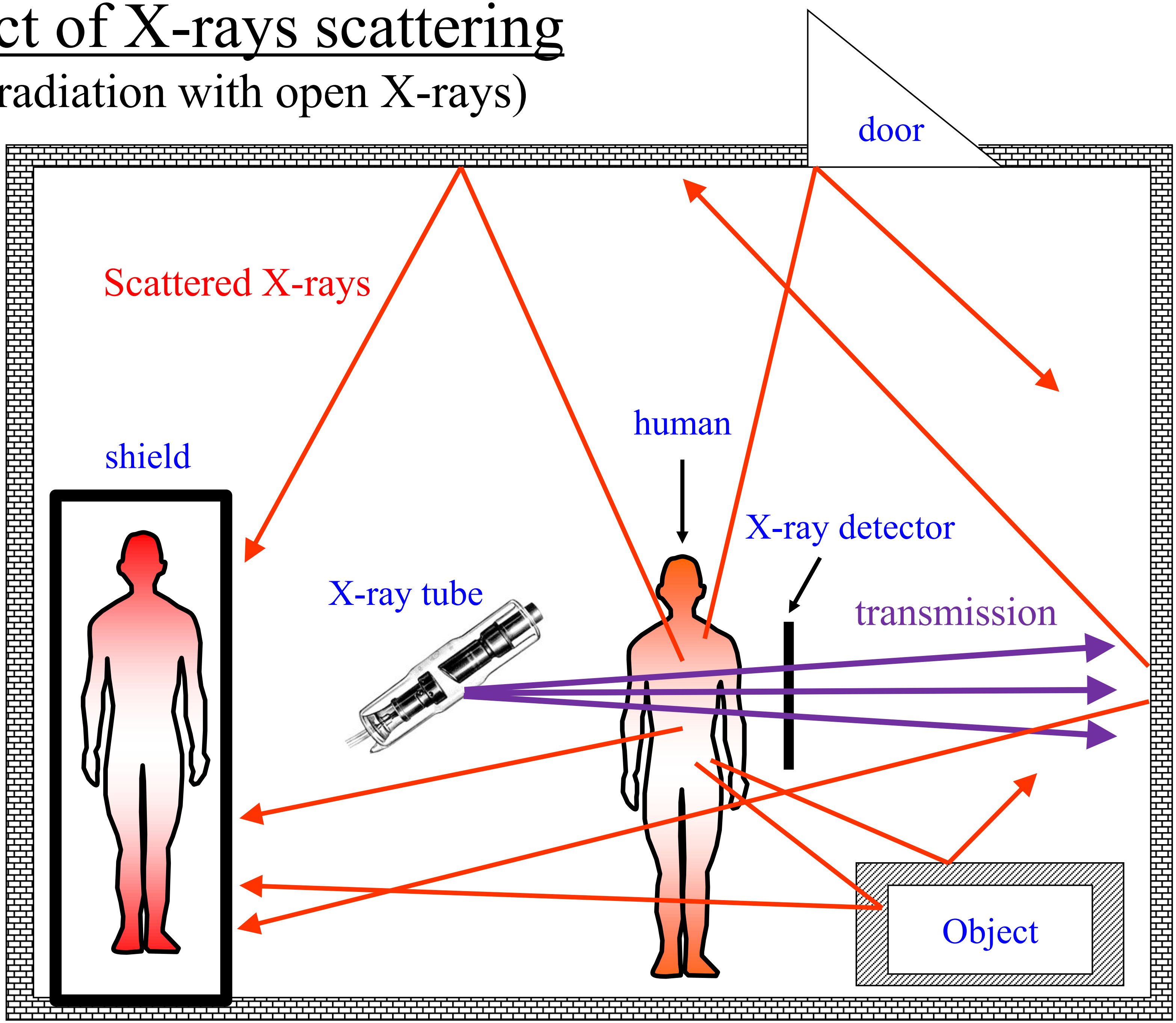
Ionization by radiation

When radiation passes through a material, it gives its energy to atoms and molecules in its path, causing ionization and excitation.

