Radiation Safety

Kanenobu Tanaka

Safety Management Group

outline

1, What is radioactive ray?

2, Interaction of radioactive ray with material

3, Biological effect of radiation dose

4, Natural background of radiation

5, Safety, etc

1, What is radioactive ray?

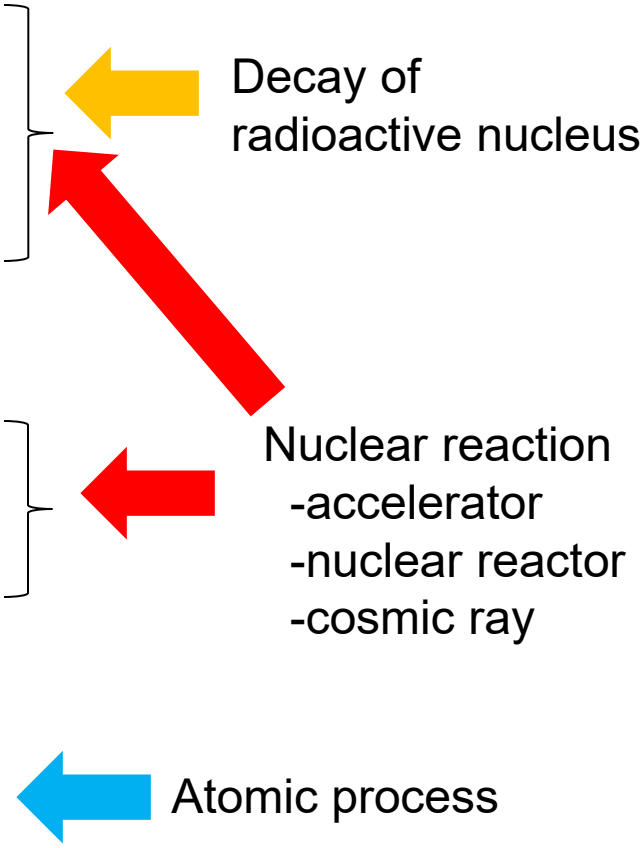
High energy photon or particle which are possible to ionize the air atom directory or indirectly

Ion generation → It break molecules, crystals structure

- Alpha ray (^{4}He nucleus)
- Beta ray (electron, positron)
- Gamma ray (photon)

- Proton, Heavy ion (nucleus)
- Neutron

- X ray (photon)



2, Interaction of radioactive ray with material

Ionization 1

Photon (γ-ray, X-ray)

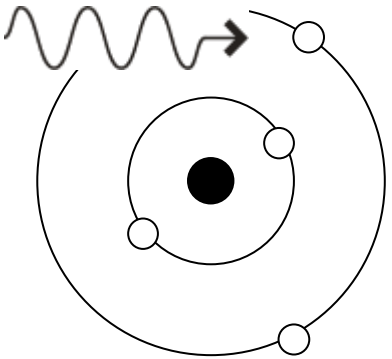
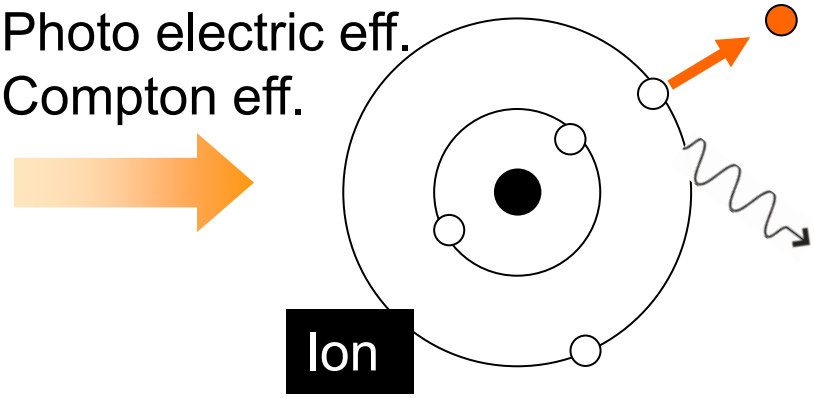
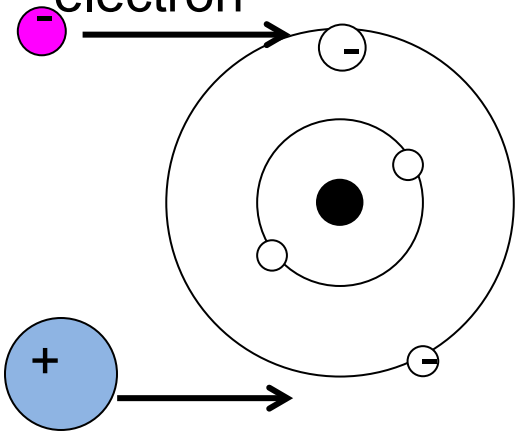


