Mar. 31, 2020

Safe Handling of Radiation

General Handling

ISBN978-4-905025-02-3

大学等放射線施設協議会

113-0032 東京都文京区弥生2-11-16
東京大学アイソトープ総合センター内
電話: 03-5841-3058　Fax: 03-5841-3050
E-mail: kyogikai@ric.u-tokyo.ac.jp

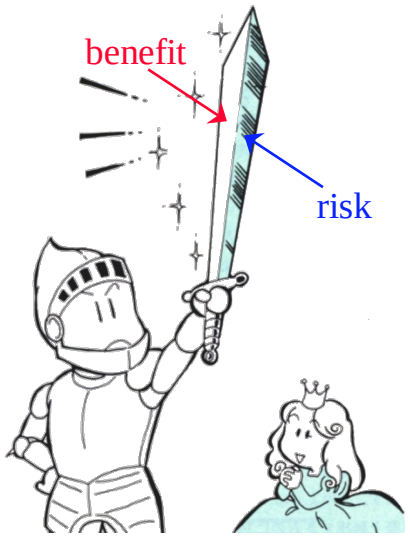
Contents

- Principles of radiation protection
- Protection from radiation exposure
- Before using radiation
- Preparation for actual work
- Checking of the equipment
- Entering the controlled area
- Working in the controlled area
- Radioactive waste
- Accidents
- When leaving the controlled area

The Principles of Radiological Protection

(ICRP Publication 103, p88-89, 2007)

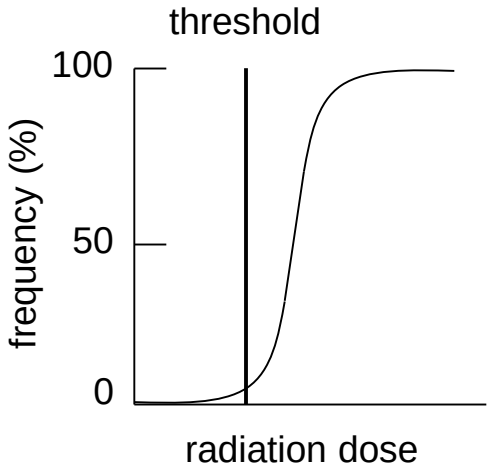
- **Justification**
  - Any decision that alters the radiation exposure situation should do more good than harm.
- **Optimization of Protection**
  - The likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors.
- **Application of Dose Limits**
  - The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the ICRP.



Using radiation is likely to “cut two ways”

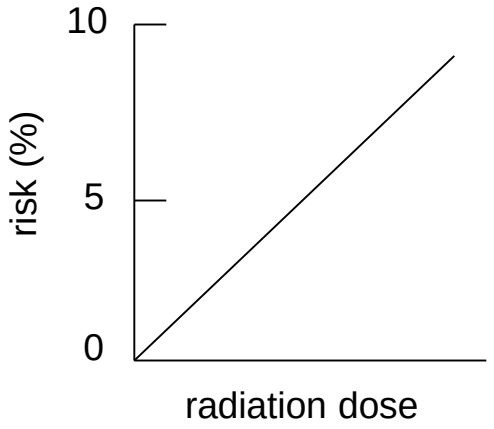
Deterministic effects

- should be prevented
- killing/malfunction of cells following doses higher than the threshold
- harmful tissue reactions



Stochastic effects

- should be limited to below the unacceptable level
- mutation of somatic or germ cells
- cancer and heritable effects



When you handle radioisotopes and accelerators ...

Please consider
yourself
nearby workers
general public

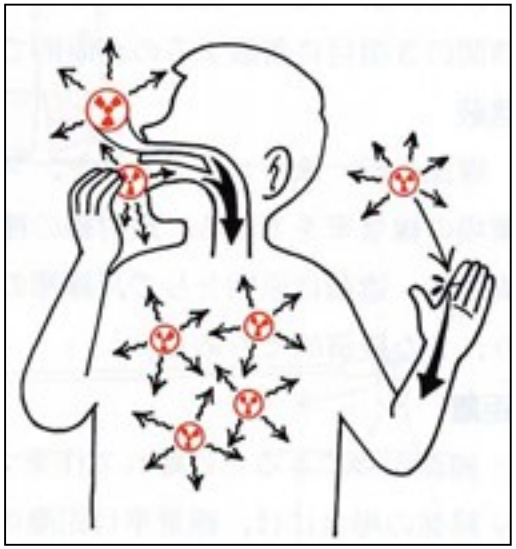
- Workers themselves have a primary responsibility for safety.
  - Past experience has demonstrated that it is impossible to expect perfection with respect to radiation safety handling, even in the case of highly experienced workers.
- Accidents are caused by insufficient and lack of consideration of the initial prudence while accustoming to the operation.
- A manager responsible for radiation protection is needed, who can advise on safety issues from the standpoint of a third person.

Types of Radiation Exposure

External Exposure

The radiation source is outside the human body.

Internal Exposure



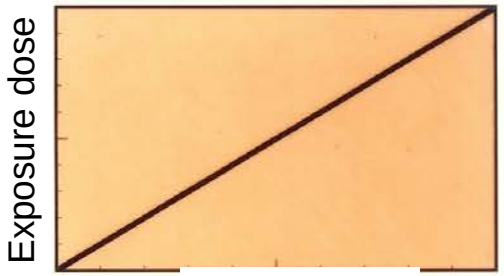
The radiation source is inside the human body.

You should pay attention to these types of exposure.

Principles of Protection from External Exposure

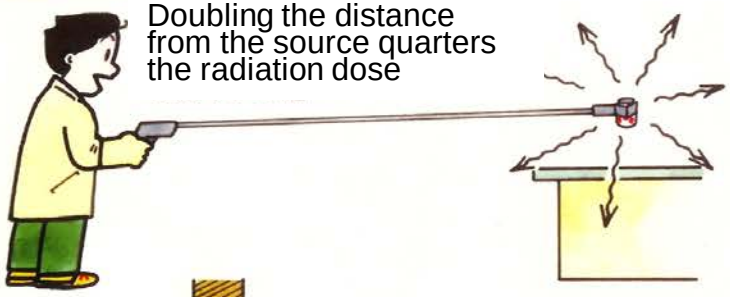
Time

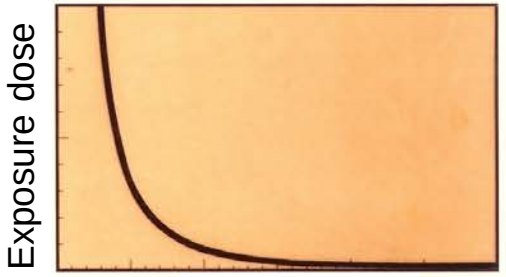
The shorter the time, the smaller the dose



Distance

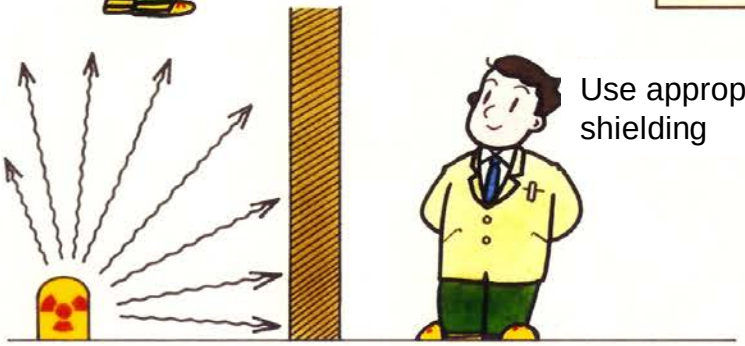
Doubling the distance from the source quarters the radiation dose

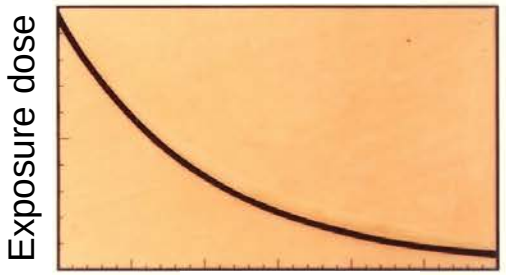




Shielding

Use appropriate shielding





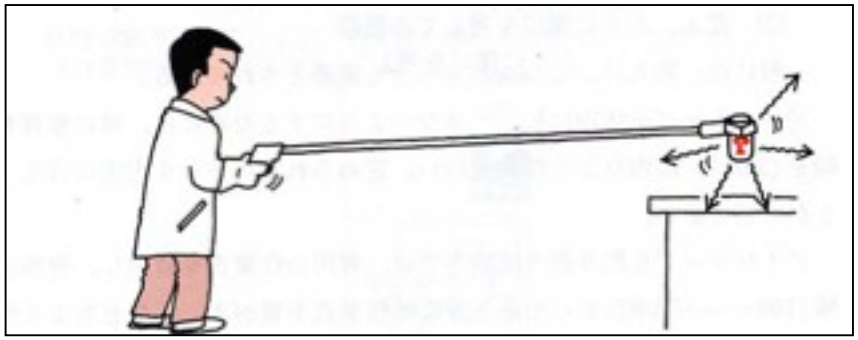
大学等放射線施設協議会

Time

Radiation dose increases in proportion to time.