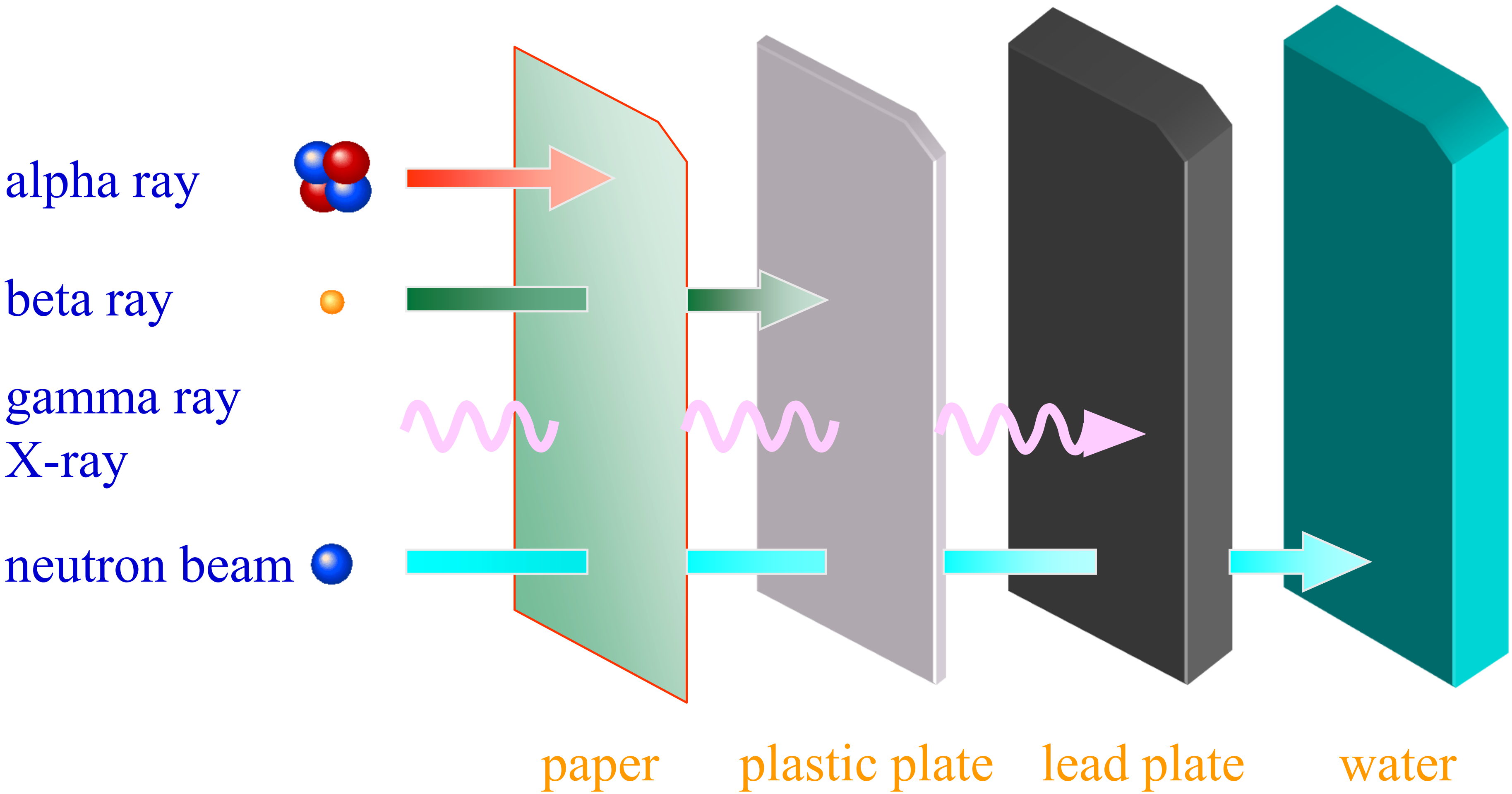


Effect of X-rays scattering

(Irradiation with open X-rays)