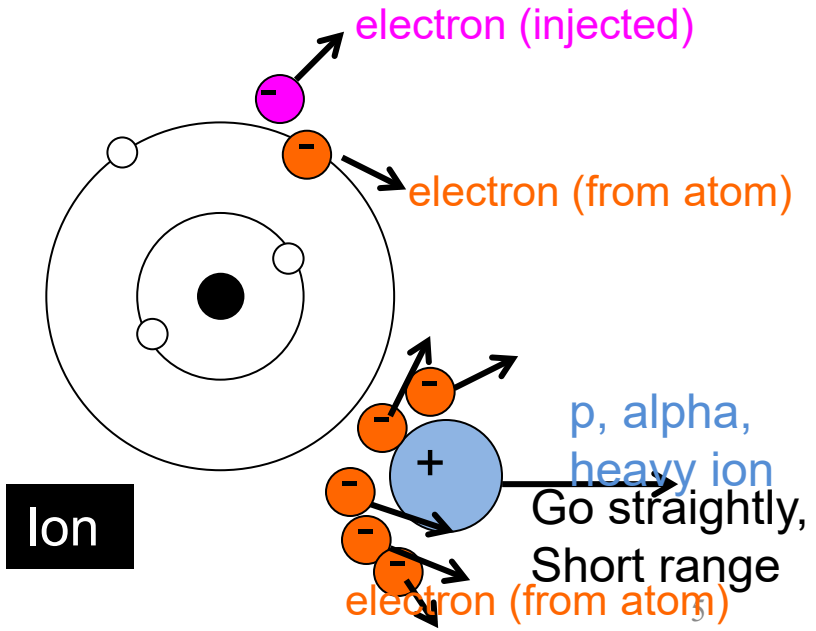
Photo electric eff.
Compton eff.