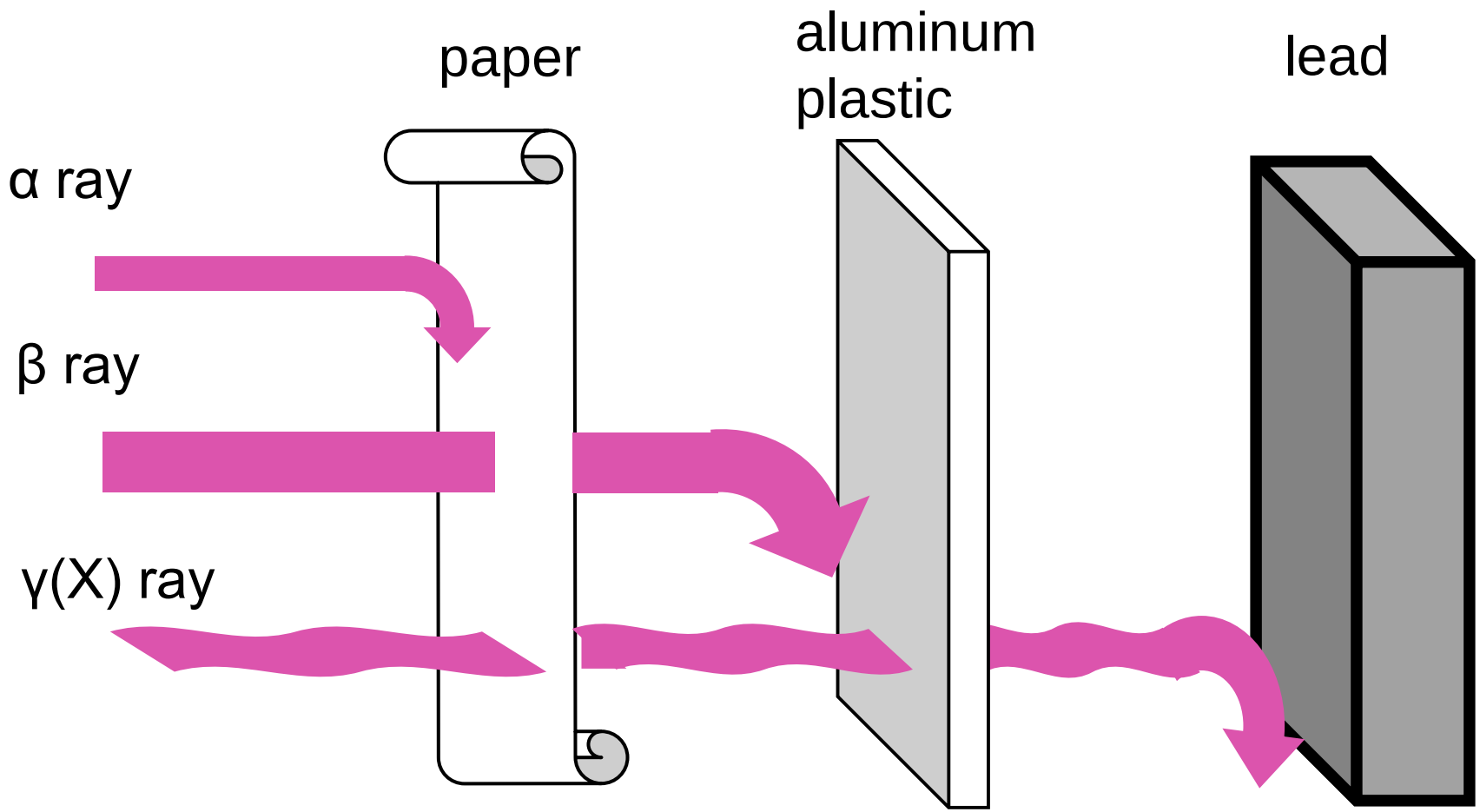
- Make the working time as short as possible!
- Do a “Cold run” practice and understand the individual steps of each procedure.

Distance

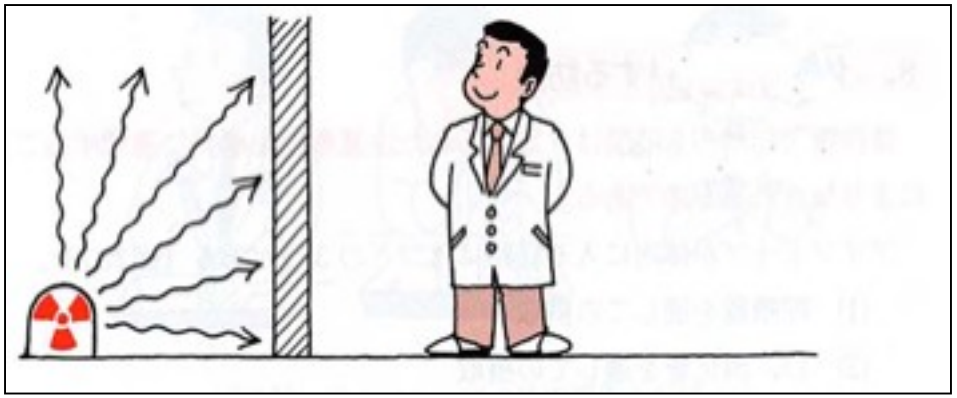


- The radiation dose decreases in inverse proportion to the square of the distance from the radiation source.
  - Keep as much distance between yourself and the radiation source as possible!
  - Don’t touch the radiation source directly.
  - Use remote handling equipment such as tongs or forceps.

Shielding



Shielding

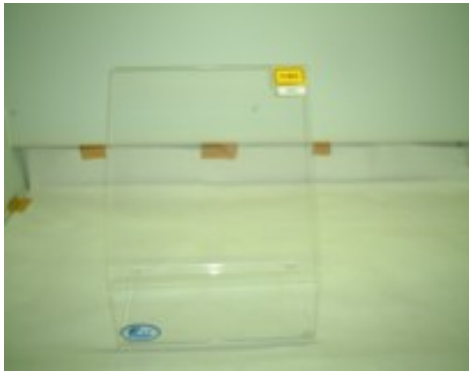


You can protect yourself from radiation exposure
by shielding the radiation source.

Radiation type	Shielding material
β -ray	aluminum board (several mm) plastic acryl board (several cm)
γ -ray	lead block, iron block, concrete block
neutron	block containing boron, water

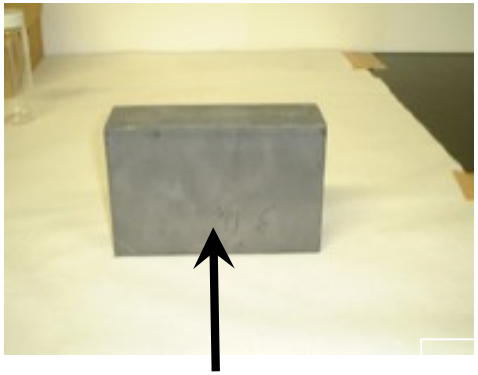
Shielding

Shielding of **β-ray**

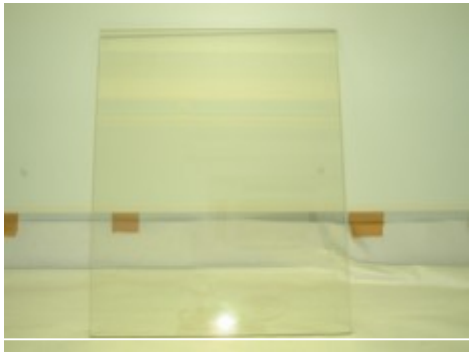


Plastic or acryl board

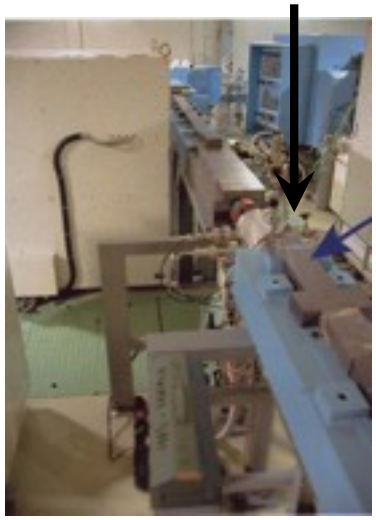
Shielding of **γ-ray**

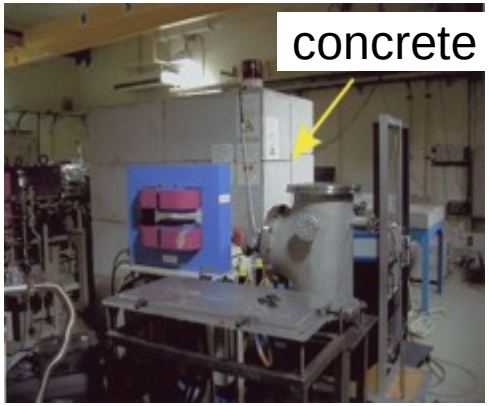


lead block



lead glass
(glass board containing lead)



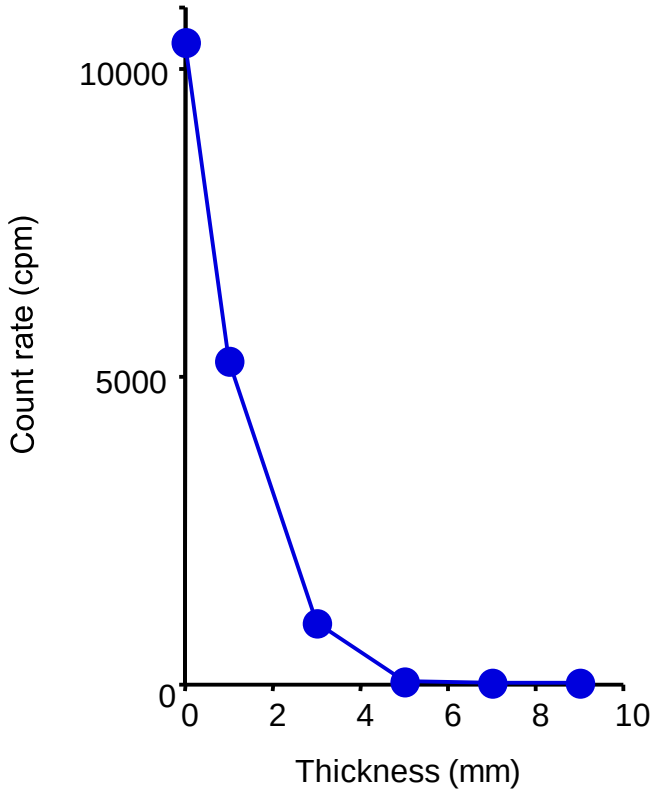


Shielding for β-ray (^{32}P, 5kBq)

Equipment

Result

Thickness of acrilate (mm)	Count rate (cpm)	Count rate - background
0	10448	10424
1	5248	5224
3	1011	987
5	60	36
7	34	10
9	33	9
Background	24	0

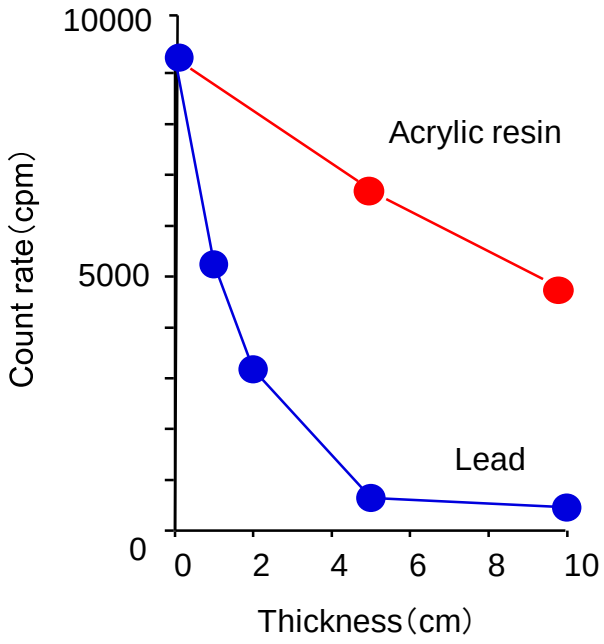


Shielding for γ-ray (^{60}Co, 37MBq)

