平成２６年度　教育訓練　講習A

Safe handling Ⅱ

Actual radiation generator handling

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Radiation generator(Accelerator)

3-1

Type and characteristic of Radiation generator

- Electrostatic accelerator

(1) Cockcroft-Walton accelerator
(2) Van de Graaff accelerator
(3) Transformer type accelerator

- Radio-frequency accelerator

(4) Cyclotron
(5) Synchrocyclotron
(6) Synchrotron
(7) Betatron
(8) linear accelerator
(9) Microtron
(10) Plasma generator

Range of subject to the law

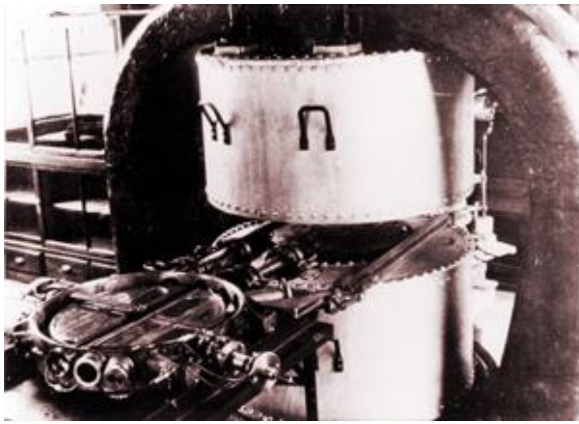
1) A device that generates radiation by accelerating charged particles such as electrons and protons using an electric or magnetic field (those with an energy of 1 MeV or more).

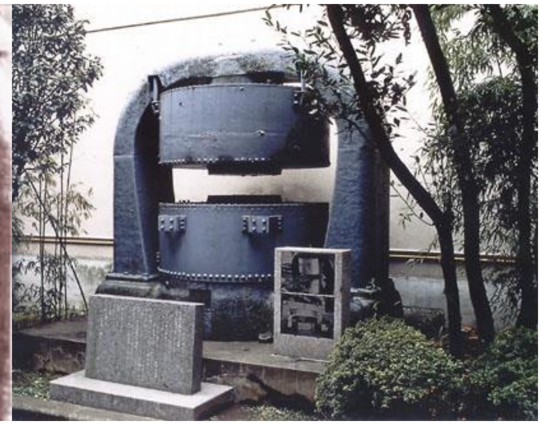
2) A 1 cm dose equivalent rate exceeding 0.6 μSv/h. (at 10cm distance from the surface of device)

Accelerator used in medicine

	Linac 	Cyclotron 
type	Linear accelerator	Cyclic accelerator
accelerating particle	electron	proton
purpose	radiotherapy	PET nuclide generation

Cyclotron



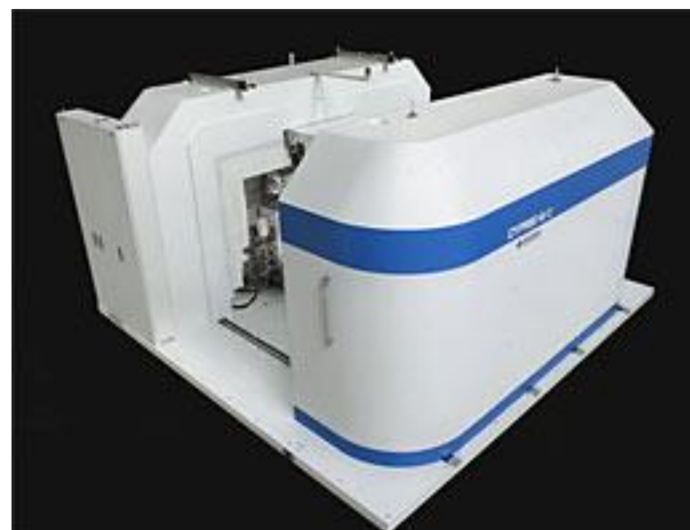


Succeeded in accelerating proton 9MeV with Units 1 and 2 and RIKEN 60-inch cyclotron.
Abandoned in Tokyo Bay by the U.S. military in 1945

Unit 3 (1953) Electromagnet: Saved in Japan Radioisotope Association (Komagome, Bunkyo-ku)

Small AVF cyclotron for self-shielding PET (CYPRIS-HM12S)

Proton 12MeV
Deuteron 6MeV
Weight 60t



3-2 Number of radiation generators permitted to use (by type and institution)

Generator \ Institution	Total	Ratio(%)	Medical	Education	Research	Private sector	Other
Total	1,528		1,133	64	152	141	38
Ratio(%)	100		74.1	4.2	9.9	9.2	2.5
Cyclotron	206	13.5	139	4	23	37	3
Synchrotron	40	2.6	8	3	25	3	1
Synchrocyclotron	—	—	—	—	—	—	—
Linear accelerator(Linac)	1,144	74.9	982	23	45	60	34
Betatron	3	0.2		1 —	2	—	—
Van de Graaff accelerator	37	2.4	—	14	22	1 —	
Cockcroft–Walton accelerator	72	4.7	—	16	24	32	
Transformer type accelerator	16	1.0	—	—	8	8	—
Microtron	9	0.6	4	3	2		—
Plasma generator	1	0.1	—	—	1	—	—

（出典:「放射線利用統計」, 2012）

Cancer therapy by external irradiation

○Linac：Radiation therapy equipment using X−ray and electron beams

Novalis, CyberKnife：Special linac device for X−ray stereotactic radiotherapy

○Cobalt irradiation device: Radiation therapy equipment using γ−ray (less used in Japan)

GammaKnife：Cobalt device by γ−ray stereotactic irradiation

Medical accelerator：Cyclotron, Synchrotron

・Heavy ion beam cancer treatment device: Heavy ion beam (HIMAC: Carbon ion)

・Proton beam / heavy particle beam combined treatment device: (Hyogo Ion Beam Medical Center)

・Heavy ion beam cancer treatment device: Heavy ion beam（ Gunma University Heavy Ion Medical Center)

・Heavy ion beam cancer treatment device: Heavy ion beam (SAGA Heavy ion Medical Accerelator in Toshu)