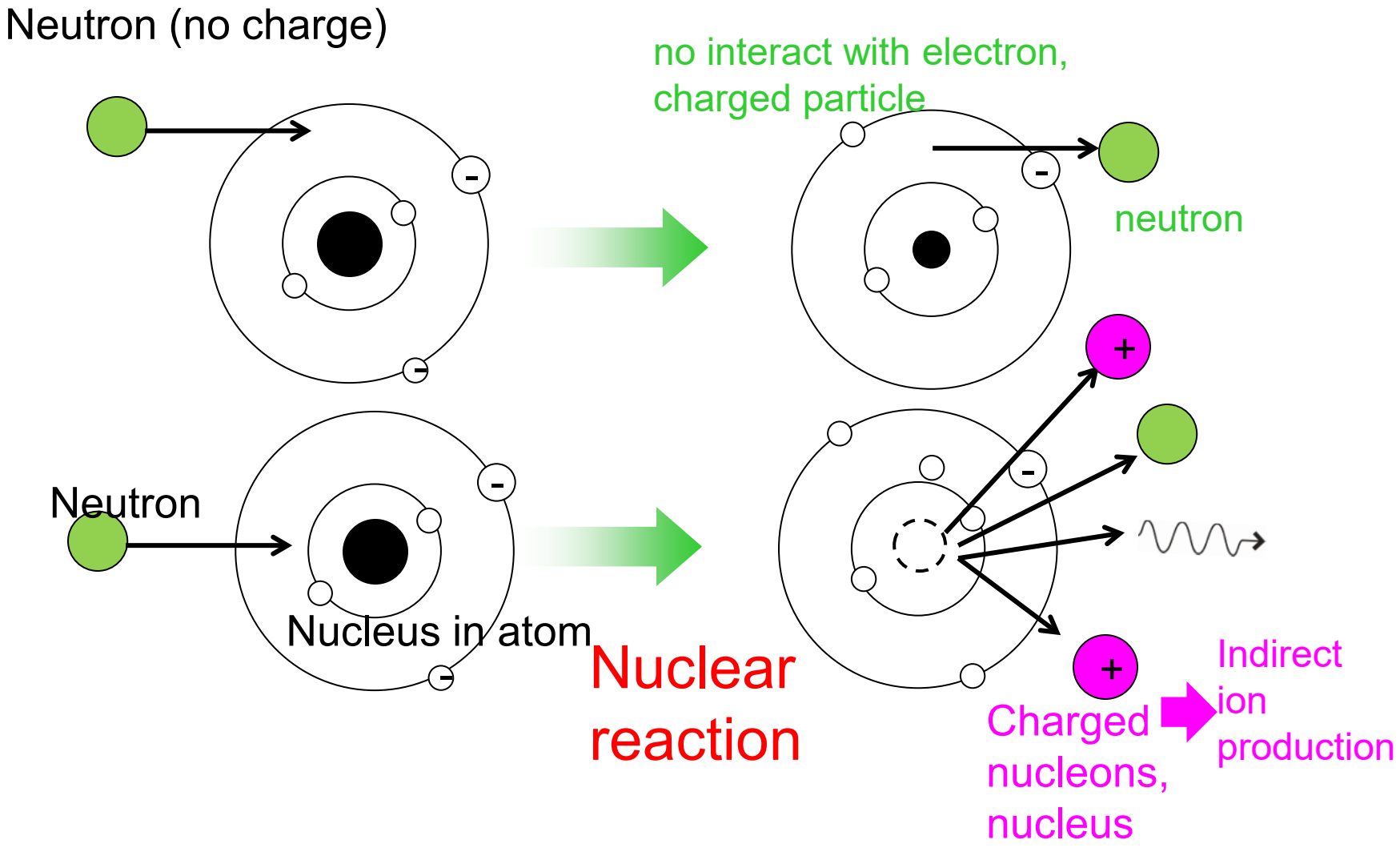
Charged particle
electron



p, alpha, heavy ion
>2000*electron mass = slow speed at same E

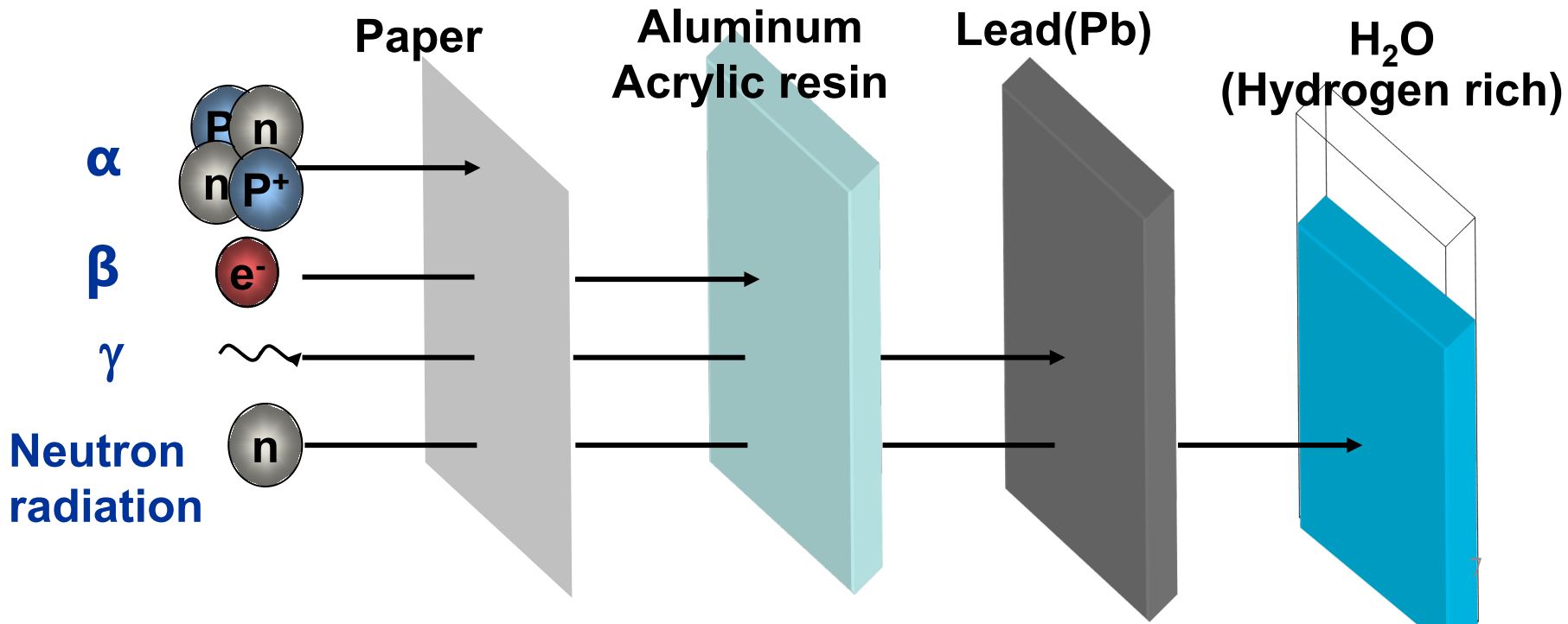


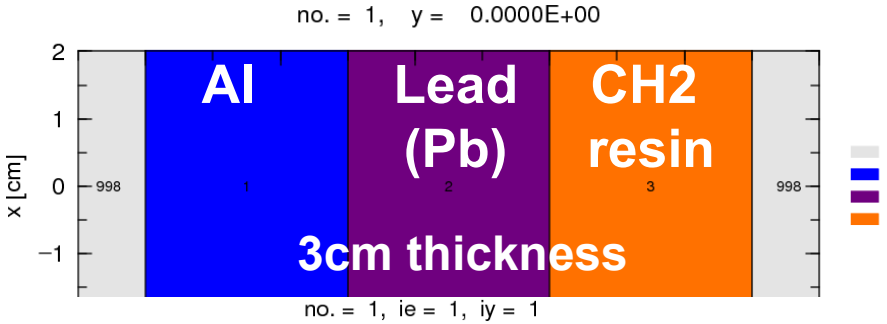
Ionization 2

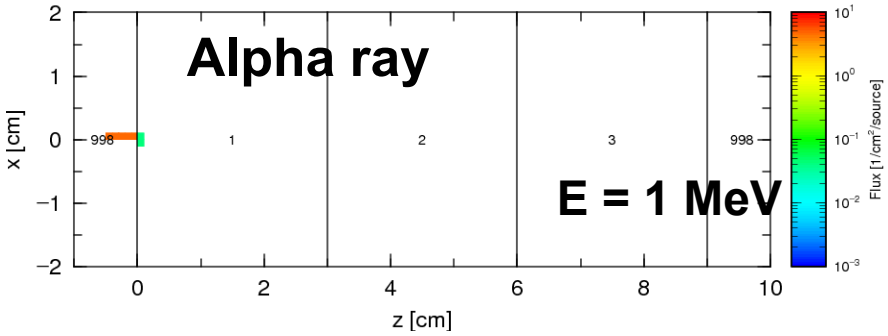


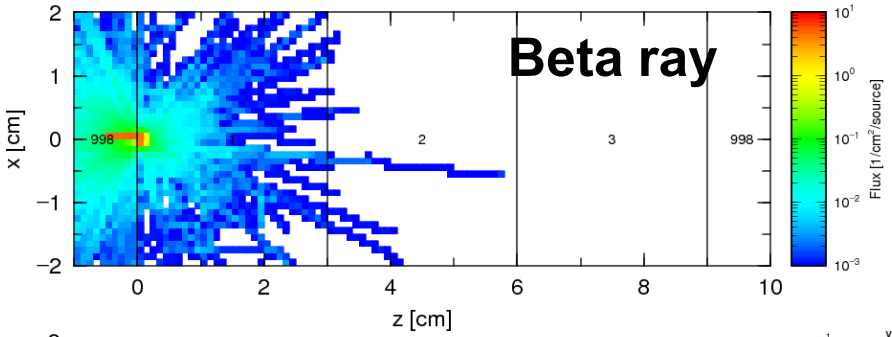
Penetrating Ability of Radiations

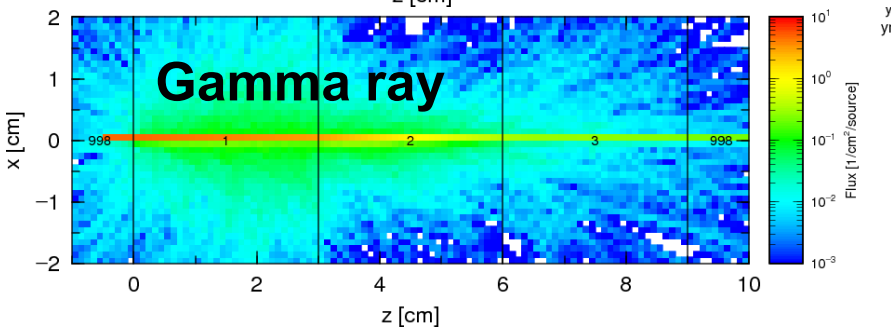
	Sensitivity in material	Range in material	Effective shielding material
Alpha	electron	short	Paper (heavy element)
Beta	electron	middle	Aluminum ~cm (high Z element)