Equipment

Result

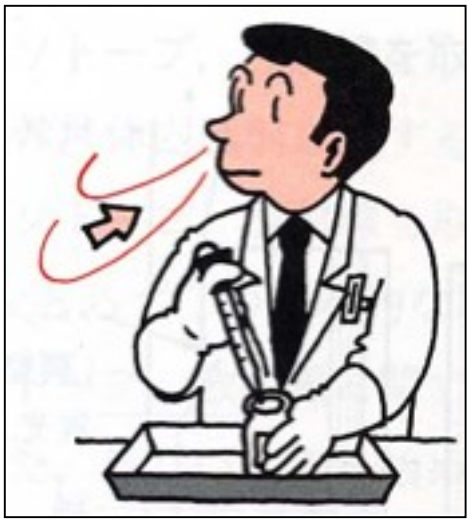
Thickness of shielding (cm)	Lead (cpm)	Acrylate (cpm)
0	9271	9271
1	5226	
2	3142	
5	630	7089
7		
9		
10	424	4553



Protection against Internal Exposure

Unsealed radioisotopes can enter into the body through the following three intake routes

Inhalation

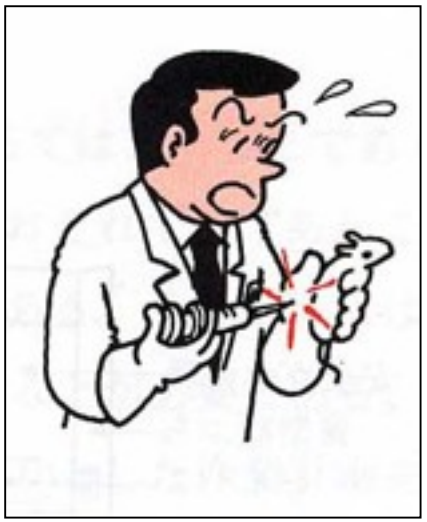


Through the respiratory system

Ingestion

Through the digestive system

Percutaneous uptake



Through the skin, especially a wound

Protection against Internal Exposure

- Protection against internal exposure can be attained by faithfully observing all rules and guidelines.

- In the controlled area, rules are as follows;

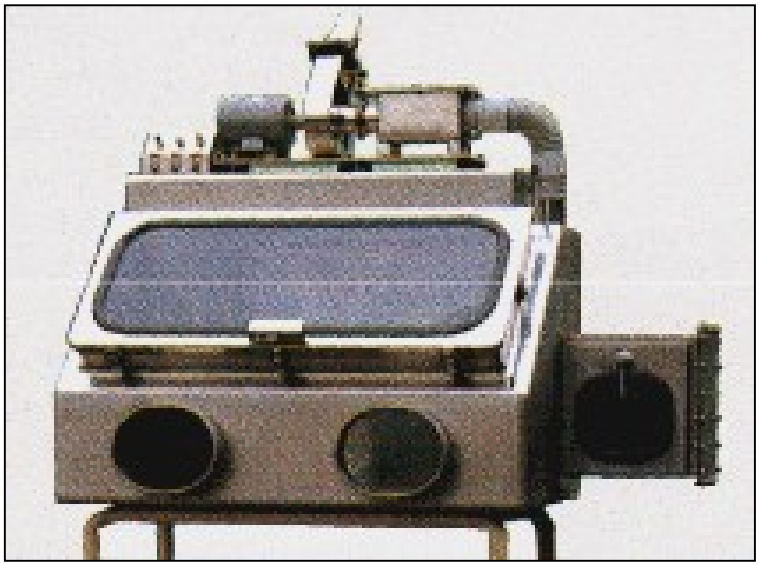
Inhalation	Turn on the switch of the ventilation system Use a hood or glove box
Ingestion	Don’t eat! Don’t smoke!
Percutaneous uptake	Wear gloves at all times

- Whenever you exit from the controlled area, the surface of your hands, clothes, and any equipment brought out from the controlled area must be checked for contamination.

Protection against Internal Exposure

When you handle volatile and/or high-concentrated radioisotopes, please use a hood or glove box.

hood



glove box

Before using radiation

- You must understand the characteristics of the radiation source

- What kind of radiation?
  - α-ray, β-ray, γ-ray, X-ray, or neutron

- Which type of radiation source?
  - Radioisotope
    - Sealed or Unsealed
  - Radiation Generating Equipment
    - Cyclotron, Synchrotron etc.
  - Radioisotope-equipped device
    - Irradiator etc.

Characteristics of radioisotopes used in life science

Nuclide	^{3}H	^{14}C	^{32}P	^{35}S	^{125}I
Radiation (energy)	β (18.6keV)	β (0.156MeV)	β (1.709MeV)	β (0.167MeV)	γ (35keV) X (27-32keV)
Half-life	12.3y	5370y	14.3d	87.4d	59.6d
Detection	Smear and Liquid scintillation counter	Gas-flow counter	GM detector	Gas-flow counter	Scintillation detector
Monitoring internal exposure	Bioassay (urine)	Bioassay (urine or respiration)	Bioassay (urine)	Bioassay (urine)	Scanning of thyroid gland
Range	6 mm (air) 6 μm (water)	24 cm (air) 0.28 cm (water)	790 cm (air) 0.8 cm (water)	24 cm (air) 0.28 cm (water)	
Shielding	No need	Acrylic resin (1 cm)	Acrylic resin (1 cm)	Acrylic resin (1 cm)	Lead (0.02 mm)

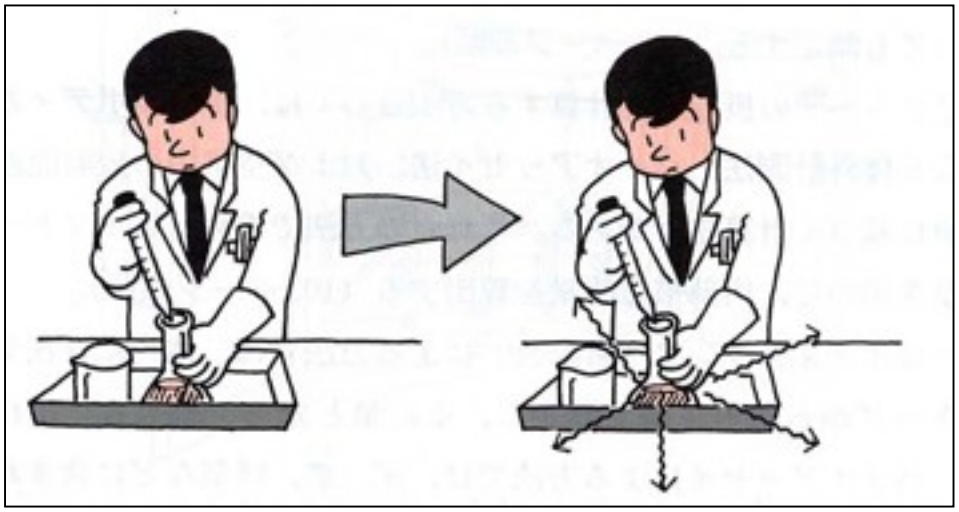
Useful radioisotopes in life science

Nuclide	Half-life	Application
^{3}H	12.3y	cell proliferation (thymidine uptake)
		micro-autoradiography
^{14}C	5370y	labeling of organic compounds
		pharmaco-dynamics
^{32}P	14.3d	labeling of probes for hybridization
		kinase assays
^{35}S	87.4d	metabolic labeling
^{51}Cr	27.7d	cytotoxic assay
^{125}I	59.6d	receptor binding assay
		radioimmunoassay
		labeling of peptides

Preparation for Actual Work

- Cold run
- Check the equipment you need
  - Personal dosimeter
  - Survey meter
  - Shielding materials
  - Laboratory instruments
  - Radiation protection gear (clothes, gloves, slippers, etc.)
- Don’t bring any unnecessary equipment into the controlled area.

Cold Run



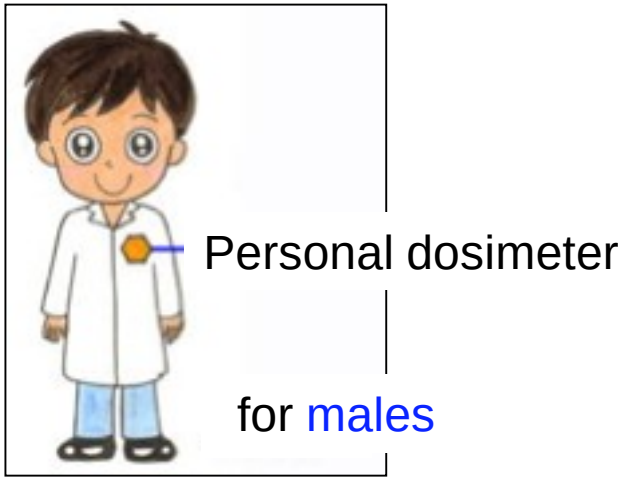
You should conduct a “**cold run**” to understand each step of experimental procedures before using radioactive materials.

Personal dosimeters

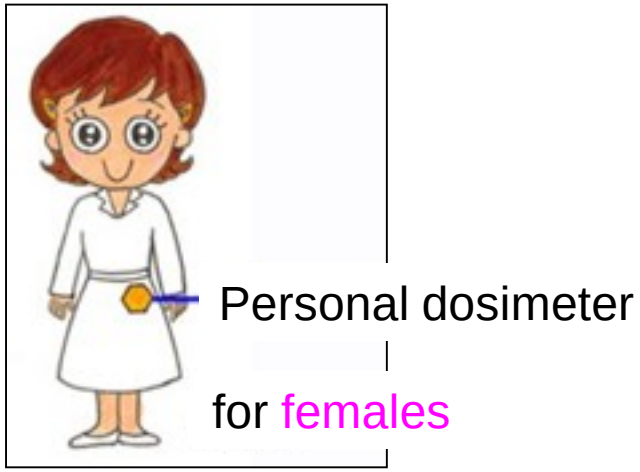
Luxel badge

Glass badge

Pocket dosimeter



Put on the chest for males



Put on the abdomen for females

Survey meters

β-rays		γ-rays	neutrons
low energy ^{3}H, ^{14}C	high energy ^{32}P		
$^{3}H/^{14}C$ survey meter	GM survey meter	Ionization chamber	Rem counter

Entering the controlled area

- The time of getting in and out of the controlled area for each radiation worker is automatically recorded.
- The radiation safety officers check the individual period of stay inside the controlled area.