Boron Neutron Capture Therapy Equipment (Medical Reactor): Research Stage

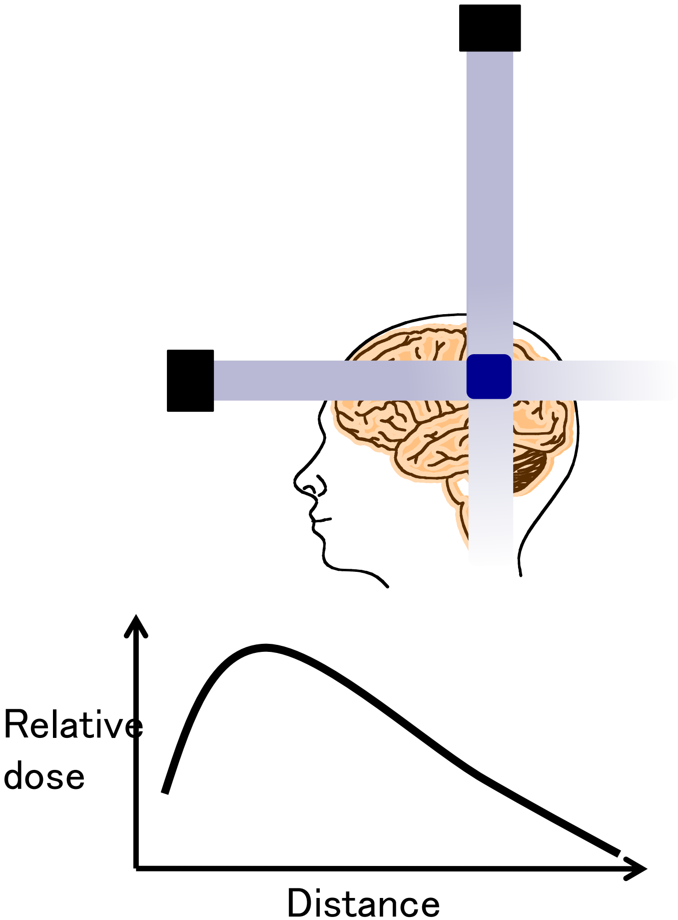
・Kyoto University Reactor (KUR): Thermal neutron beam . Utilization of nuclear reaction $^{10}B(n,\alpha)^{7}Li$.

・Japan Atomic Energy Agency Research Reactor (JRR4): Thermal Neutron Ray

Pinpoint irradiation by particle beam therapy

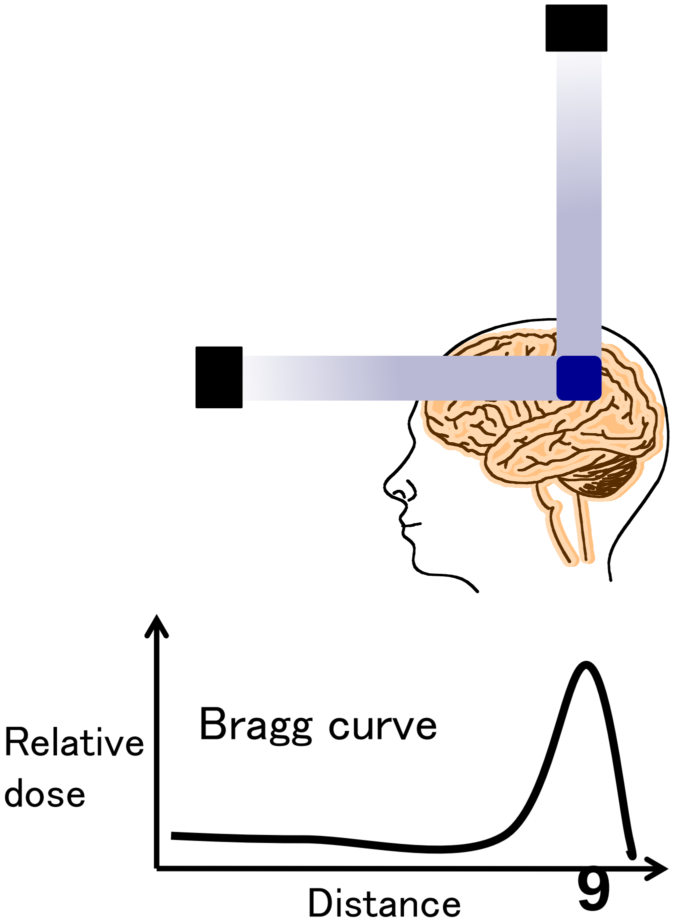
X-ray and gamma ray therapy

Cyberknife
Gamma knife



Particle therapy

Heavy ion radiotherapy device
Proton therapy device



What kind of tumor is heavy ion beam effective for?

Diseases that were intractable with conventional treatments ;

- Skull base tumor
- Head and neck adenocarcinoma,
- Adenoid cystic carcinoma,
- Malignant melanoma, sarcoma
- Bone and soft tissue sarcoma
- Rectal cancer postoperative recurrence
- Pancreatic cancer
- Kidney cancer ... etc.

Diseases that can be treated more safely and in a shorter period of time than conventional treatments ;

- Prostate cancer
- Lung cancer (stages I-II)
- Liver cancer
- Head and neck squamous epithelial cancer
- Metastatic lung tumor (single)
- Metastatic liver tumor (single)