Gamma X ray	electron	middle, longer than β	High electron density, high Z element (Pb etc.)
Proton, Ion	electron	short	High electron density, high Z element (Pb etc.)
neutron	Nucleus, proton	long	High Proton density (H_2O, CH_2)



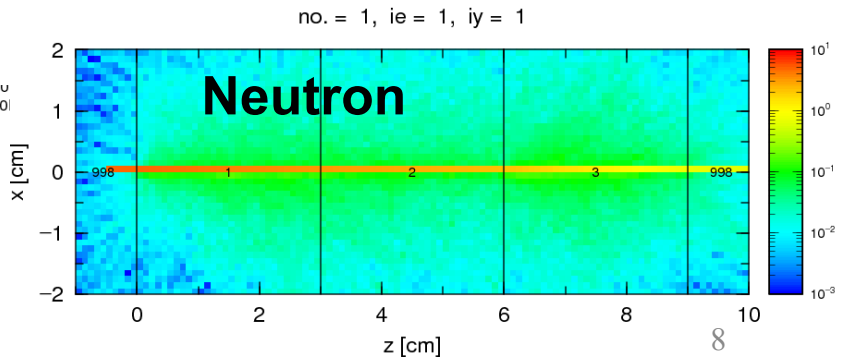








	Range in material	Effective shielding material
Alpha	short	Paper (high Z material)
beta	middle	Al (high Z material)
Gamma X ray	middle	High electron density, High Z element (Pb etc.)
Proton, Ion	short	
neutron	long	High Proton density (H_2O,CH_2)