Ventilation system

To minimize internal exposure, turn on the ventilation system when you enter the controlled area.

Using unsealed β-ray source

Prepare this equipment before you start working.

Survey meter

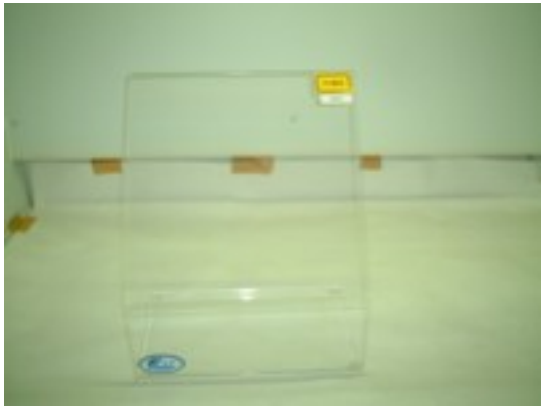
High energy (^{32}P)

Geiger-Müller (GM) counter

Low energy (^{3}H, ^{14}C)

$^{3}H/^{14}C$ Survey meter

Shielding material



Plastic or acryl board

Using unsealed γ-ray or neutrons

Survey meter

γ-ray

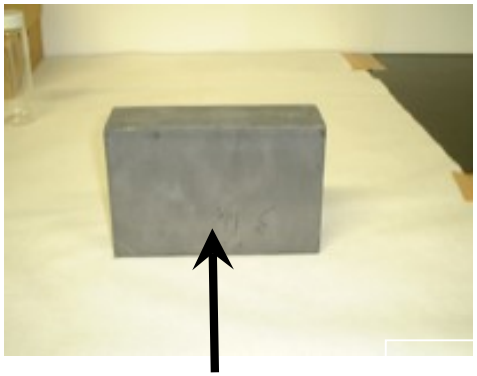
Ionization chamber

neutrons

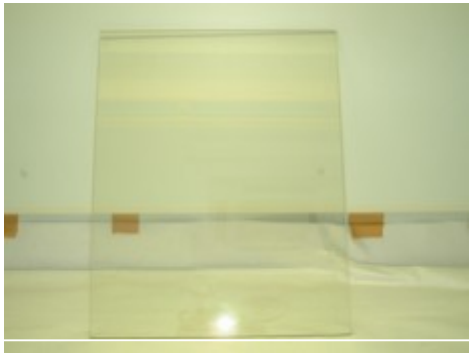
Rem counter

Neutron occurs when using Radiation Generating Equipment (Cyclotron, Synchrotron etc.)

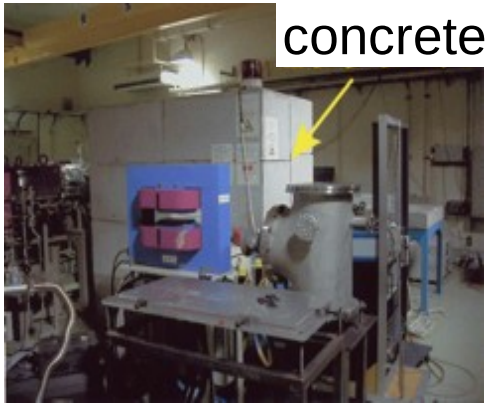
Shielding materials for γ-ray



lead block



lead glass
(glass board containing lead)

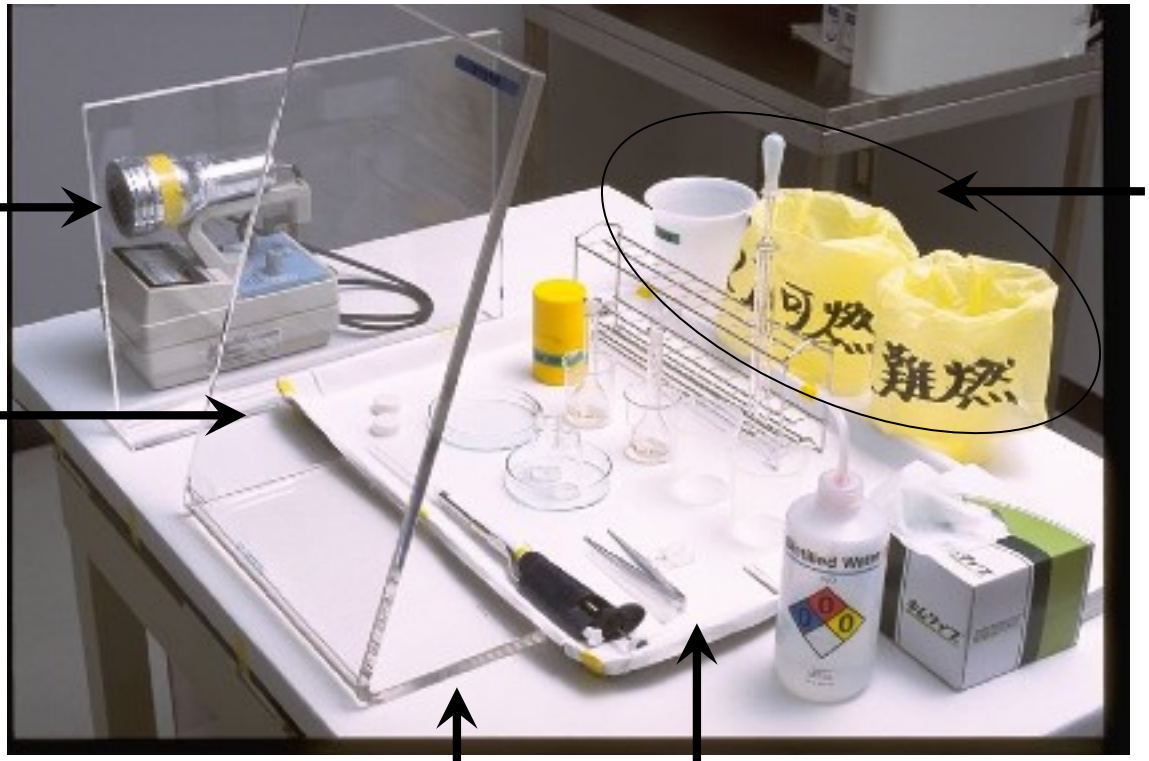


concrete

Example of working area for unsealed radioisotopes

Prepare the survey meter and keep the switch on.

Set the appropriate shielding material.



Prepare temporary waste containers adjacent to the working area.

Cover the polyethylene-coated paper sheet on the surface of a lab bench.

Treat the radioisotope in the tray covered with polyethylene-coated paper sheet.

You should not bring any unnecessary items into the controlled area.

For working safely in the controlled area

- Understand the law concerning prevention from radiation hazards due to radioisotopes, etc.
- Understand the nature of radioisotopes and use them in an appropriate manner
- Understand the effects of radiation on humans and the environment
- Handle radioactive substances appropriately to prevent contamination
- Dispose of radioactive waste by authorized routes
- Follow the emergency procedures in case of natural disaster or fire

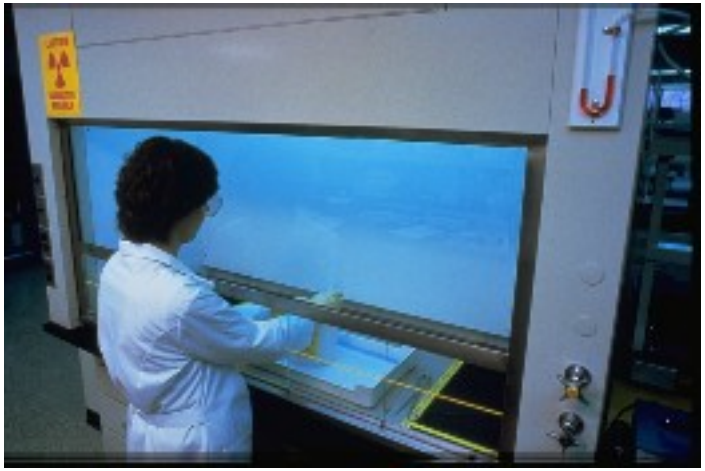
Attitude

Don’t be overly afraid　Don’t panic　Don’t take things too lightly

You should be accompanied by your instructor or experienced person at your first radiation work.

If you have any problems, ask the radiation protection supervisor and/or radiation protection officers (staff members of the RI facility).

Measures against contamination



When you use the hood, don’t forget to cover the tray with a polyethylene-coated paper sheet.

Don’t touch the radiation source directly.
Use the remote handling equipment such as tongs or forceps.

Measures against contamination

use a tray

use a cart

use a bucket

To avoid accidents, use of a tray, a cart and a bucket is recommended.

The surface of a tray and a cart should be covered with polyethylene-coated paper sheets.

Decontamination protocol

	Reagent	Protocol
Hand / Skin	Neutral surfactant	Spread powder over spilled area and wet brush under tap water
	Titanium oxide paste	Use together with neutral surfactant
Clothing	Neutral surfactant	Use washing machine
	Cut and fix	
Glasses	Neutral surfactant	
	EDTA, Oxalate	Use as 3% warm solution
Metal	dil. Nitrate	
	10% ammonium citrate	
Plastic	Neutral surfactant	
	EDTA	
	10% ammonium citrate	
	dil. Acid	
Painted surface	10% Sodium phosphate	

Radioactive waste

Classification by the Japan Radioisotope Association

Combustible Type I	Paper, cloth, wood pieces
Combustible Type II	Plastic tube, plastic vials, polyethylene sheets rubber gloves
Incombustible	Glass vials, other glass equipment, syringe needles, vinyl chloride pipes, vinyl chloride sheets, silicon tubes, ceramics, aluminum foil, material containing lead, Teflon products
Incompressible and Incombustible	Soil, sand, iron bars, pipes, concrete pieces, castings, clock parts, large amounts of TLC plate, machinery and equipment
Animals	Animals after being dried
Inorganic liquids	Fluids after testing
Combustible filters Normal filters	HEPA filters, pre-filters, charcoal filters HEPA filters, pre-filters, charcoal filters

When leaving the controlled area

- Wash hands and check for contamination on hands and feet.
- Change clothes and shoes.
- Check for contamination on everything taken out of the controlled area (notebook, pen, calculator, etc.)