Penetrating power of radiation



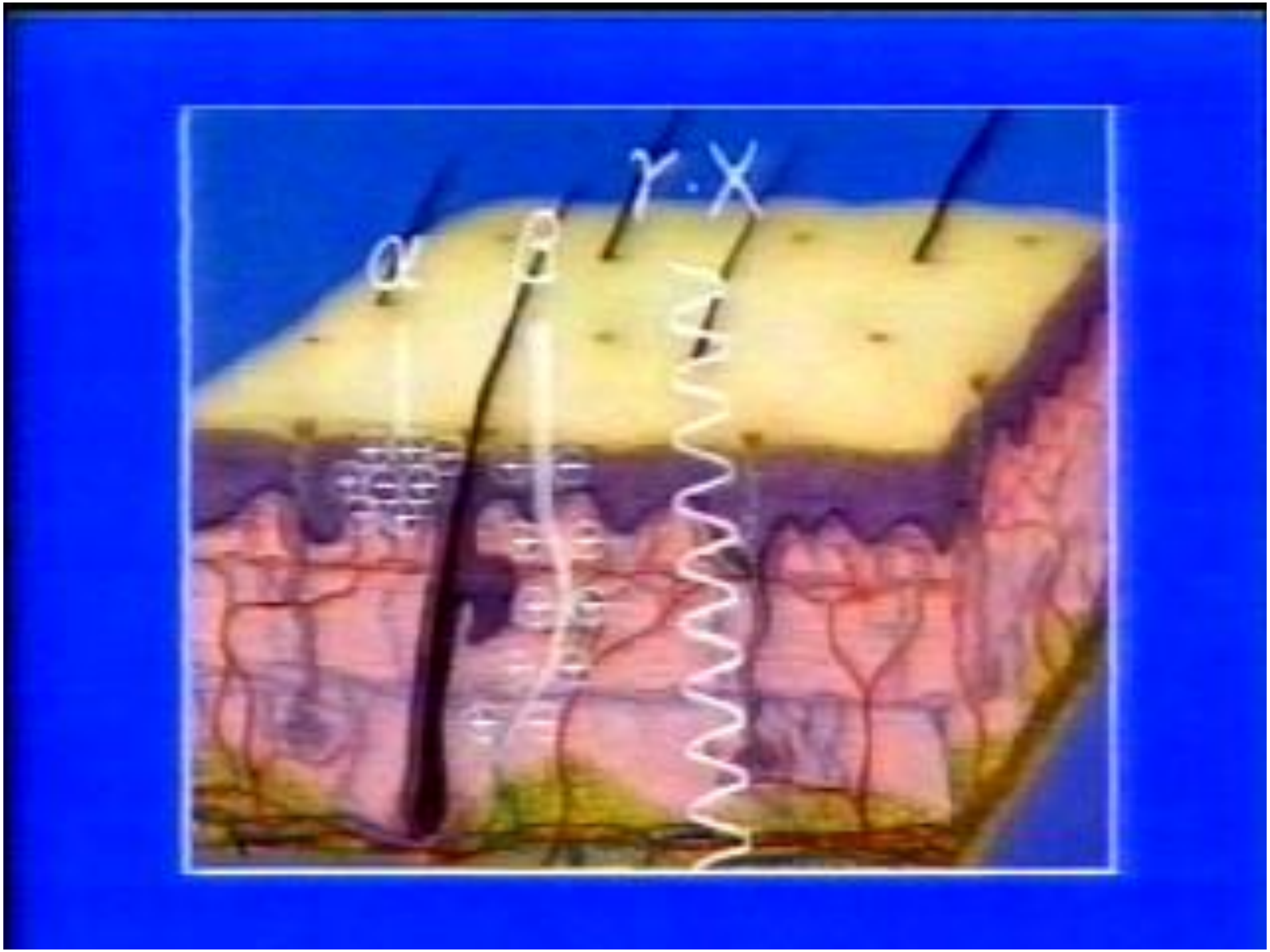
Radiation shielding

alpha rays shielding

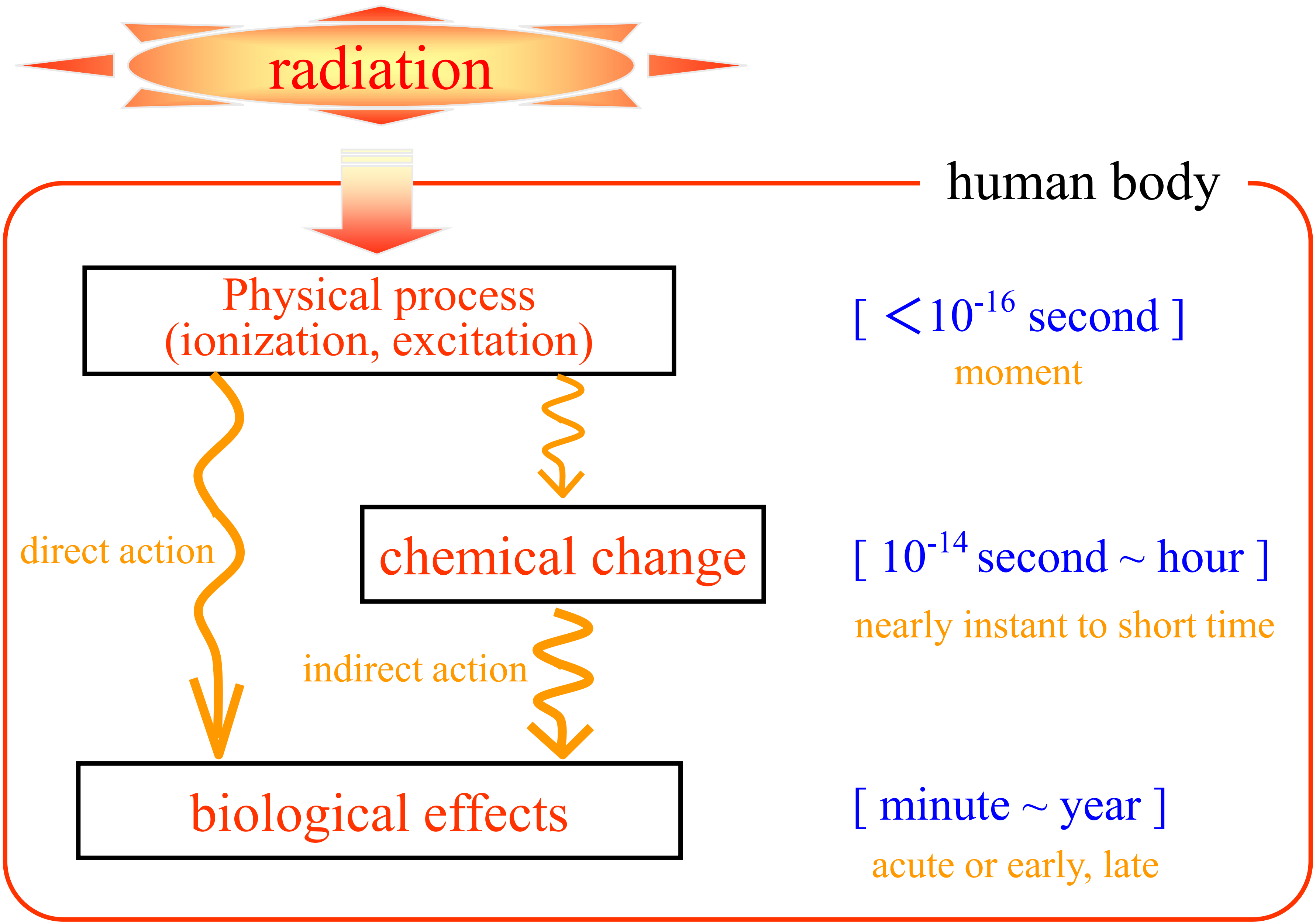
beta rays shielding

gamma rays shielding

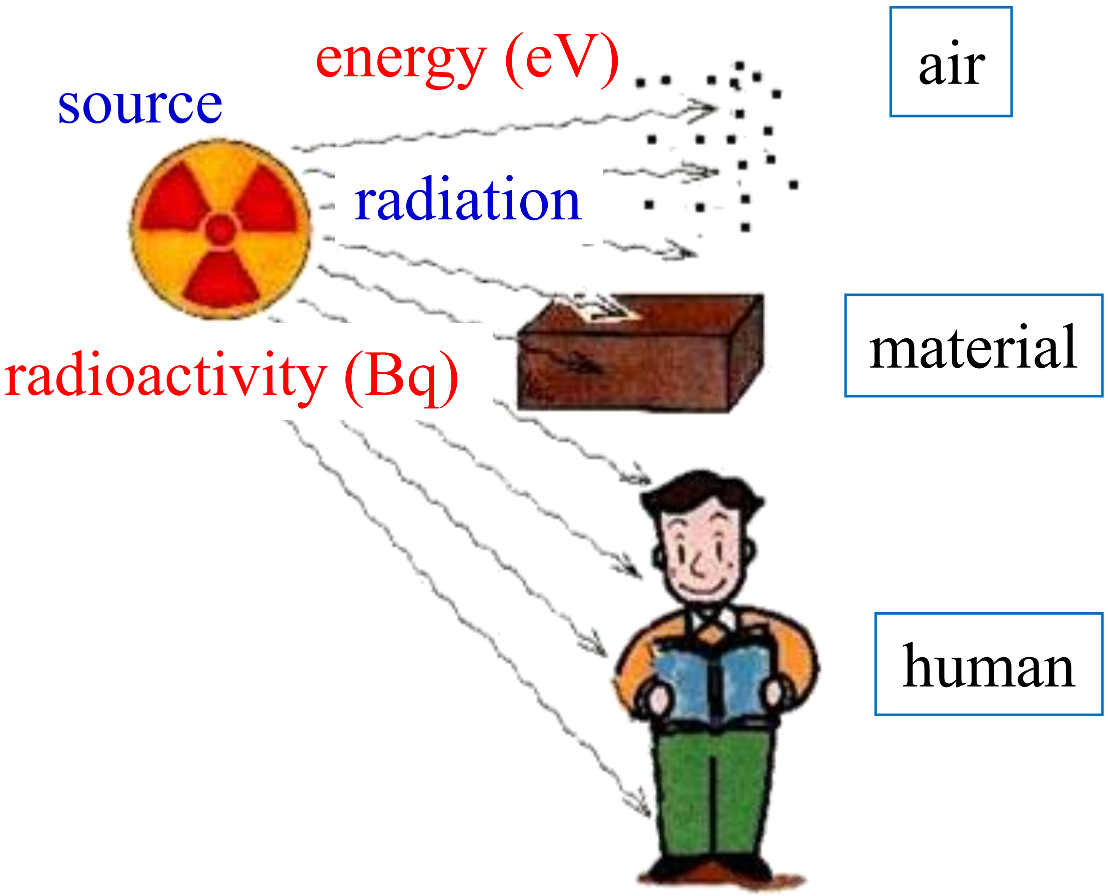
Penetration of radiation within the body



What happens when radiation hits the human body?