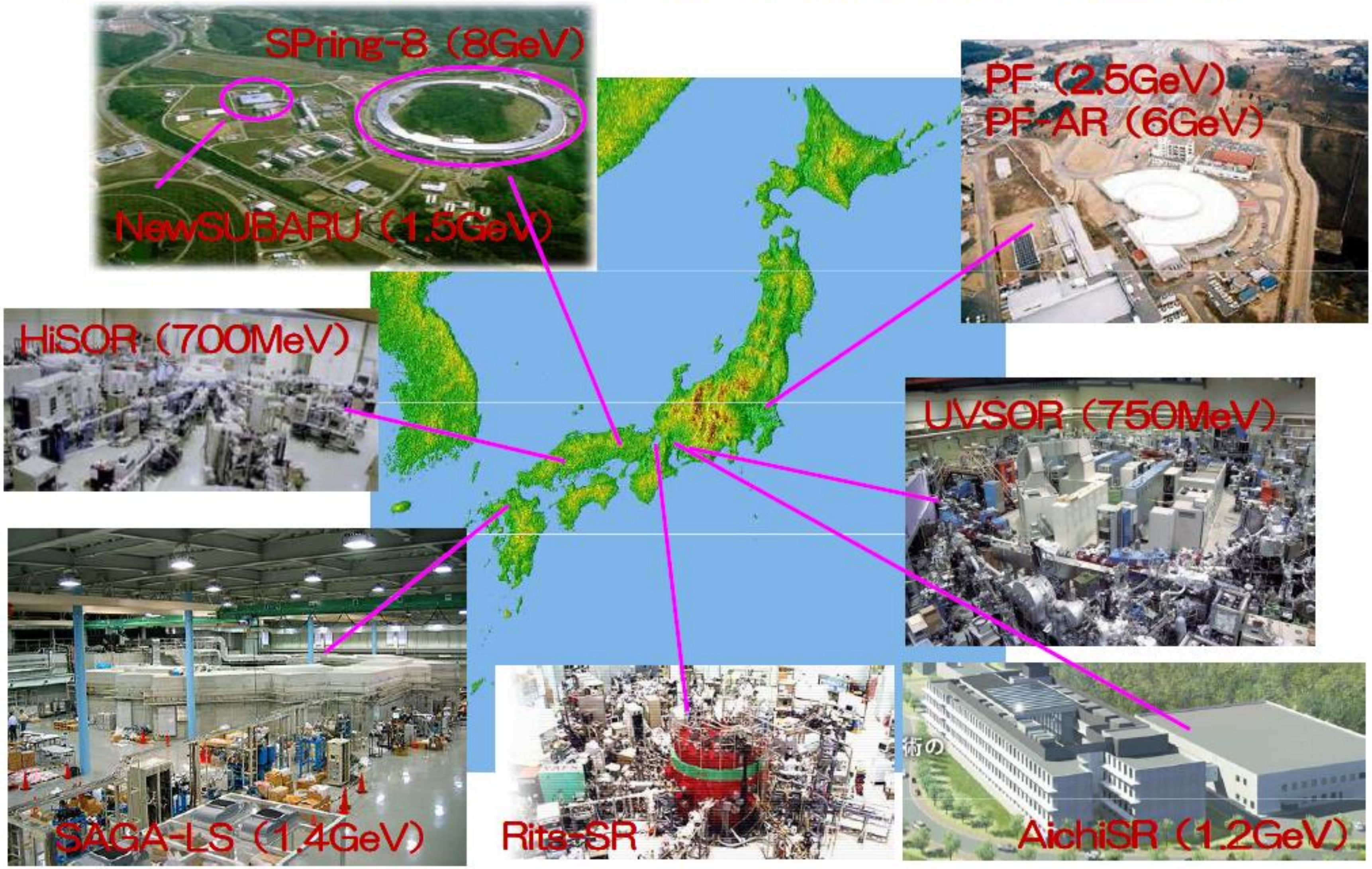
Diseases that are difficult to adapt

Wide range: hematological tumors, extensive metastatic tumors
(Other treatments have been established: breast cancer, cervical cancer)

Heavy ion radiotherapy facility（HIMAT）

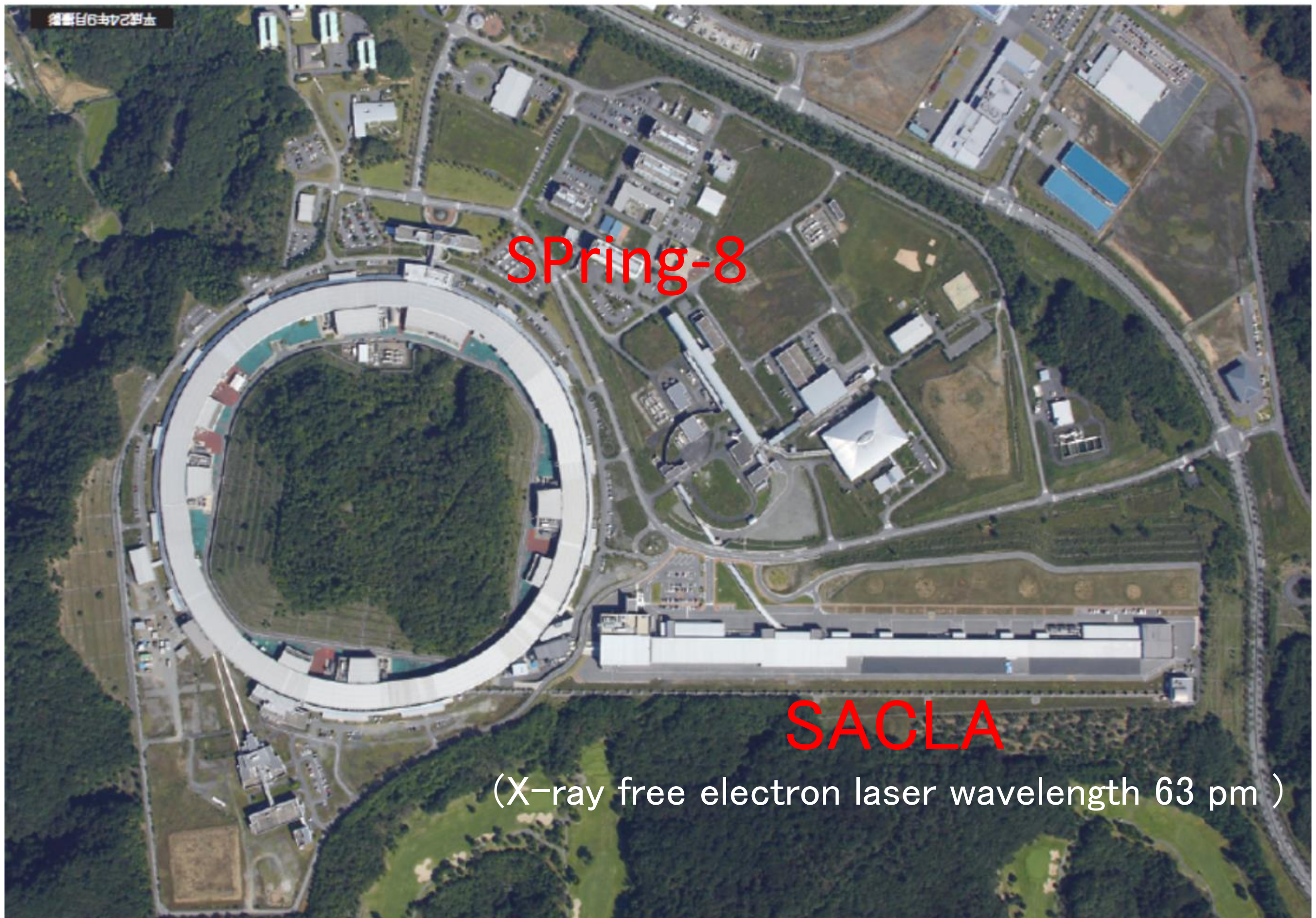
SAGA Heavy ion medical accelerator in Tosu. Toshu city, Saga Pref.