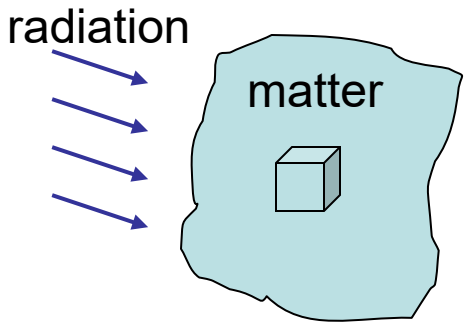


Radiation-Related Quantities and Units

Absorbed Dose吸収線量 : **Gray (Gy)**

1 **Gy** = 1 **J/ kg**

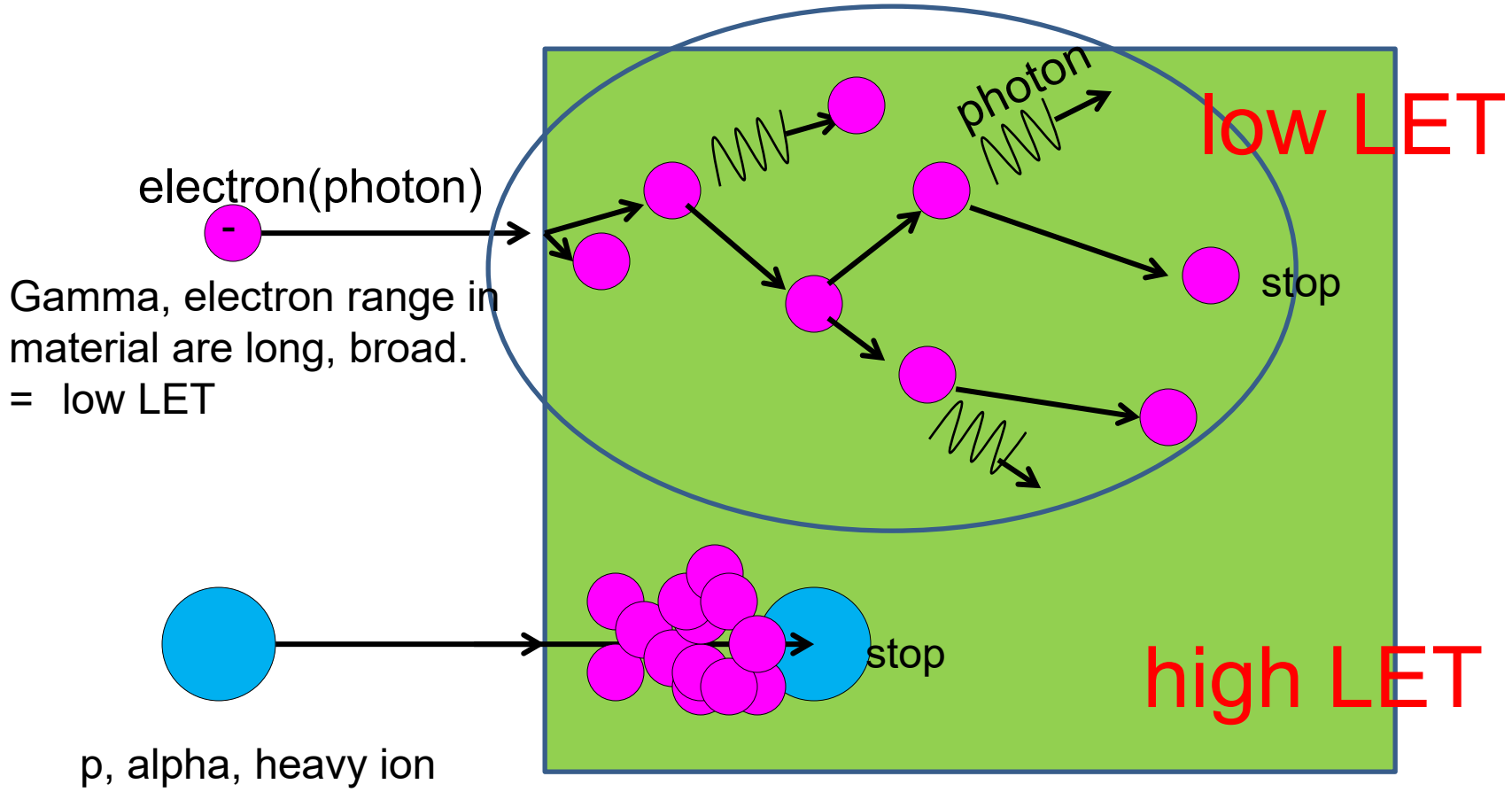
- A fundamental dosimetric quantity (physical unit)
- The energy absorbed per unit mass of the material
- Regardless of the kind of radiation
- Dose not reflect the degree of biological effects



$$D = \frac{d\varepsilon}{dm}\left[\frac{\mathrm{J}}{\mathrm{kg}} = \mathrm{Gy}\right]$$

Linear Energy Transfer(LET, dE/dX)

The energy transferred per unit distance is important for biological damage ! (later)



Proton, ion (=heavy particle) in material are short = high LET

Summary of “Interaction of radioactive ray with material”

Radiation of electron and photon : long range, low LET,
sensitive to high Z(Pb, etc.) material

Ion, proton: short range, High LET
sensitive to high Z(Pb, etc.) material

Neutron: long range,
sensitive to high proton density material (H_2O, CH_2)

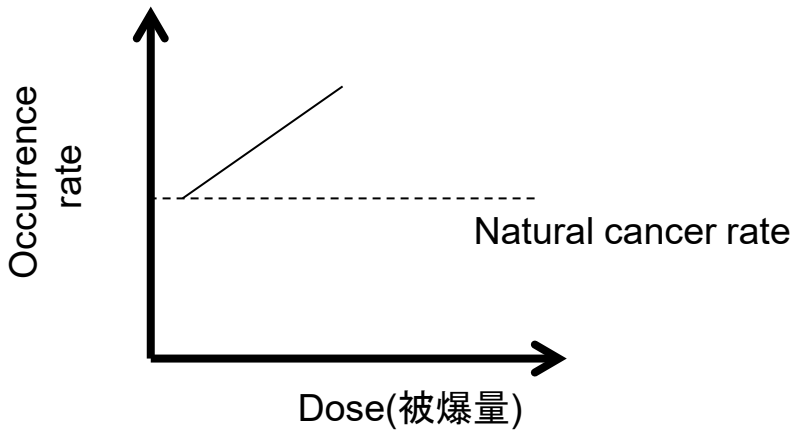
Absorbed dose(absorbed radiation energy): Gy [=J/Kg]