Units of radiation and radioactivity



radiation exposure (C/kg)

How much can γ(X) rays ionize the air?

absorbed dose (Gy)

How much radiation energy is absorbed by matter?

dose equivalent (Sv)

What is the effect on humans?

Dose received by a specific tissue of the human body -- equivalent dose (Sv)

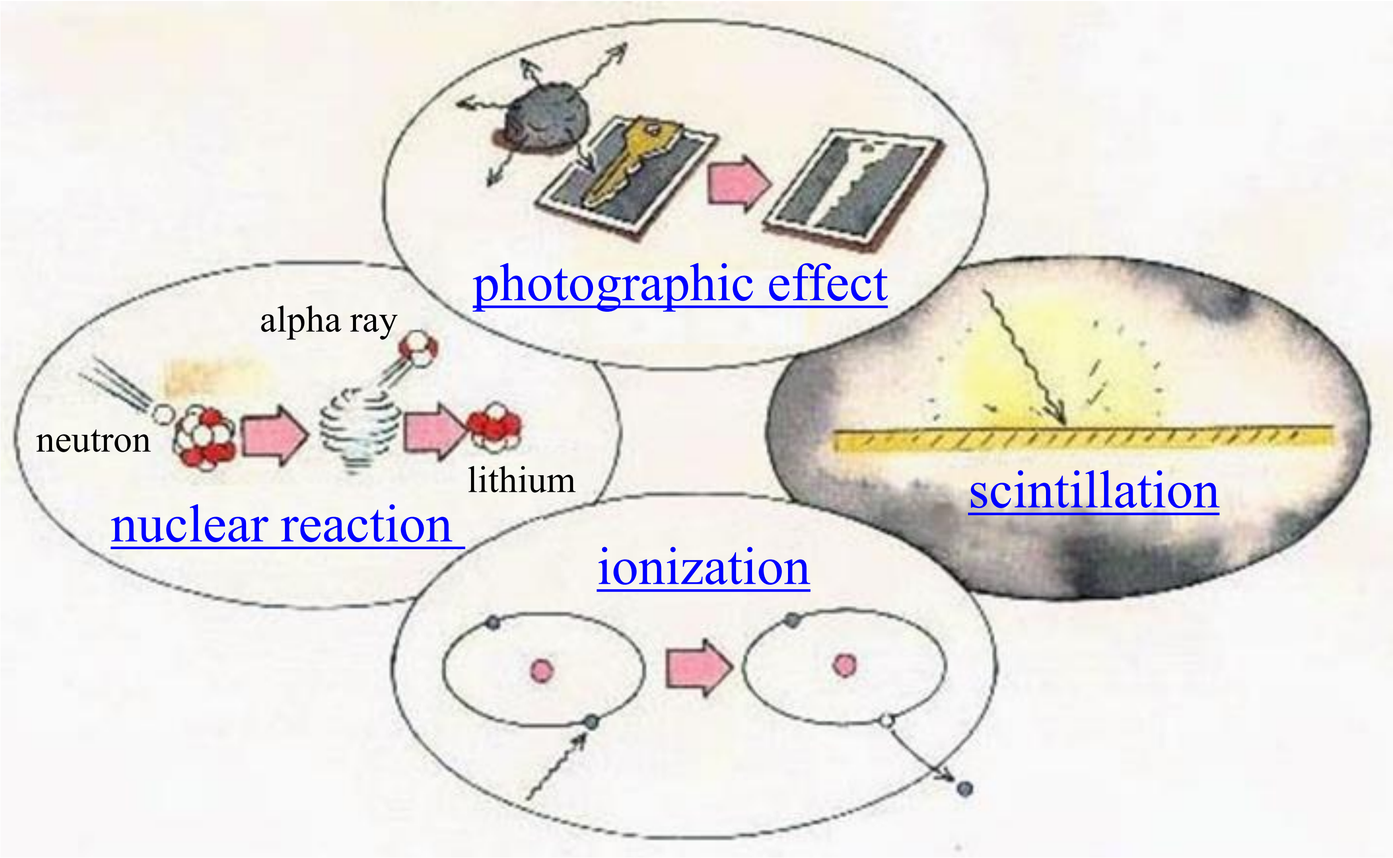
(= radiation weighting factor w_R × absorbed dose (Gy))

Dose that evaluates the sum of effects on various tissues of the human body

(= tissue weighting factor w_T × equivalent dose (Sv)) -- effective dose (Sv)

Detection of Radiation

Interaction between radiation and substances



Radiation gives energy to substances → detection and measurement
(ionization, excitation)

Principles of radiation measurement

1. Utilization of ionization of air or gas

   Gas filled detectors : ionization chamber, Geiger–Müller (GM) counter, proportional counter, etc