Synchrotron radiation facility（Domestic）

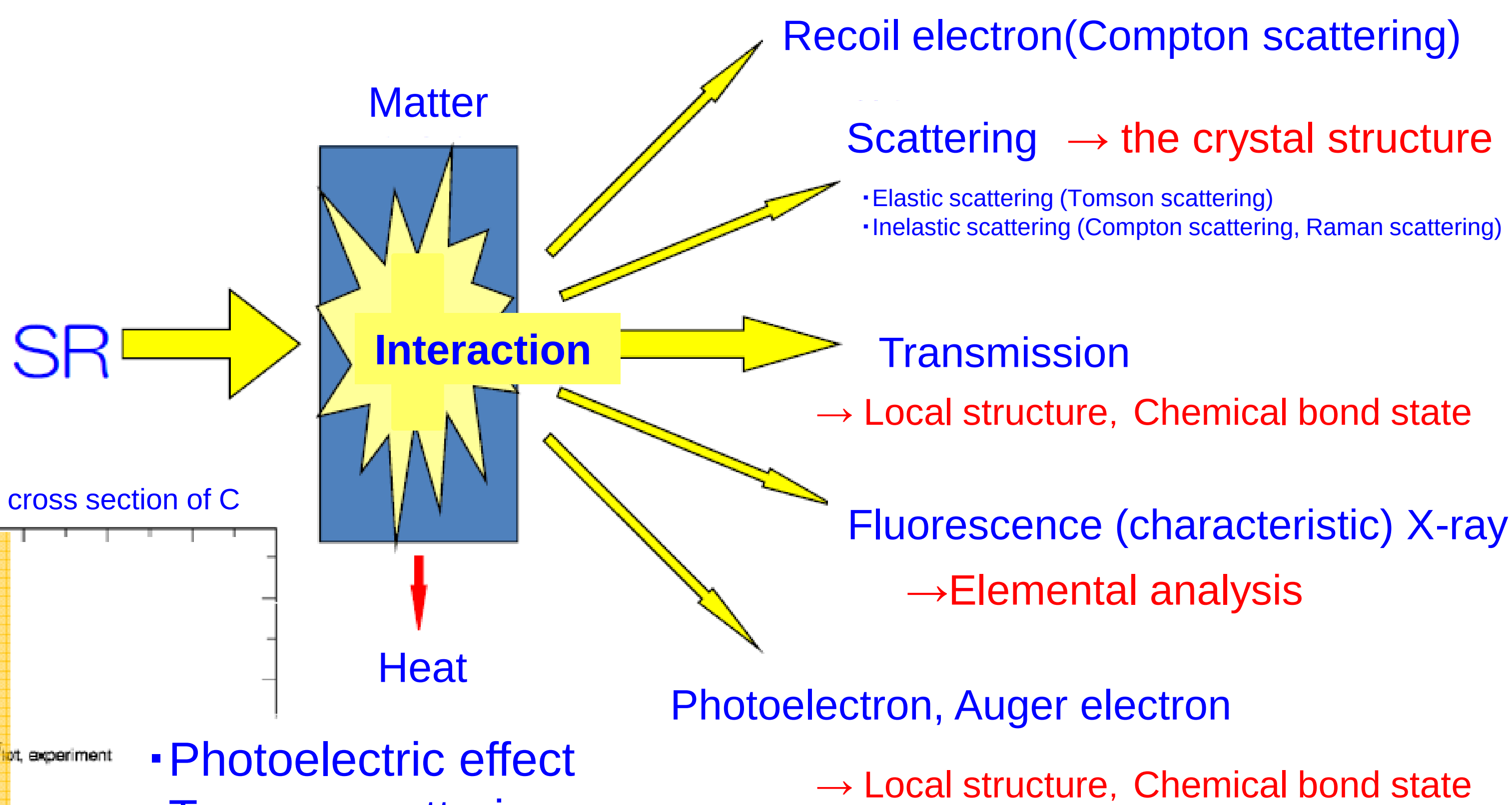


RIKEN HARIMA BRANCH

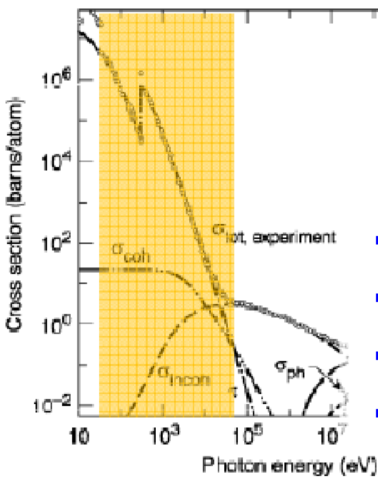
SPring-8 (Super Photon ring-8、Energy Maximum 8 GeV)



Interaction between synchrotron radiation (X-ray) and matter



Scattering cross section of C



- Photoelectric effect
- Tomson scattering
- Compton scattering
- Electron-pair creation

Various scientific fields pioneered by synchrotron radiation

Crystal structure analysis
Electron density distribution

electron spectroscopic analysis

magnetic scattering

inelastic scattering

elemental analysis
chemical-bonding state

Crystal
Protein

phase transition
Constructive －
Electronic －
Magnetic －
Dielectric －
Chemically bound －

Photoelectron spectrometry
Compton scattering
Photoelectron microscope

XMCD
XMD
Magn Strain
Magn Scatt

Mossbauer resonance

Phonon Spectr.

XAFS
X-ray florescence analysis

microbeam/ micro spectroscopy

Radiography
Topography

Bioscience/ material science

Geoscience

Electron magnetic device

Physics/ Chemistry

Environment / Energy science

Safe handling of Radiation generator

Radiation generated by radiation generator

- **Primary radiation**
  - **Accelerated electrons, protons and heavily charged particles**
- **Secondary radiation**
  - **X-rays from bremsstrahlung**
  - **neutron ray**

Beware of unexpected radiation

- **Induced radioactivity**
  - **Radionuclides are generated by the nuclear reaction between the components of the accelerator particle beam passage and the primary and secondary radiation. (activated)**

- Primary radiation

Most of the radiation is generated in operation of the accelerator. Therefore, if the accelerator is stopped, the radiation will be greatly reduced.

- Induced radioactivity（ **Activated** ）

When the beam is irradiated with a target or the like (shutter, slit, etc.), the irradiated substance is activated. The radiation emitted from it remains even if the accelerator is stopped (residual radioactivity).

Almost no radioactive material is produced in facilities that use electron accelerators with maximum energies less than 6.0 MeV (or Ion accelerator with maximum energy per nucleon less than 2.5 MeV).

- Secondary radiation

When the beam (primary radiation) hits the target, the nuclear reaction generates secondary radiation such as radiation and braking X-rays. If the beam is not properly controlled, the beam may hit an unexpected place to generate secondary radiation, or the part hit by the beam may be activated.

- Neutron ray

Among the secondary radiation, neutrons are troublesome. Surrounding substances including air are activated by the neutron capture reaction. In addition, it easily changes its direction due to elastic scattering with the atomic nucleus, and may come out through the gap of the shield.

3-3-3

- Slit beam

  The beamline is usually equipped with shutters and slits to stop and throttle the beam. However, if they are incomplete, the beam may leak through the surrounding gaps. Since the beam is thin, it is difficult for the detector to catch it.

> Please note that the GM tube type survey meter interferes with the measurement due to the counting drop and suffocation phenomenon.

- Sky shine

  When radiation is radiated toward the sky, it is scattered by the air and part of it returns to the ground (Sky shine). Insufficient ceiling shielding will cause radiation to fall outside the controlled area.

Safety management system

- **Automatically display equipment**
  - A device that automatically displays that "accelerator is in operation"
- **Interlock**
  - It is a control that can be operated only when the entrance door of the use room is "closed".
- **Entry / exit management**
  - Carry a measuring instrument with an alarm when entering the room
  - Know the emergency release switch, escape exit, etc.