Accidents

If you encounter any accidents such as fire or earthquake.

In case of accident

- At first, think and act to save yourself.
  - Escape to a safe place
  - Notify other workers in a loud voice
  - Push the emergency button
- If time permits, take action to prevent expansion of the accident.
  - Bring the radioisotope back to the storage room
  - Extinguish the fire at an early stage
- Notify the radiation protection supervisor or radiation protection staff members.

Effects of Radiation

on Human Health

ISBN978-4-905025-12-2

大学等放射線施設協議会

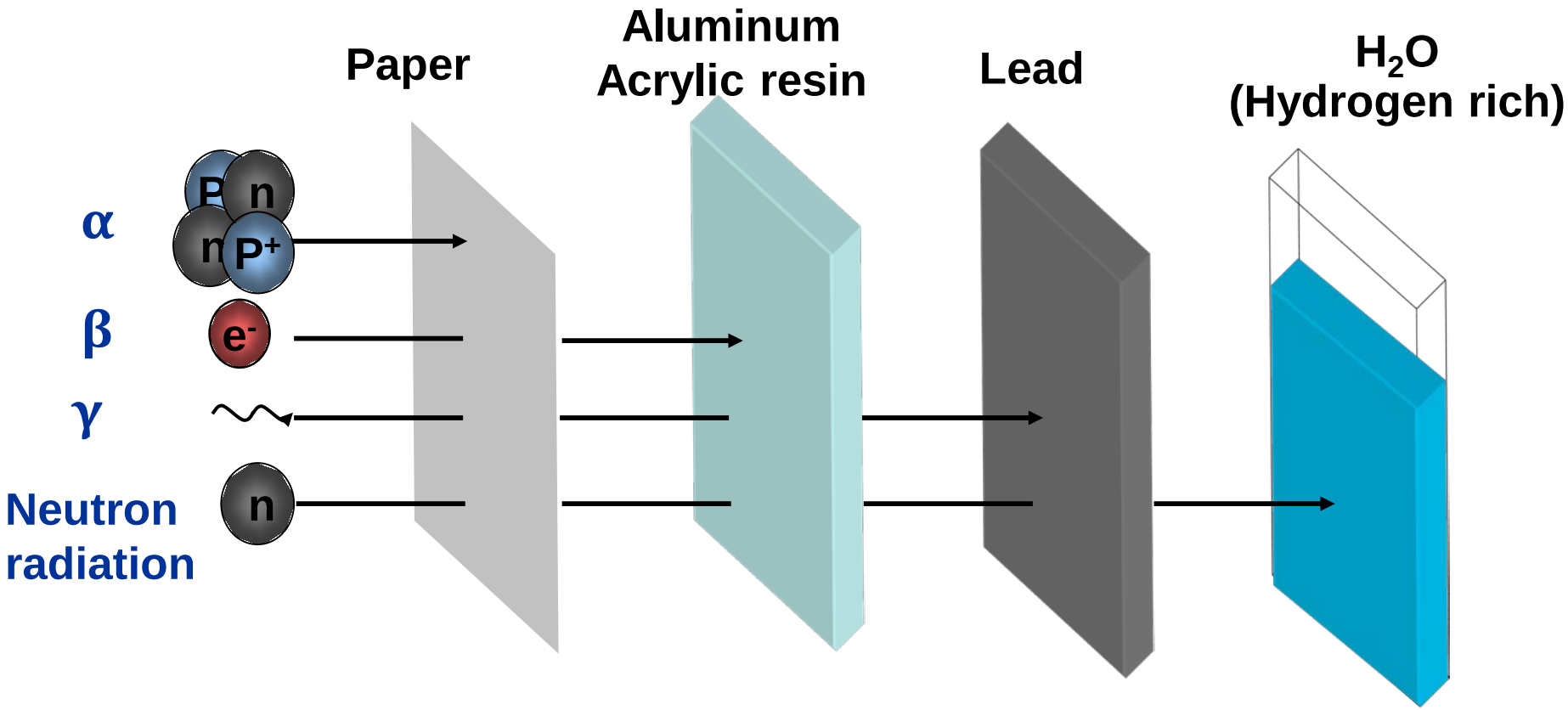
113-0032 東京都文京区弥生2-11-16
東京大学アイソトープ総合センター内
電話: 03-5841-3058　Fax: 03-5841-3050
E-mail: kyogikai@ric.u-tokyo.ac.jp

Factors that relate to biological effects

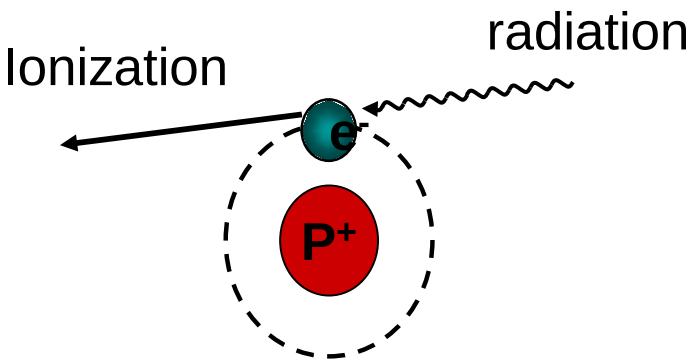
1. Penetrating ability

2. Linear Energy Transfer (LET)

1. Penetrating Ability of Radiations



2. Linear Energy Transfer (LET)

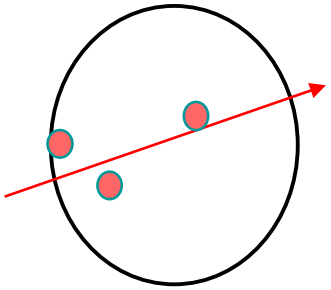


The energy transferred per given distance of track

‖

Linear Energy Transfer (LET)

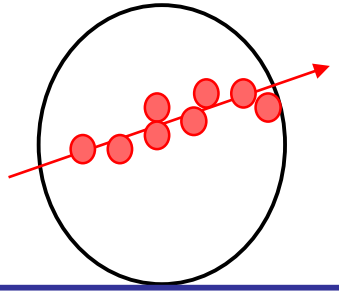
Low LET radiations (X, γ, β)



Sparsely ionizing

Less biological effect

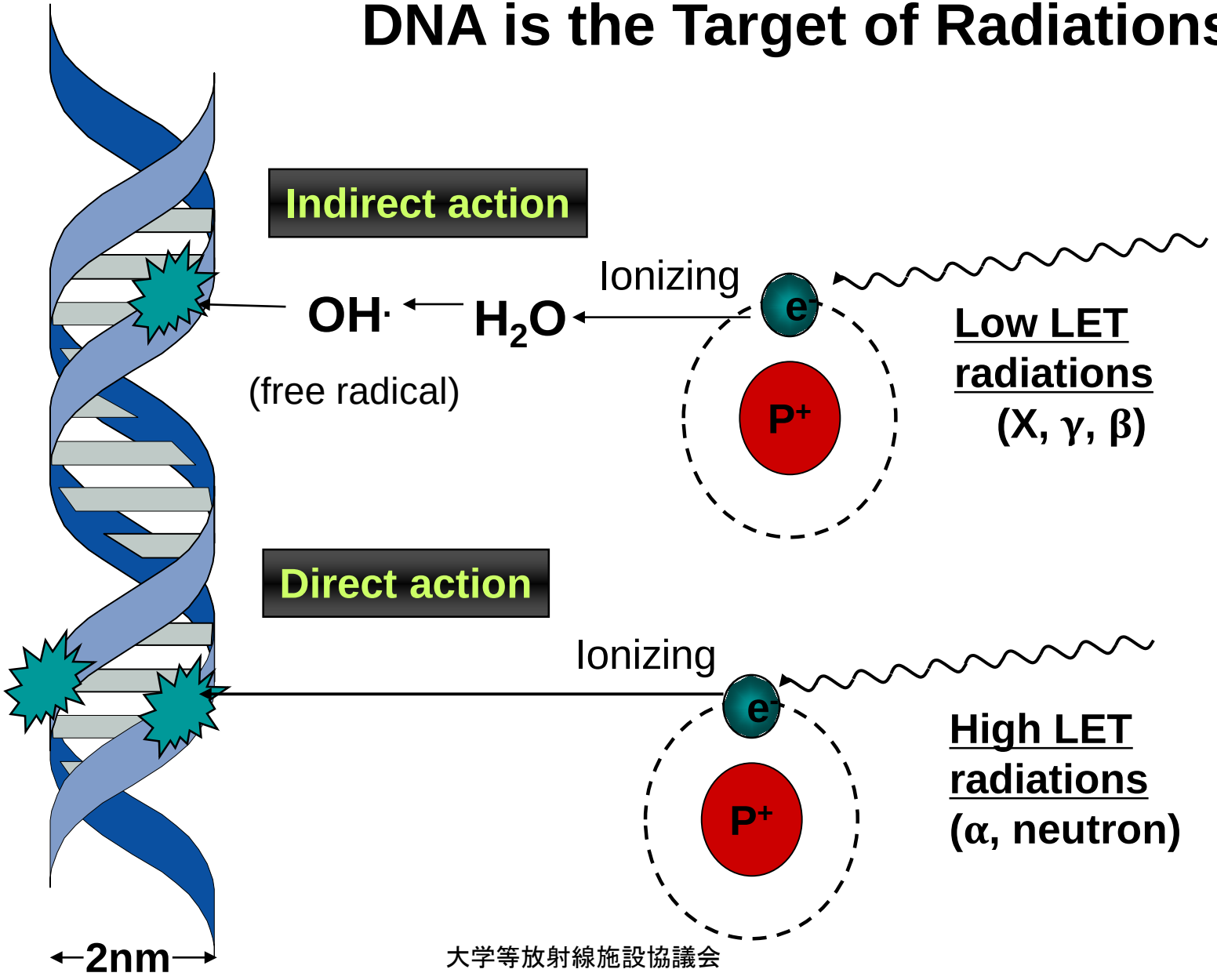
High LET radiations (α, neutron)



Densely ionizing

More biological effect

DNA is the Target of Radiations



Classification of Biological effects of Radiations on the Human Body

- **Acute Effects** vs. **Late Effects**
- **Deterministic Effects** vs. **Stochastic Effects**
- **Somatic Effects** vs. **Genetic Effects**

Classification of Biological effects of Radiation on the Human Body

- **Acute Effects** vs. **Late Effects**
- **Deterministic Effects** vs. **Stochastic Effects**
- **Somatic Effects** vs. **Genetic Effects**