2. Scintillation of solid or liquid materials

   Detectors : solid scintillation counter, liquid scintillation counter

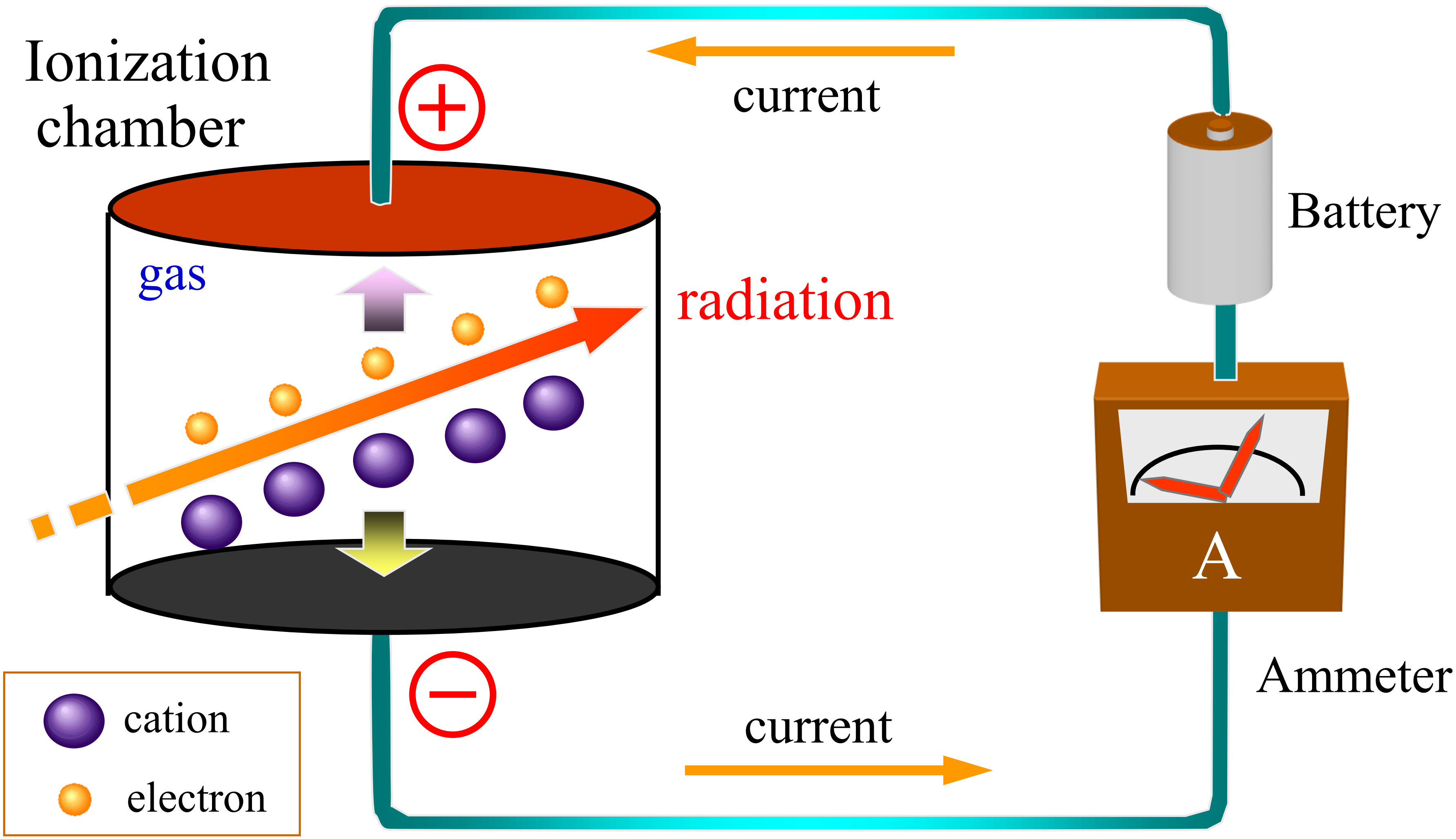
3. Utilization of solid state materials generating electron-positive hole pairs

   Solid state detectors : silicon (Si), germanium (Ge) semiconductor
   cadmium telluride (CdTe) semiconductor,
   cadmium zinc telluride (CZT) semiconductor

4. Chemical reaction

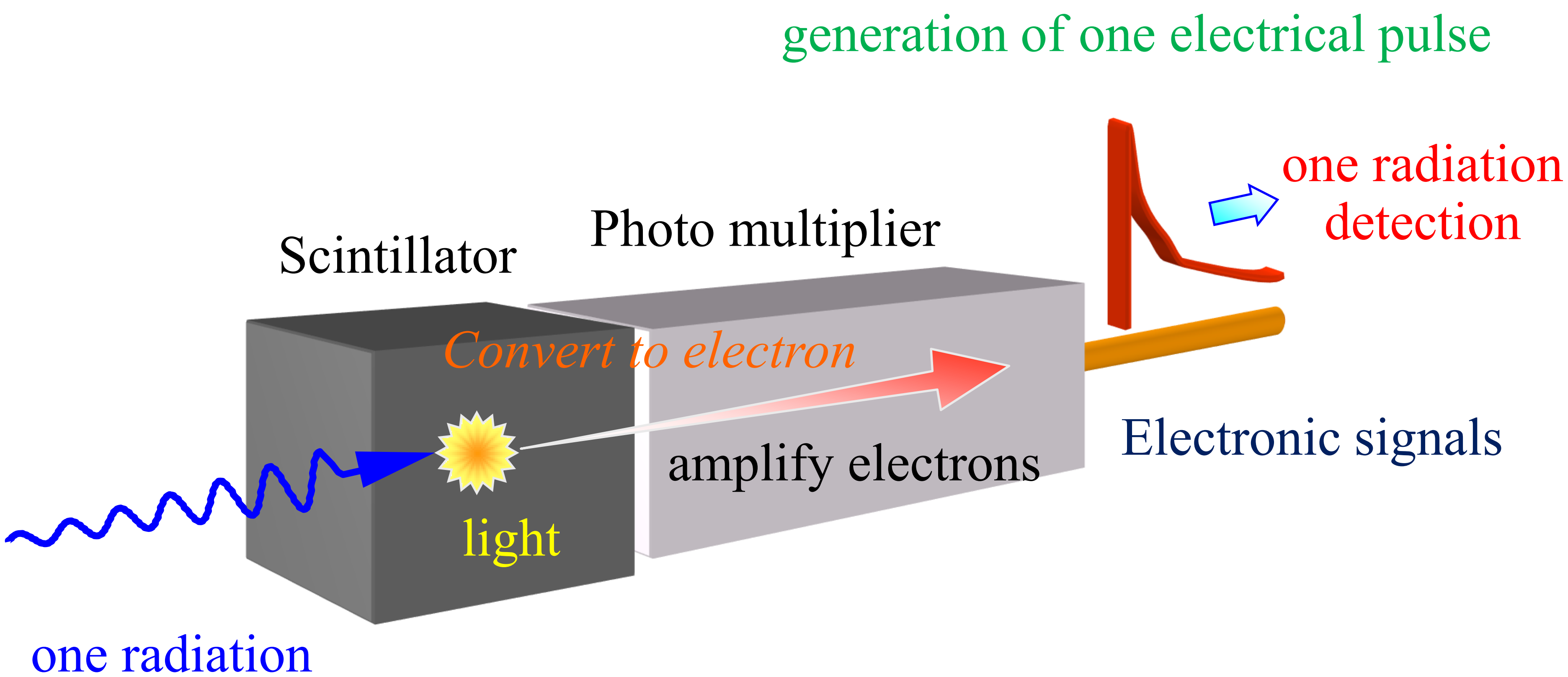
   Detectors : X-ray film, autoradiography, film badge