3-4-2

Automatically display equipment

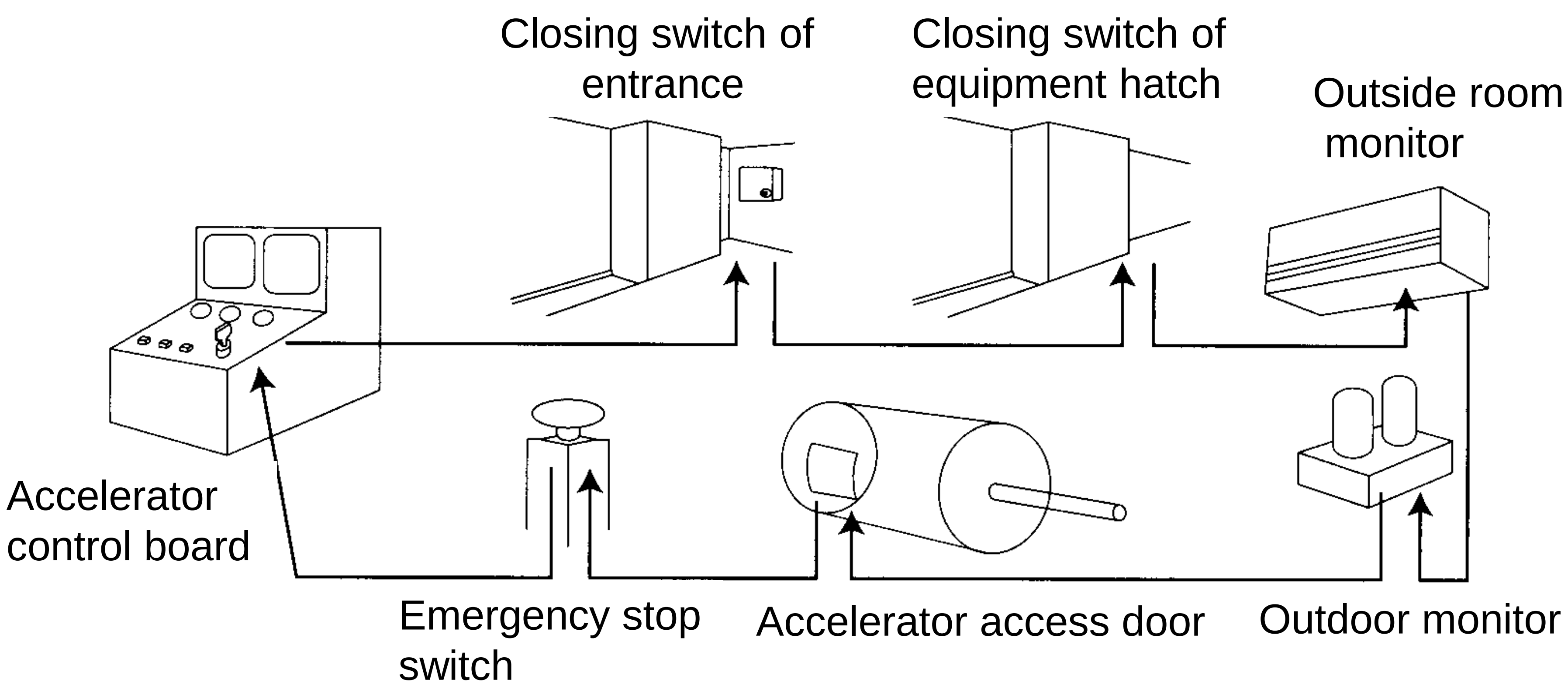
- The radiation generator is obliged to indicate that the generator is in operation by a display device such as a lamp during operation.

Interlock

- An interlock is a mechanism that prevents the generator from operating if the conditions required for safe operation are not met. When all the conditions are satisfied, the generator can be operated.

Due to the installation of the interlock, the accelerator will stop if any one of them becomes abnormal.
In addition, the interlock must not be released intentionally under any circumstances.

Example of accelerator interlock system



（出典：「放射線・アイソトープを取扱う前に」，2012）

3-4-1

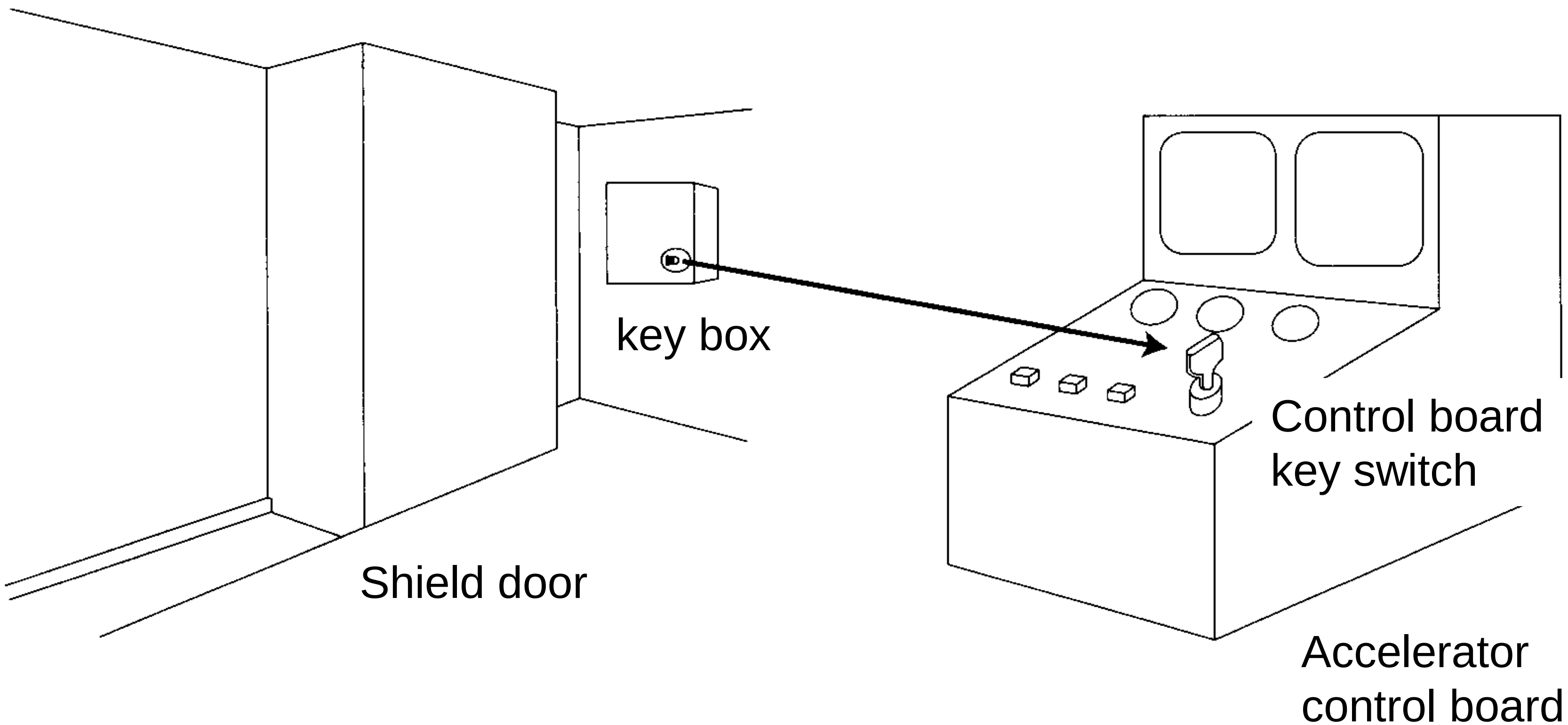
Entry / exit management system

- By introducing an entry / exit management system, the opening and closing of doors is controlled so that entry during accelerator operation can be prohibited.