3, Biological Effects of Radiation Dose

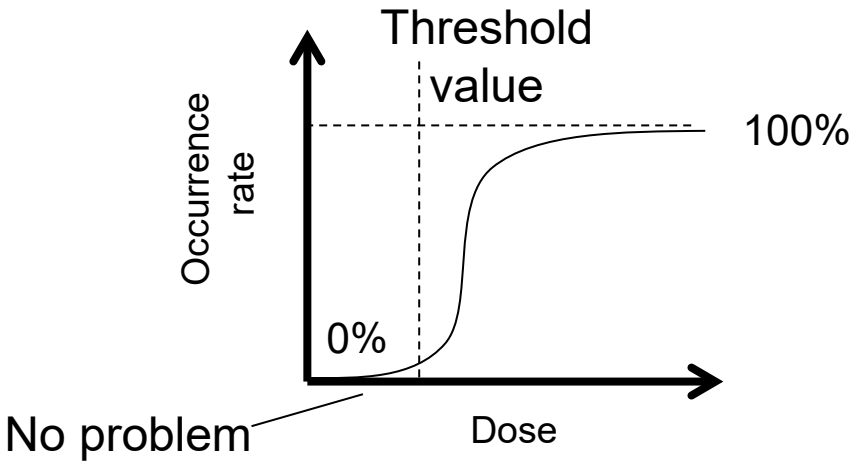
3-1, Stochastic Effects
3-2, Deterministic Effects

Stochastic Effects vs. Deterministic Effects

確率的効果



確定的効果



Stochastic Effects

An effect, that is cancer, may occur later when a person is exposed to small amount of radiation.

No threshold, but proportional to dose(放射線量). Risk in future.
- Cancer, leukemia(白血病)
- Genetic effects

DNA damage

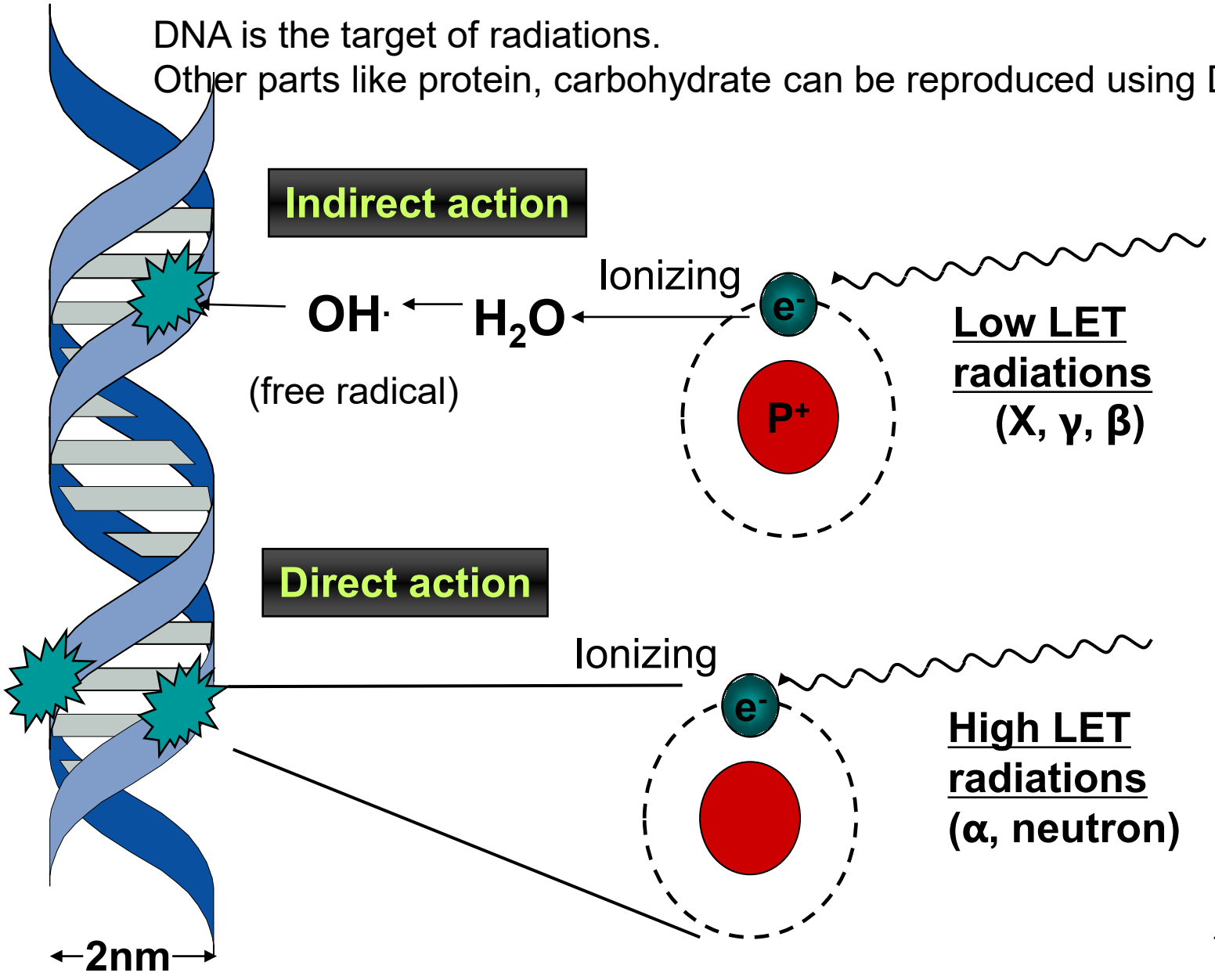
Deterministic Effects

An effect appears without exception when a person is exposed to large amount of radiation. We can prevent this to occur.