Detection by gas ionization



When radiation passes inside a chamber, it causes ionization of gas atoms, separating atoms into cations and electrons. Separated electrons and cations are attracted to the electrodes, causing a current to flow. This is converted into electric signals, which are then measured as the amount of radiation.

Detection by scintillation of materials



radiation ⇒ light ⇒ electronic signal ⇒ measurement

Scintillation detector

Solid scintillator

Gamma rays measurement

Liquid scintillator

Beta rays measurement

radiation ⇒ light ⇒ electronic signal ⇒ measurement

Radiation measurement (semiconductor detector)

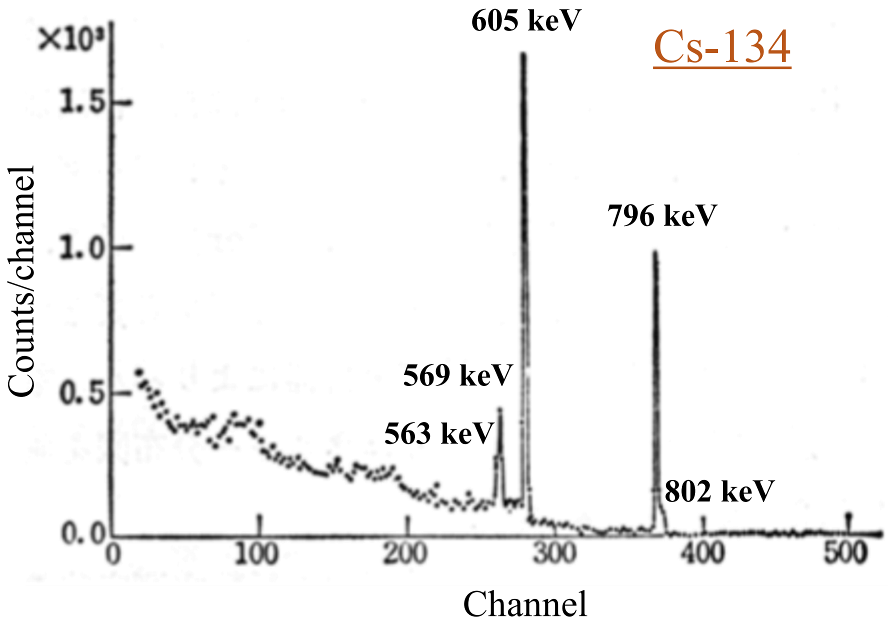
Utilization of solid state materials generating electron-positive hole pairs