- By sharing the key of the accelerator control panel and the key of the door, there is an advantage that the accelerator will not be operated unless the person who opened the accelerator main body room or the laboratory brings the key.

- With this system, the number of people in the room can be constantly grasped, and the exposure of workers due to the operation of the generator can be prevented.

Standardization of keys for shield doors and control board



（出典：「放射線・アイソトープを取扱う前に」, 2012）

3-4-3

Radiation monitoring system

- Since the amount of radiation increases in the main body room and laboratory while the accelerator is in operation, γ-ray and neutron monitors are installed outside the shielding wall to constantly check for radiation leaks.
- When radiation amount (rate)is exceeded the threshold, an alarm sounds and measures such as stopping the accelerator operation are taken.
- Even after the end of operation, the radiation dose does not drop immediately because the beam duct, target, slit, and air are also activated in the main body room and laboratory.

Only after the dose has dropped below the threshold can you enter the room.

For safe use (entrance / exit)

- A person who conducts an irradiation experiment or develops a device in a laboratory or a main body of a radiation generator must be registered as a radiation worker at the place of business.
- When you actually enter or leave the room, you must follow the prescribed procedure.
- Even if you are trapped in a room, you can open the shield door from the inside, so you can open it without hassle.
- Notify the control room by intercom. If it is unlikely that the operation will start in time, press the emergency stop button.

3-5-2

（Records）

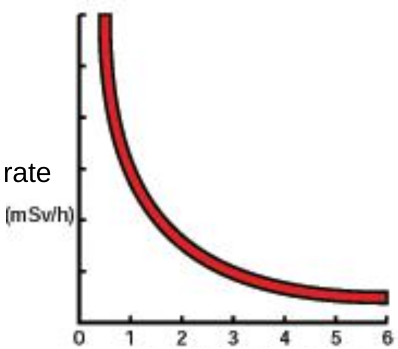
- Records are indispensable for finding the cause of any trouble.
- When entering or leaving the controlled area, be sure to read the ID card and sign the register book.
- Clarify who is responsible for the operation and record the operation so that the person involved in the operation can understand it.

Radiation protection

Three principles of external exposure protection

- **Distance**

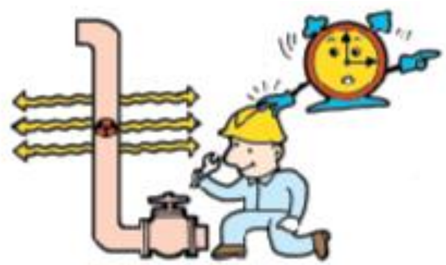
Inverse of (Dose)=(Distance)^2

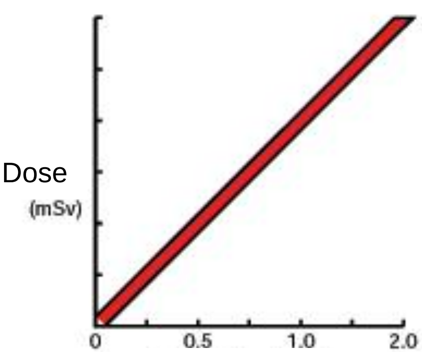
Dose rate


Distance from radioactive material (m)

- **Time**

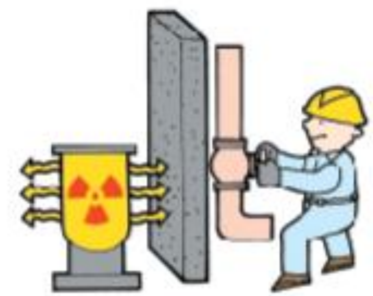
(Dose)=(Dose rate on workplace)×(Time)

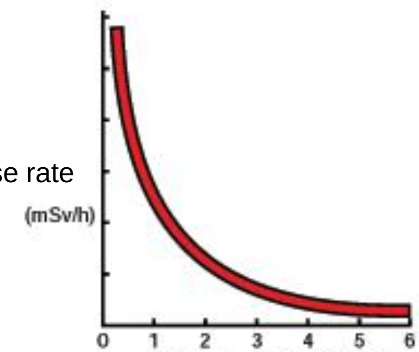


Dose


Time(h)

- **Shield**



Dose rate


Concrete thickness(cm)