Acute Effects

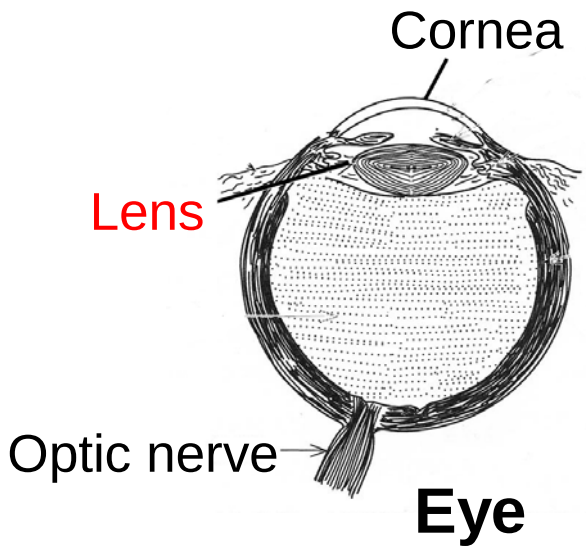
Symptoms of acute effects and dose delivered
(Whole body, single exposure to gamma rays (or X-rays))

Dose (Gy)	Symptoms
0.25 or less	Almost no clinical symptoms
0.5	Temporary reduction of white blood cells (lymphocytes)
1	Nausea, vomiting, whole-body languor, substantial reduction of lymphocytes
1.5	Radiation sickness to 50%
1	Death to 5%
4	Death to 50% within 30 days
6	Death to 90% within 14 days
7	Death to 100%

Late Effects

Cataracts: clouding of the lens of the eye

- Latent period: several years to a few decades
- Do not occur below a single exposure dose of 2 Sv



Eye

Cancers

- Latent period: several years to a few decades

Genetic effects

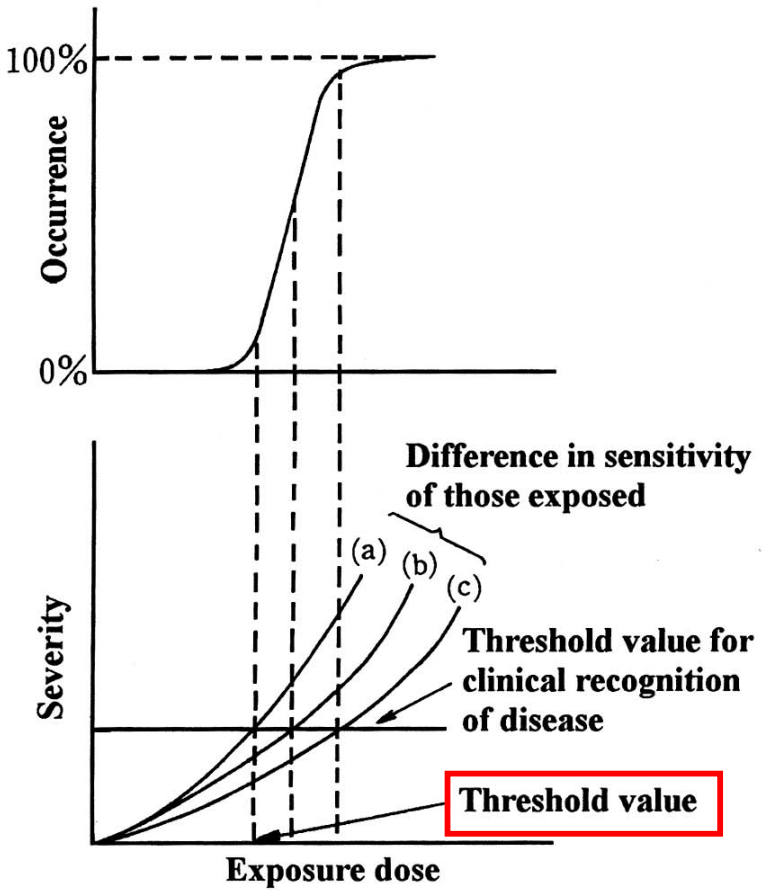
- Could be
- But not verified in human beings so far

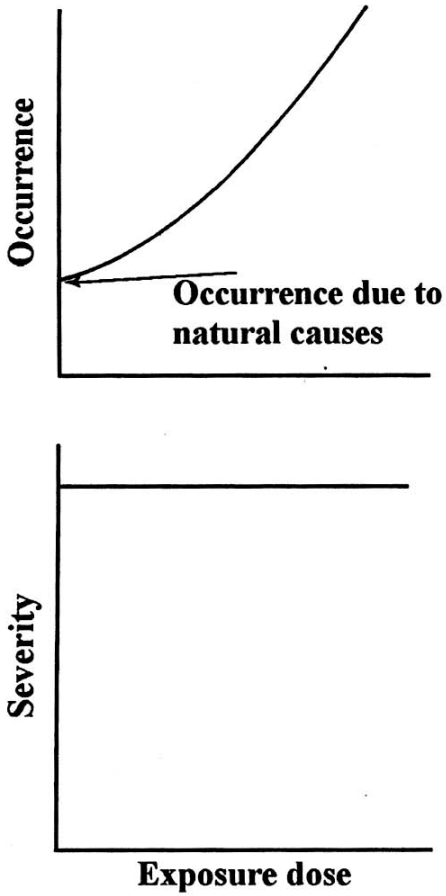
Use a appropriate shield in front of your eyes

Classification of Biological effects of Radiation on the Human Body

- **Acute Effects** vs. **Late Effects**
- **Deterministic Effects** vs. **Stochastic Effects**
- **Somatic Effects** vs. **Genetic Effects**

Deterministic Effects vs. Stochastic Effects





Deterministic Effects

- Acute effects
- Cataract

Stochastic Effects

- Cancer, leukemia
- Genetic effects

Deterministic effects

Projected threshold estimates of the acute absorbed dose for 1% morbidity after whole body gamma ray exposures

Effect	Organ/Tissue	Time to develop effect	Absorbed dose (Gy)
Temporary sterility	Testes	3-9 weeks	～ 0.1
Permanent sterility	Testes	3 weeks	～ 6
	Ovaries	< 1 week	～ 3
Depression of blood forming process	Bone marrow	3-7 days	～ 0.5
Skin reddening	Skin (large areas)	1-4 weeks	< 3-6
Skin burns	Skin (large areas)	2-3 weeks	5-10
Temporary hair loss	Skin	2-3 weeks	～ 4
Cataract (visual impairment)	Eye	Several years	～ 1.5

ICRP publication 103, pp168, Table A.3.4, 2007

Deterministic effects

Projected threshold estimates of the acute absorbed dose for 1% mortality after whole body gamma ray exposures

Exposed population	Organ/Tissue	Time to develop effect	Absorbed dose (Gy)
Bone marrow syndrome			
without medical care	Bone marrow	30-60 days	～ 1
with good medical care	Bone marrow	30-60 days	2-3
Gastro-intestinal syndrome			
without medical care	Small intestine	6-9 days	～ 6
with good medical care	Small intestine	6-9 days	> 6
Pneumonitis	Lung	1-7 months	6

ICRP publication 103, pp168, Table A.3.4, 2007

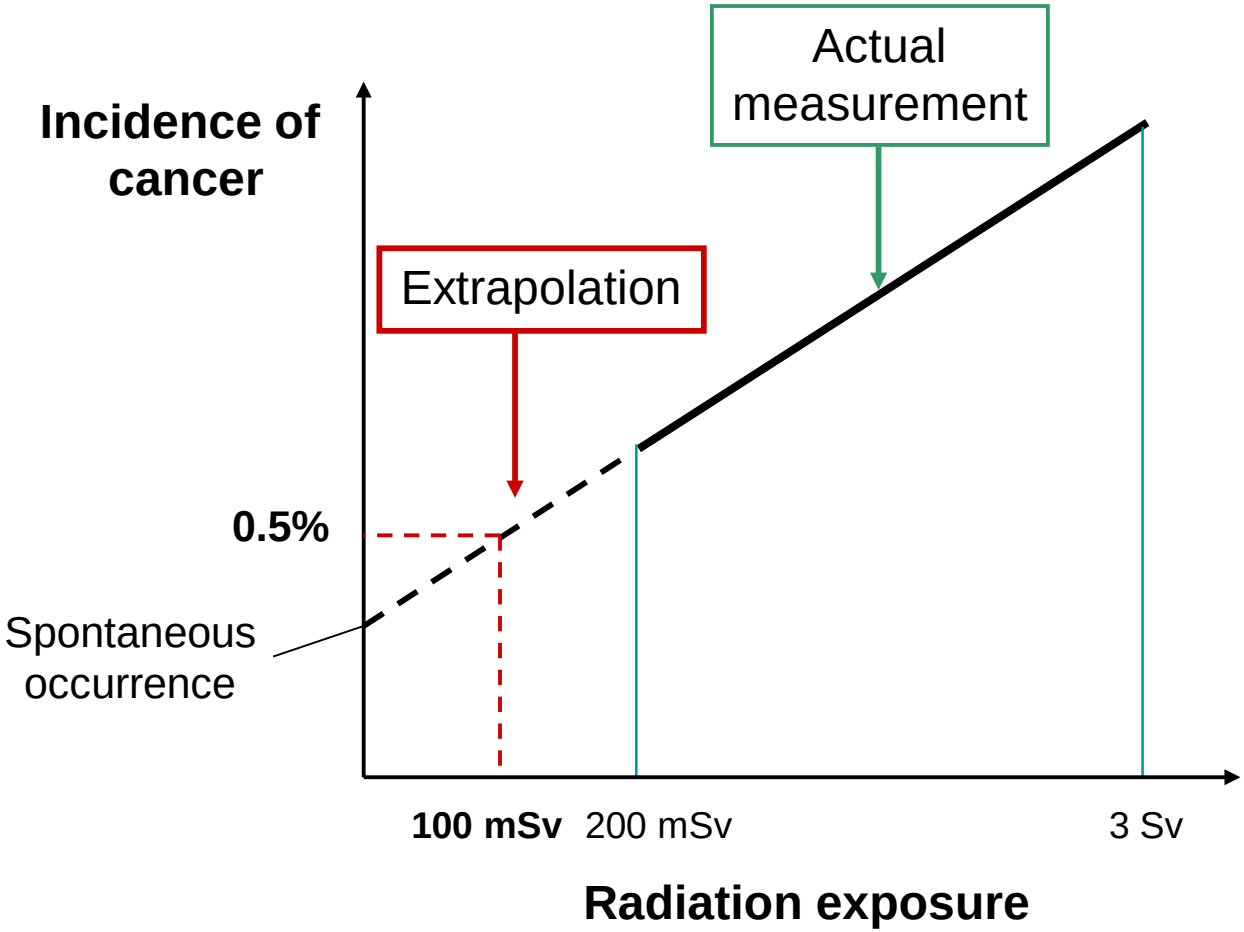
Stochastic effects

Detriment-adjusted nominal risk coefficients after exposure to radiation at low dose rate