Good energy resolution

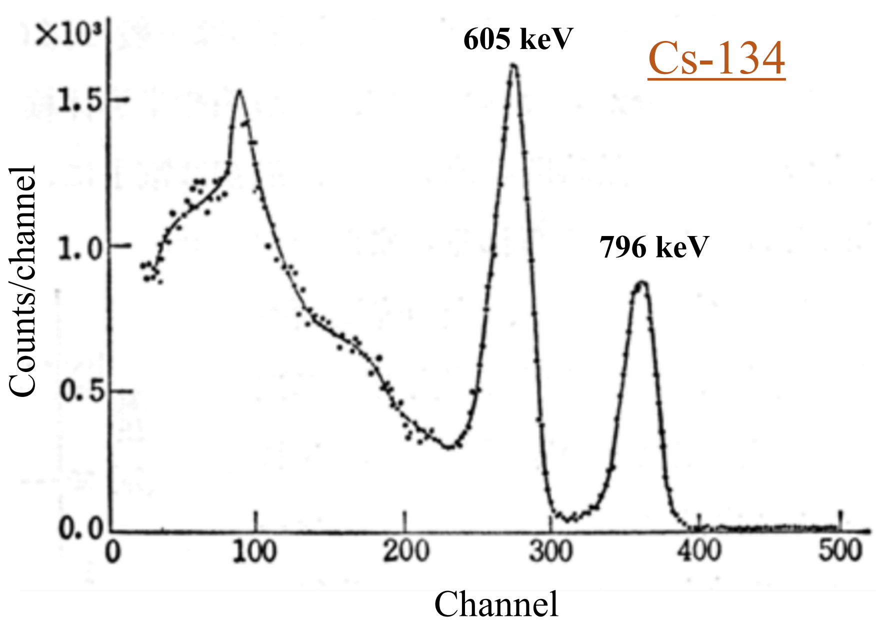
Ge (Li) semiconductor detector

Comparison of energy spectra detected for Cs-134

Ge (Li) semiconductor detector



NaI scintillation detector

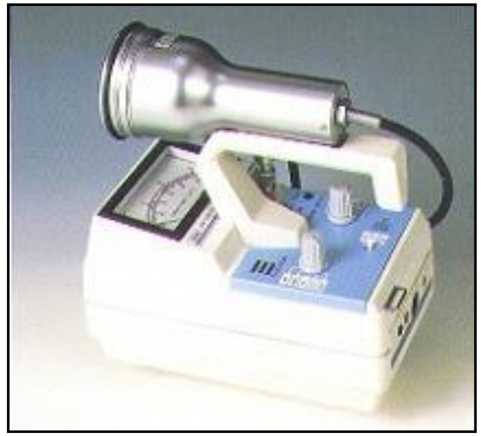


Survey meters

portable handheld radiation detectors

Ionization chamber type

for γ-ray ambient dose rate measurement

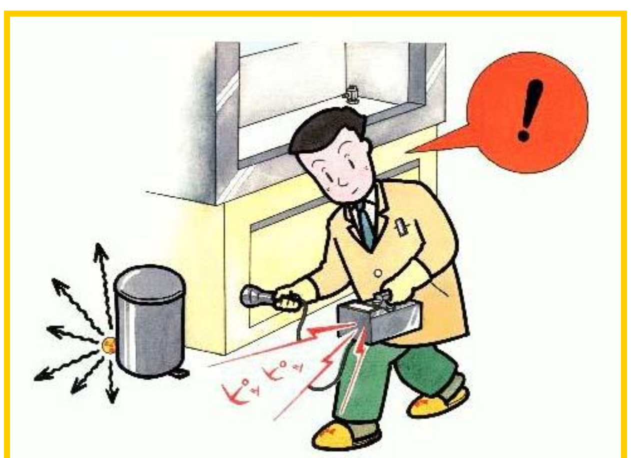


Geiger–Müller (GM) type

for contamination detection, highly sensitive to β-particles

Scintillation type

for γ-ray ambient dose rate measurement



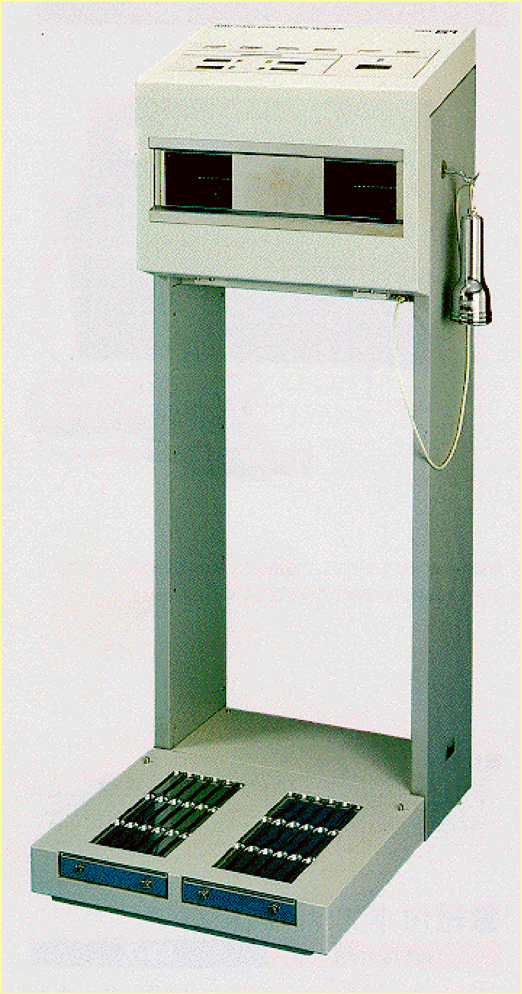
Radiation detection

Inspection of surface contamination with GM survey meter

Detecting radioactive contamination

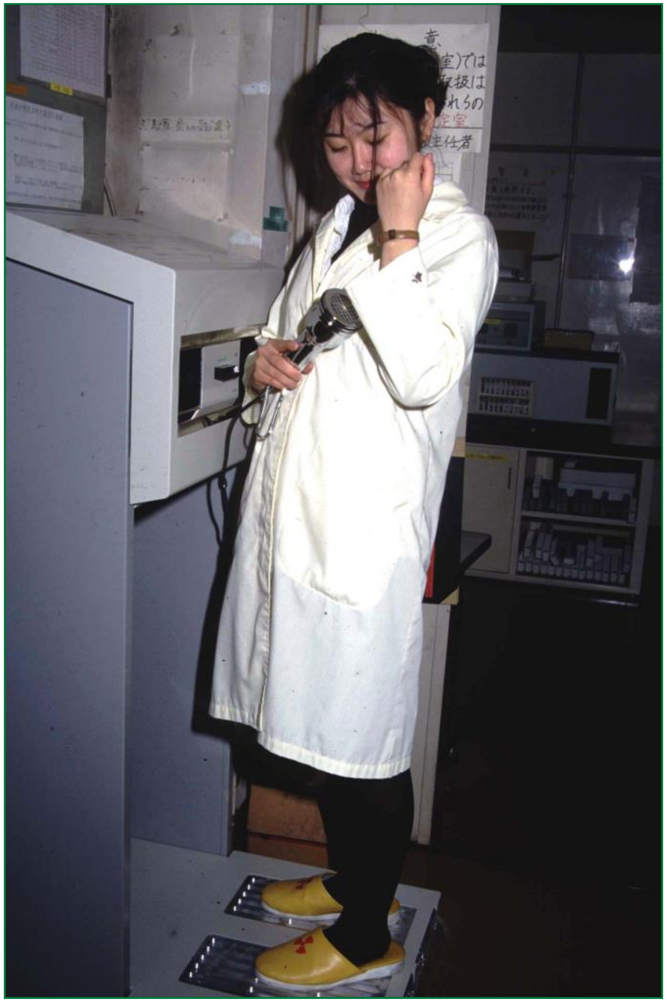
Hand-foot-cloths monitor

Radioactive contamination inspection for radiation workers
(when leaving a radiation controlled area)



Geiger–Müller (GM) type

Inspecting for hands and foots



Inspecting for lab coat

Instruments for measuring personal external exposure

Radiation exposure

- External exposure

  Exposure due to radiation from radiation sources outside the body

- Internal exposure

  Exposure due to radioactive materials inside the body

Cumulative exposure dose

Optically stimulated luminescence (OSL) dosimeter (badge type)

Radiophoto-luminescence (RPL) glass dosimeter (badge type) (ring type)