（出典：原子力図面集2005年）

1-6 Five principles of internal exposure protection（3D･2C）

- Dilute

  （Dilution by addition of solvent or carrier, etc.）
- Disperse

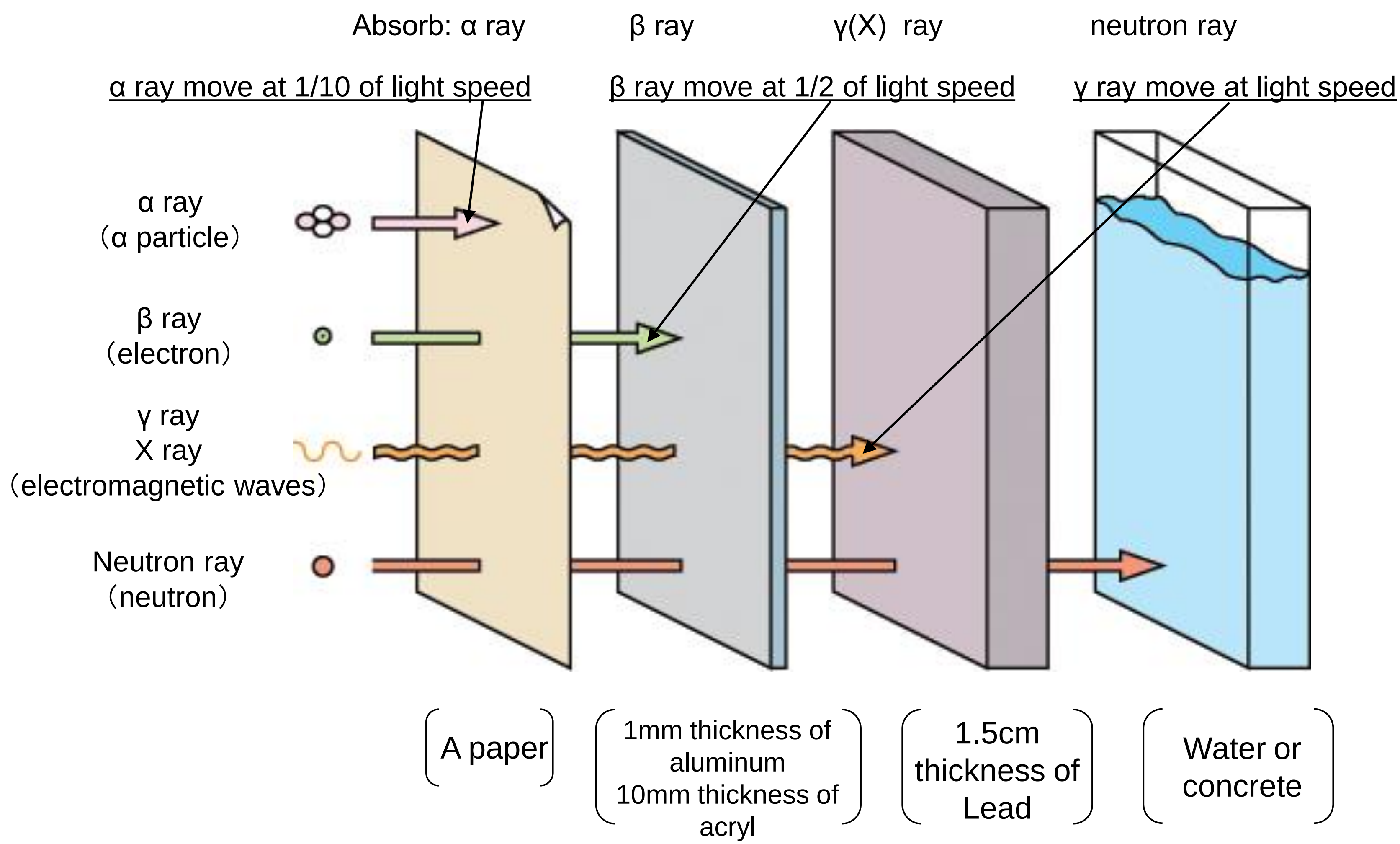
  （Ventilation, dilution of radioactive effluent, etc.）
- Decontaminate

  （Use of hood, decontamination, etc.）
- Contain

  （Storage in a container, use of a glove box）
- Concentrate

  （RI concentration separation, storage of radioactivity, etc. ）

Radiation type and penetrating

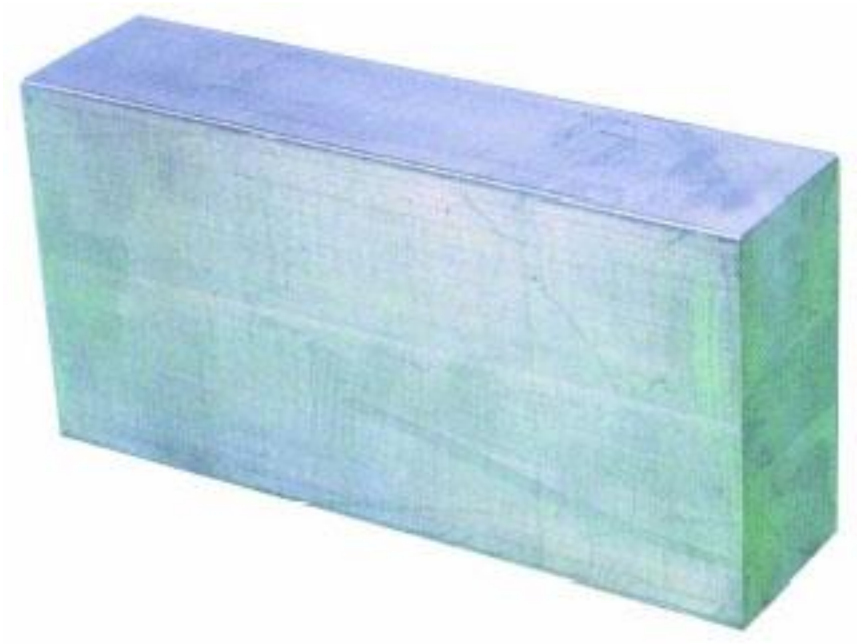


（出典:原子力図面集2005年、原子力防災基礎用語集 ）

Tool for shielding γ (X) rays

- Lead is mainly used as a shielding material. Lead blocks having a thickness of 5 cm, a height of 10 cm, and a width of about 20 cm are commercially available, and a plurality of these blocks are often used side by side or stacked.(Be careful of gaps, earthquake resistance, and load capacity.)
- In addition to lead, concrete blocks and iron plates can also be used, but they have a lower shielding effect than lead and take up a lot of space. In addition, there is a lead glass partition, which is useful for visual observation of the radioactive source.
- Tungsten and molybdenum are used to shield low-energy gamma rays and X-rays. Flexible sheet-shaped shields are commercially available.

X-ray, gamma ray shielding material（Lead block）



Do not crush the corners!

（出典:（株）千代田テクノルHP ）

Tools for shielding neutron rays

- Polyethylene blocks and paraffin blocks are commercially available.
- Paraffin blocks containing boron, which has a high ability to absorb thermal neutrons, are also used.

1-5-4

Shielding material due to difference in neutron energy

Energy	Reaction	Shielding material
A few MeV	Inelastic scattering	Substances with large atomic numbers such as iron and lead are effective
Hundreds of keV or less	Elastic scattering	Paraffin and water containing a lot of hydrogen are effective
When decelerated to about 0.1eV	Absorb neutrons using capture reaction (n, γ)	Boron and lithium are effective as absorbent materials $^{6}Li(n, \alpha)^{3}H$, $^{10}B(n, \alpha)^{7}Li$

Usually, in the case of a small shielding container, iron is often used on the inside, then polyethylene having a thickness of about 10 cm, and iron or lead on the outside. Boron and cadmium is often contained in polyethylene.

Neutron shielding material
(special polyethylene block for neutron shielding)

（出典：（株）千代田テクノルHP ）

4-13-1

Handling of radioactive substances

- When irradiating neutrons with an accelerator, be careful not to irradiate excessive neutrons. Due to its strong radioactivity, it may not be possible to handle it directly by hand.

- Irradiated samples are doubly enclosed in polyethylene bags to prevent contamination. When the irradiation time is lengthened, it is advisable to wrap the inner bag with paper or use a polypropylene bag instead of the polyethylene bag in order to prevent the polyethylene bag from being welded by heat.

4-13-2

Characteristics of radioactive substances

- It is too large to fit in a waste container.
- Mostly incombustible
- There are places where the surface dose equivalent rate is locally high.
- The material itself is activated and there is almost no surface contamination.

GM tube type / scintillation type survey meter

The time constant is basically set short (3 seconds) for contamination inspection and long (30 seconds) for dose rate measurement, but it is usually measured in 10 seconds. (Never set the time constant to 30 seconds and do not perform contamination inspection or radiation source loss survey.)