Exposed population	Cancer	Heritable effects	Total
Whole population	5.5×10^{-2}/Sv	0.2×10^{-2}/Sv	5.7×10^{-2}/Sv
Adult workers	4.1×10^{-2}/Sv	0.1×10^{-2}/Sv	4.2×10^{-2}/Sv

ICRP publication 103, pp53, Table 1, 2007

Risk Estimate for Cancers (Stochastic Effect)



Classification of Biological effects of Radiation on the Human Body

- **Acute Effects** vs. **Late Effects**
- **Deterministic Effects** vs. **Stochastic Effects**
- **Somatic Effects** vs. **Genetic Effects**

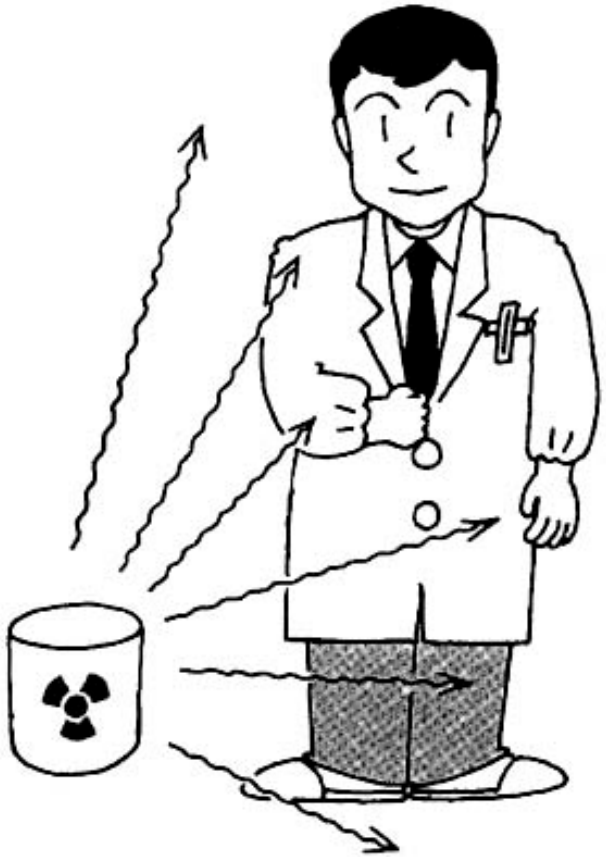
Somatic Effects

Effects of radiation limited to the exposed individual, as distinguished from genetic effects, that may also affect subsequent unexposed generations.

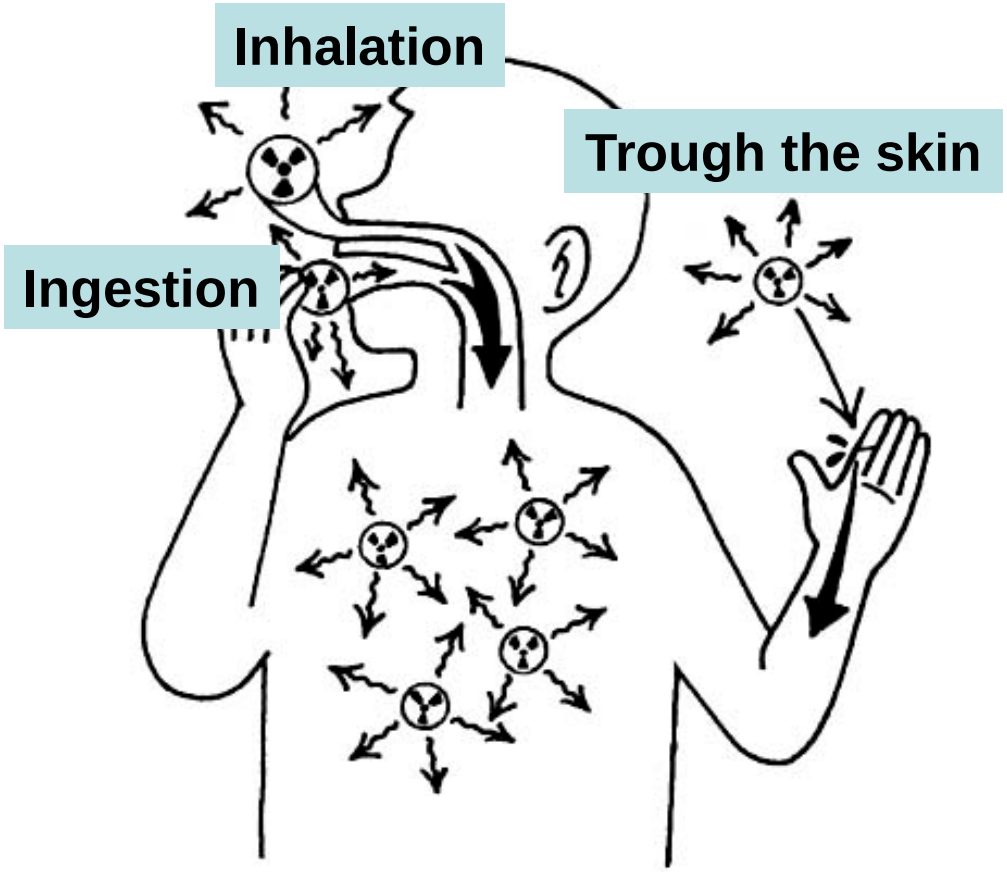
Genetic Effects

The radiation induced change in the DNA of germ cells resulting in the passing of the altered genetic information to future generations.

External Exposures vs. Internal Exposures



External exposure

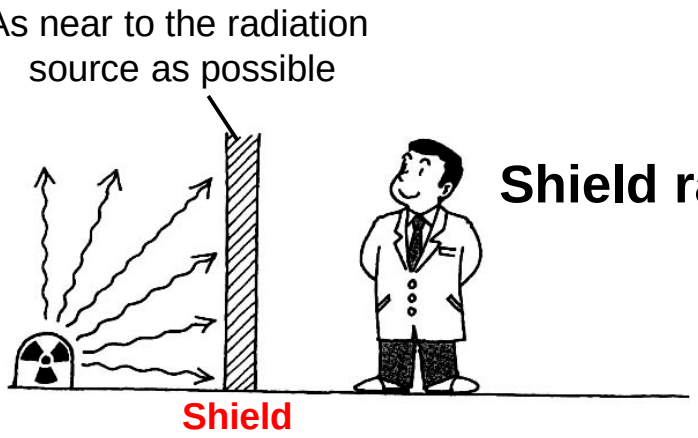


Internal exposure

Protecting Against External Exposure

3 principles

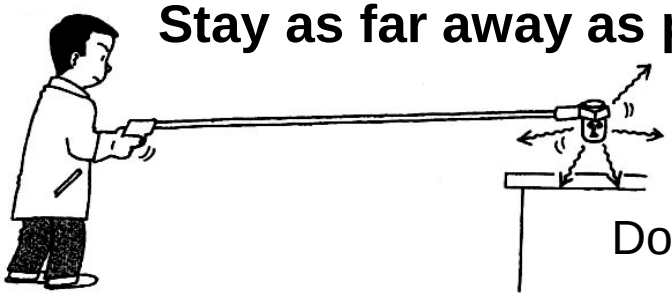
Shielding



Shield radiation sources.

Distance

Stay as far away as possible.



Dose rate = K/ R^2
K: constant
R: distance

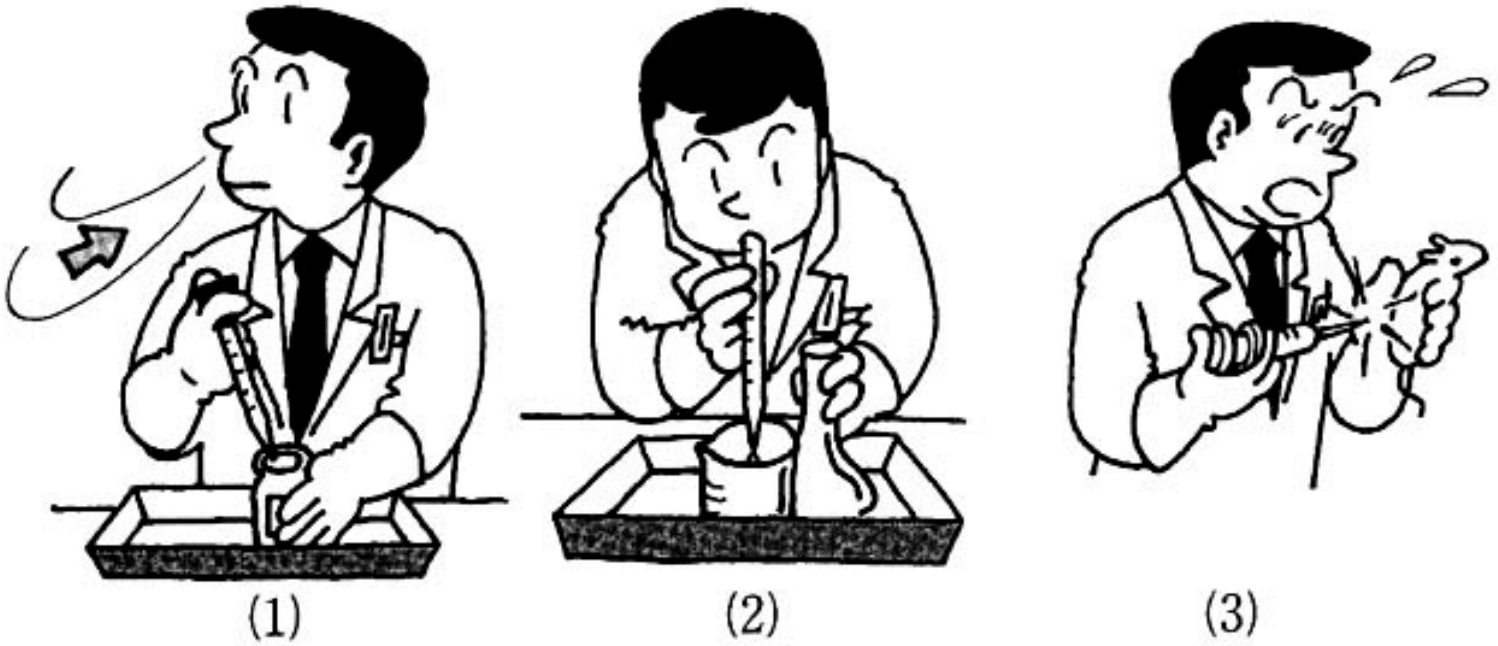
Time

Keep exposure time short !