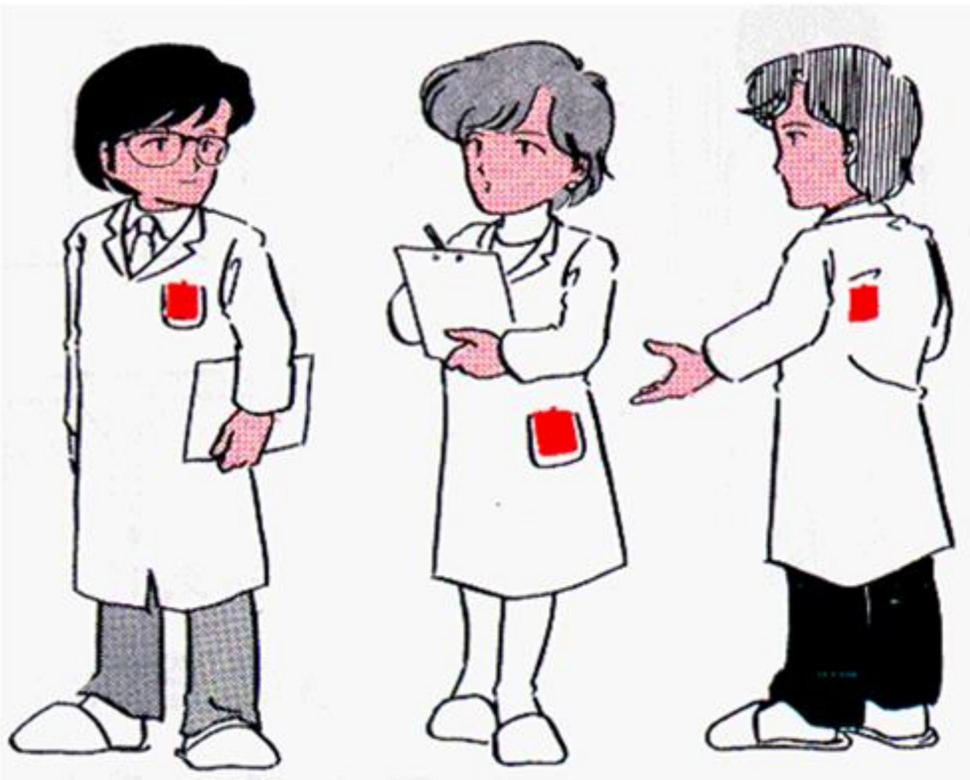
- Worn on the body for 1-3 months
- Cumulative dose measured by the manufactures
- Radiation workers receive each personal external exposure dose report

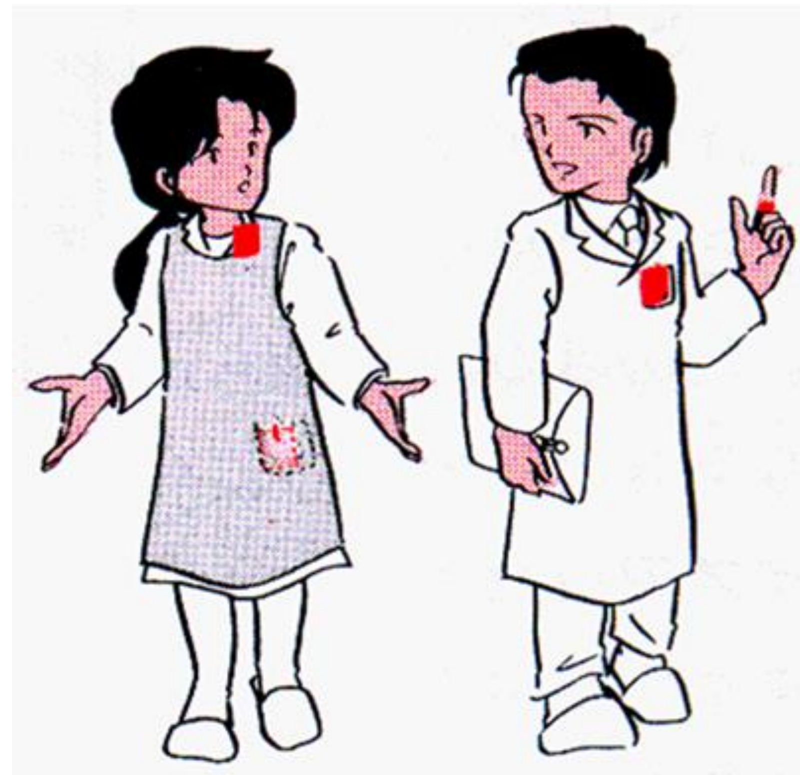
Electronic personal dosimeter
(direct reading display-type of cumulative doses)

Electronic personal dosimeter
(with alarm function)

How to wear personal exposure dosimeter

Purpose : estimation of equivalent dose and effective dose for external exposure





Chest Belly Back

Neck and one inside the lead apron

Chest and finger

Single use

Multiple use

Internal exposure dose measurement

Measuring and estimating internal exposure dose from radioactive materials ingested into the body

1. Whole-body counter method

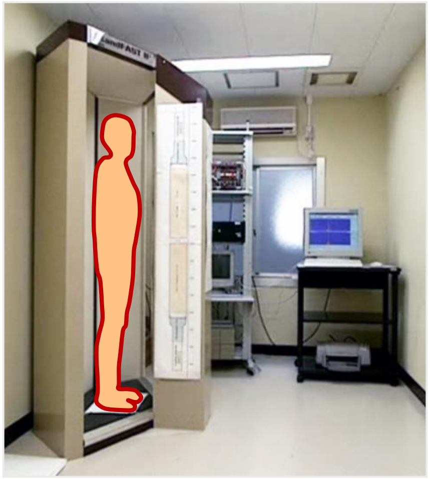
   Measuring gamma rays emitted directly from the body by an external large detector

2. Nasal smear method

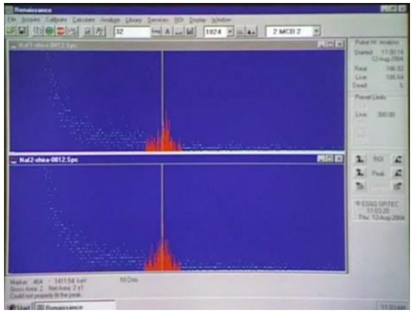
   A simple method to determine the presence or absence of inhalation intake
   Sampling by smearing the nasal cavity with a cotton swab with filter paper

3. Bioassay method

   Measurement of radioactivity of radioactive materials contained in excrement (urine, feces, saliva, exhaled breath) and body tissues (skin, hair, blood), etc



Stand-up whole-body counter



Result of measurement of potassium (K)-40 in the body

4. Measuring method of radioactivity concentration in air

   On-site measurement of radioactivity concentration in air by sampling a gas with a dust monitor or gas monitor