（出典:（株）アロカHP ）

Accidents and countermeasures

Occurrence of radioactive material leakage accident at accelerator experimental facility J-PARC in Tokai Village, Ibaraki Prefecture

Radioactive material leak occurred (noon on the 23rd)

Alarm indicating abnormality

Judging that the alarm is malfunctioning, continue the experiment

Increased radiation dose and surface contamination (10 times) on the afternoon of the 23th

Release radioactive substances to the outdoors (short half-life, ventilation twice)

It was the evening of the 24th that the staff noticed the radioactive material leak by data analysis (report to the national and local governments 33 hours after the accident).

【Place】J–PARC Nuclear particle physics experimental facility
【Time】 Around noon on the 23th May
【Cause】 Occurrence of internal exposure due to scattering of radioactive substances (Au, Hg) into the air due to abnormal proton beam output
【Investigation】
Measured 49 out of 55 people who may be exposed (measurement subjects who were in the facility at that time)

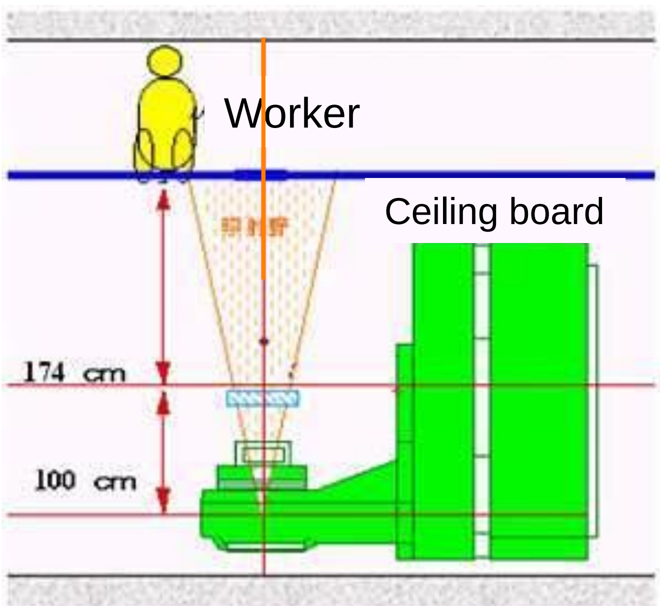
- Exposed: 30 (including 2 women)
- Exposure dose: 0.1–1.7 mSv
  (^{193}Hg inhalation intake: 1.6×10^6 Bq)

【 Impact on health 】Judgment at this stage:
"It is very unlikely that it will affect your health"

（2013/05/27までのデータより）

Safety management system is important!

Example) A worker was exposed during the installation adjustment of the linac by the manufacturer. The cause was that the radiation test was conducted without noticing that the worker was behind the ceiling. Estimated exposure dose of 200 mSv or less (National Center for Child Health and Development, 2001/12/21)

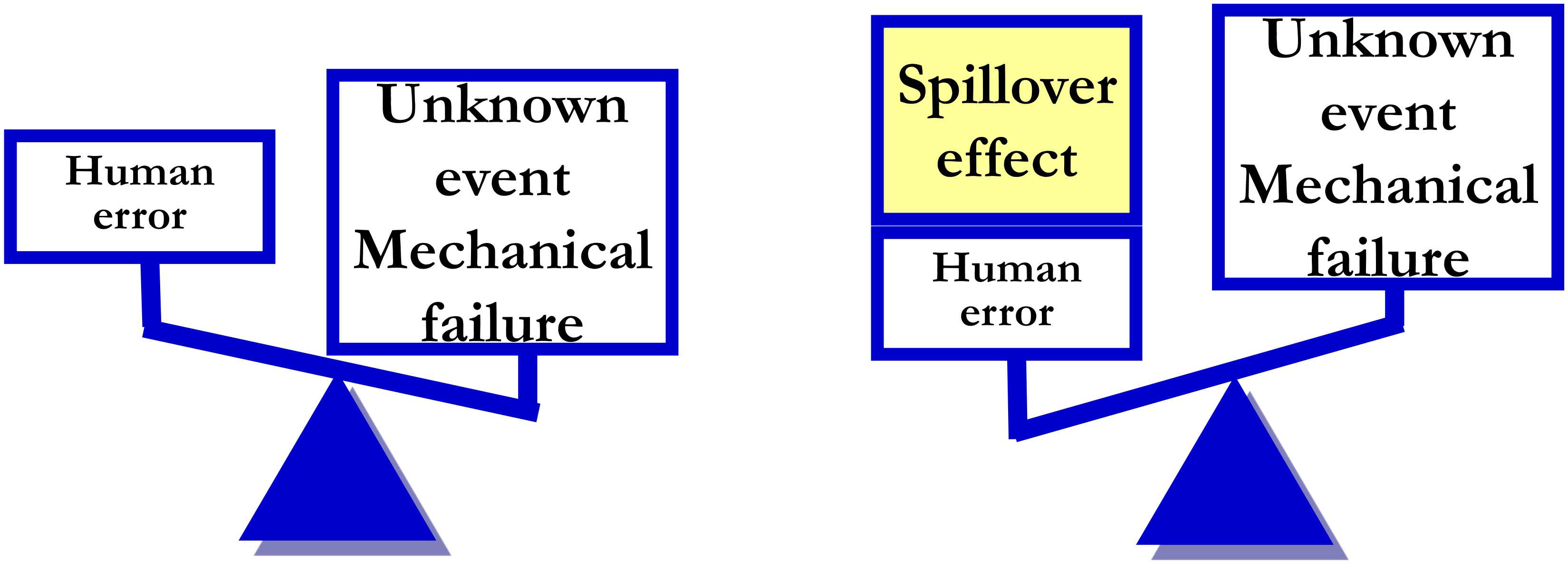


- **The direct cause is lack of contact / confirmation**
- **No interlock**
- **No entry / exit management**

➡ **Carry a measuring instrument with an alarm**

出典 ： 文部科学省原子力安全課　緊急被ばく医療 REM net

To prevent unexpected accidents



Until 50 years ago

Current

The damage is great because it is automated.

引用　:　『ヒューマンエラーを防ぐ知恵　— ミスはなくなるか—』ISBN 978-4-7598-1304-3, 化学同人

There is not always one cause

Jun, 2000 　electric parts factory

Three workers who had been conducting non-destructive inspection by unlocking the interlock of the soft X-ray equipment were locally exposed to the right hand (40-60 Gy). Radiation burns

- There is no risk of exposure because of having safety device.
- No need to appoint a authorized chief X-ray inspection engineer.

Prevention of situations that impair the safety of people around us

- Learn from past radiation accidents and establish safety management technology
- Easy to deal with after an accident, but very difficult to detect hidden dangers
  - Labor shortage, busy (overwork)
  - Veteran transfer, retirement
  - Trouble caused by new equipment, technology and procedures
  - During maintenance
  - Unsafe behavior / rule violation
- **Actions that differ from safety procedures can cause serious accidents**