大学等放射線施設協議会

Protecting Against Internal Exposure

Intake routes of radioisotopes



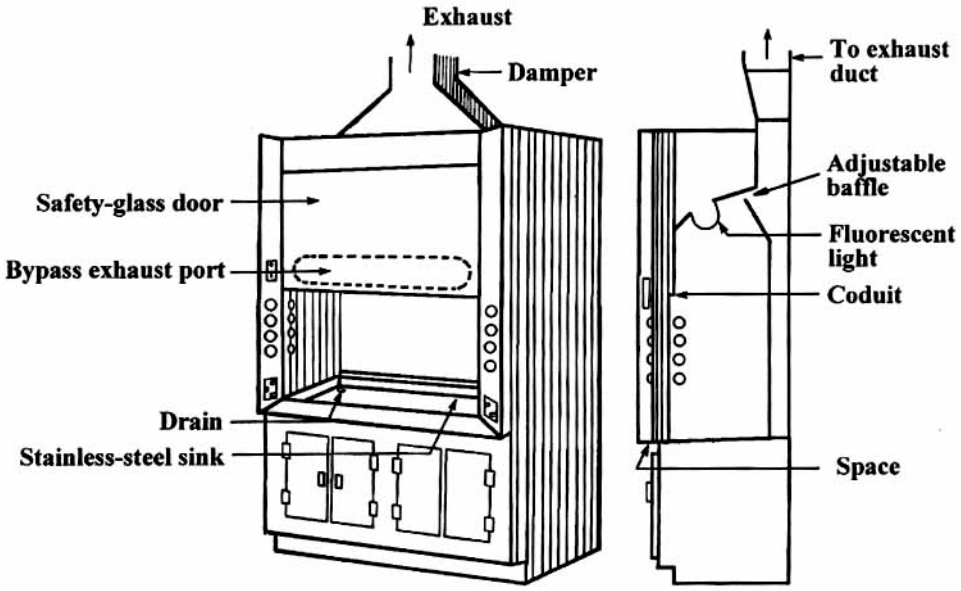
Inhalation

Ingestion

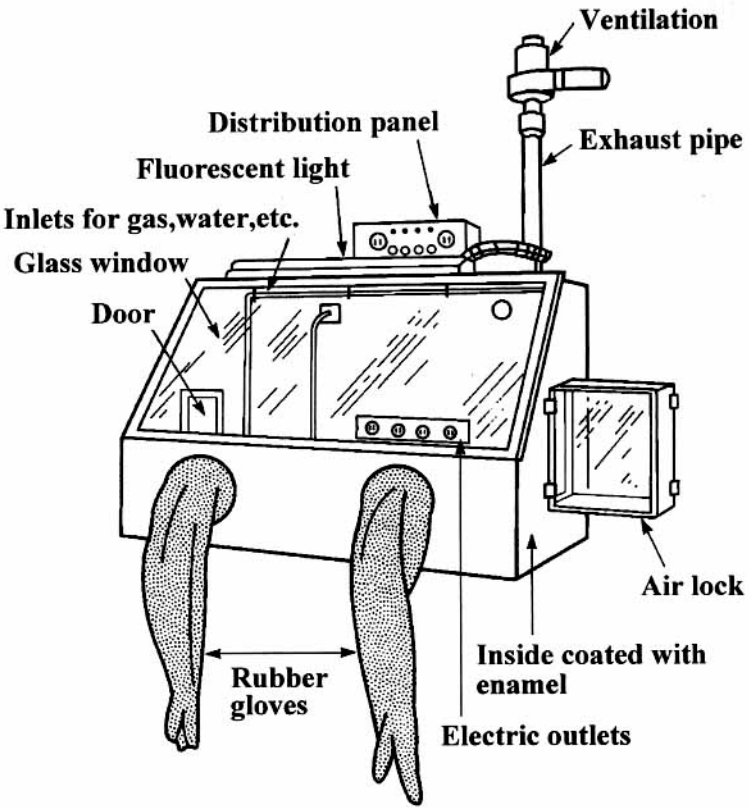
Through the skin (wound)

大学等放射線施設協議会

To Prevent the inhalation of radioisotopes



Oak Ridge-type hood



Glove box

Prohibited Matters

Eating or drinking

Smoking

Wearing make-up

Radiation-Related Quantities and Units

Absorbed Dose : **Gray (Gy)**

- The energy absorbed per unit mass of the material
- A fundamental dosimetric quantity (physical unit)
- Regardless of the kind of radiation
- 1 Gy = 1 J/ kg
- Dose not reflect the degree of biological effects

To calculate the risk of irradiation to the human body

Equivalent Dose : **Sievert (Sv)**

Effective Dose : **Sievert (Sv)**

Equivalent Dose & Effective Dose

Equivalent Dose (H_T) : **Sievert (Sv)**

- a measure of biological effects on a particular tissues or organs

- $H_T = \sum_R w_R \cdot D_{T,R}$

  w_R : Radiation weighting factor

  $D_{T,R}$: Mean absorbed dose for a tissue or organ (Gy)

Radiation weighting factor (w_R)

Radiation	Weighting Factor
γ rays & X rays	1
Beta rays	1
Proton	2
α rays, fission fragments, heavy ion	20
Neutrons	Continuous function of the energy

(ICRP 2007)

Equivalent Dose & Effective Dose

Effective Dose (*E*) : Sievert (Sv)

Stochastic effects

・a measure of biological effects throughout the body (cancers or genetic effects)

・ $E = \sum_T w_T \cdot H_T = \sum_T w_T \cdot \sum_R w_R \cdot D_{T,R}$

H_T : Equivalent dose for tissues and organs

w_T : Weighting factor for organs or tissues

Tissue weighting factors

Tissue/Organ	Weighting factor
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.12
Gonads	0.08
Bladder	0.04
Esophagus	0.04
Liver	0.04
Thyroid	0.04
Bone	0.01
Brain	0.01
Salivary gland	0.01
Skin	0.01
Others	0.12

(ICRP 2007)

Annual average dose per person

Doctors	0.24 mSv
Nurse	0.12 mSv
Radiotherapy technicians	0.68 mSv
Those engaged in research	0.01 mSv
Nuclear power plant worker	1.3 mSv

Effective Dose Limits and Tissue Equivalent Dose Limits for Radiation Workers (including Researchers)

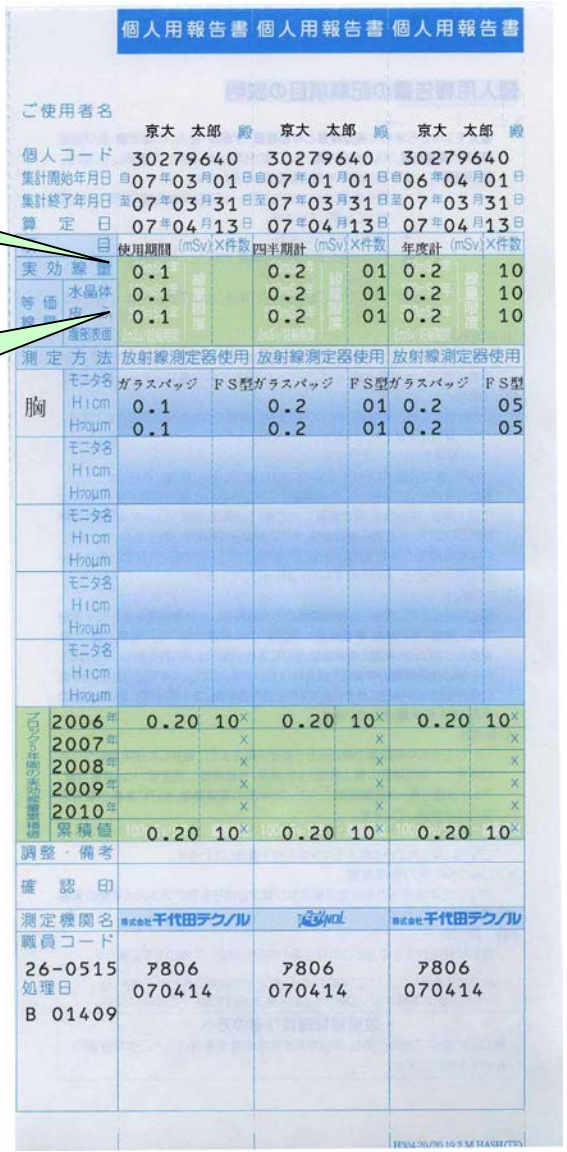
Effective dose limit	50 mSv/year; 100 mSv/5years
Women	5 mSv/3 months
Pregnant women*	1 mSv as internal exposure
Tissue equivalent dose limit	
1) Lens of the eye	150 mSv/year
2) Skin	500 mSv/year
3) Abdomen of pregnant women*	2 mSv

*From the confirmation of pregnancy to delivery

Personal Radiation Monitoring

Personal monitoring instrument

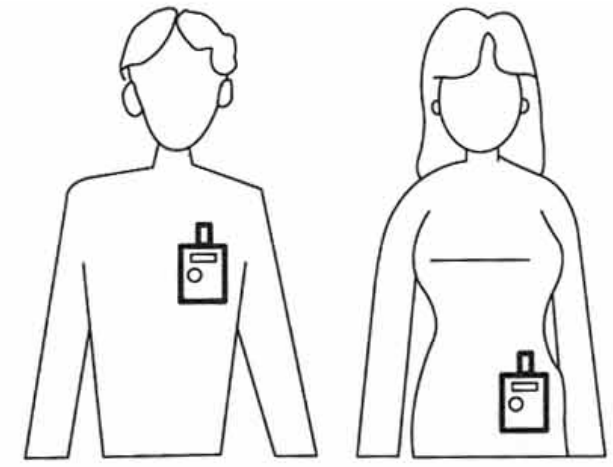
Radiation exposure report



Effective dose (実効線量)

Equivalent dose (等価線量)
for the lens, skin and abdomen

Where should a monitoring instrument be worn on?



Men Women

大学等放射線施設協議会

End of slides