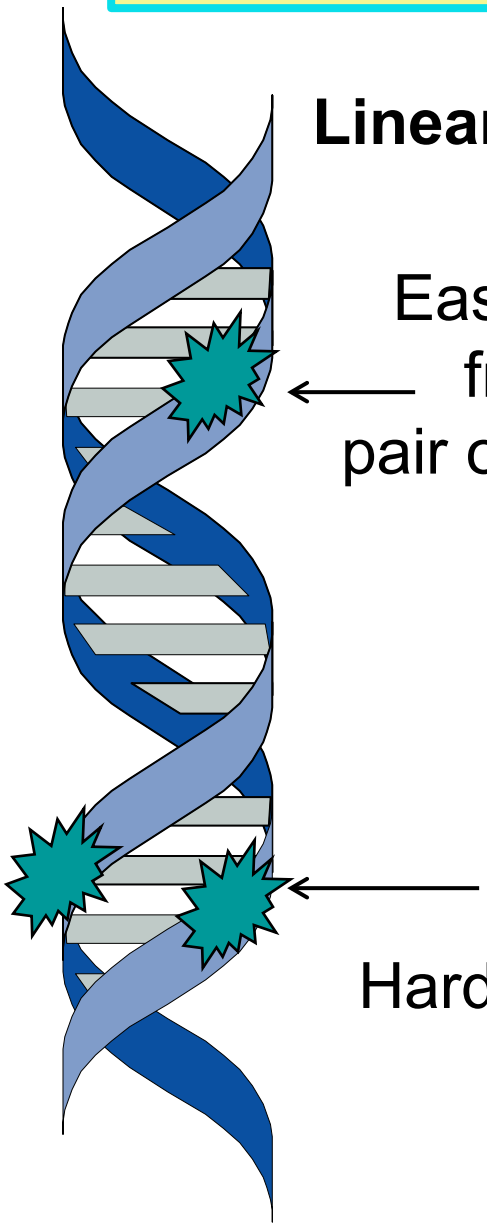
Threshold
Acute effects(急性効果)
-Hair loss, Cataract(白内障),
-sterility(不妊症)

Cell damage

3-1, **Stochastic Effects 確率的効果**



Stochastic effect確率的影響

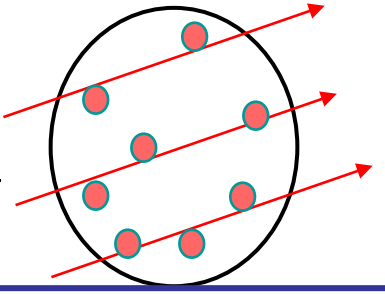


Linear Energy Transfer (LET) (keV/μm)【dE/dx (MeV/mm)】

Easy to repair from the pair of DNA chain

Hard to repair

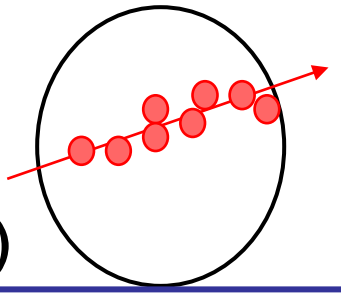
Low LET radiations (X, γ, β)



Sparsely ionizing

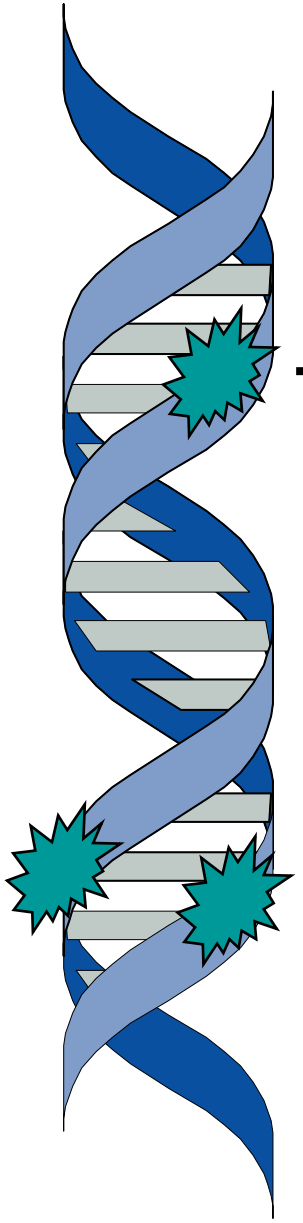
Less biological effect

High LET radiations (α, neutron)



Densely ionizing

More biological effect



Reparation success — No problem

Scarring partially — Mutation突然変異

Risk:Possibility of future cancer

Even low radiation, it is possible
→Stochastic確率的

Failure reparation — Death of cell

Damage:
No possibility at low radiation
→Deterministic確定的

Effective Dose : Sievert (Sv)

Dose quantity(放射線量) for stochastic effects (確率的影響)

・biological effects throughout the body (cancers or genetic effects)

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

No biological effect

$D_{T,R}$: Absorbed dose (Gy=J/kg), T:tissue, R: radiation type

H_T : Equivalent dose for tissues and organs

w_T : Weighting factor for organs or tissues(内臓感受性)

w_R : Radiation weighting factor depends on radiation types come from the LET

Radiation weighting factor (w_R)

Radiation	Weighting Factor	
γ rays & x rays	1	**For X, γ ray**
Beta rays	1	**Sv = Gy !**
Proton	2	
α rays, heavy ion	20	High LET->high W_R
Neutrons	Continuous function of the energy ~5-20	

(ICRP 2007)

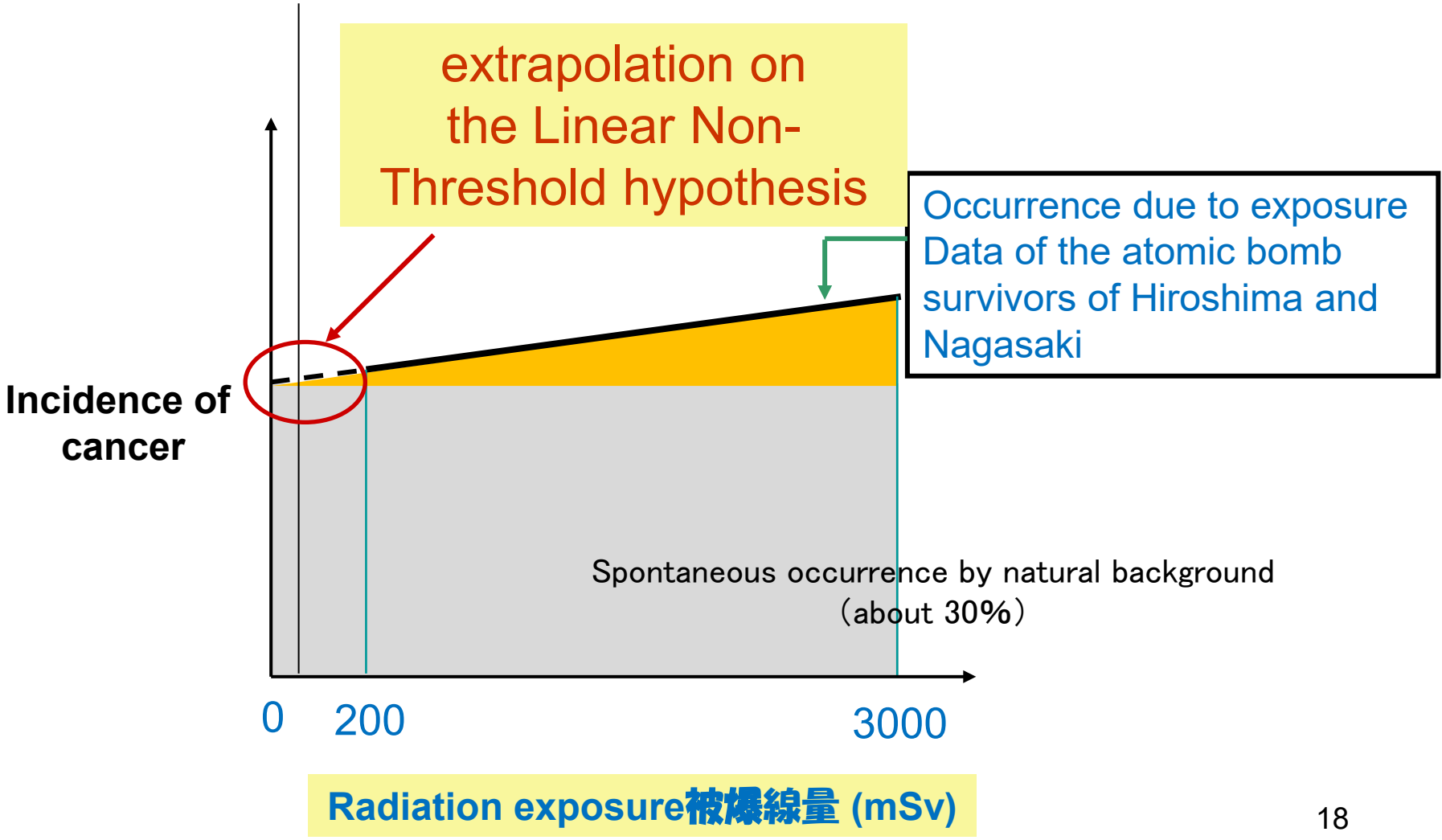
Tissue weighting factors, total 1.0

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)

Risk Estimate for Cancers (Stochastic Effect)

Legal limit 50mSv/year 0.1% cancer risk,
at emergency: 100mSv/y 0.5% cancer risk



Natural background dose ~2.4 mSv/year(next)

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

Effective dose limit	
Men	50 mSv/year; 100 mSv/5years
	(RIKEN: 20 mSv/year)
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

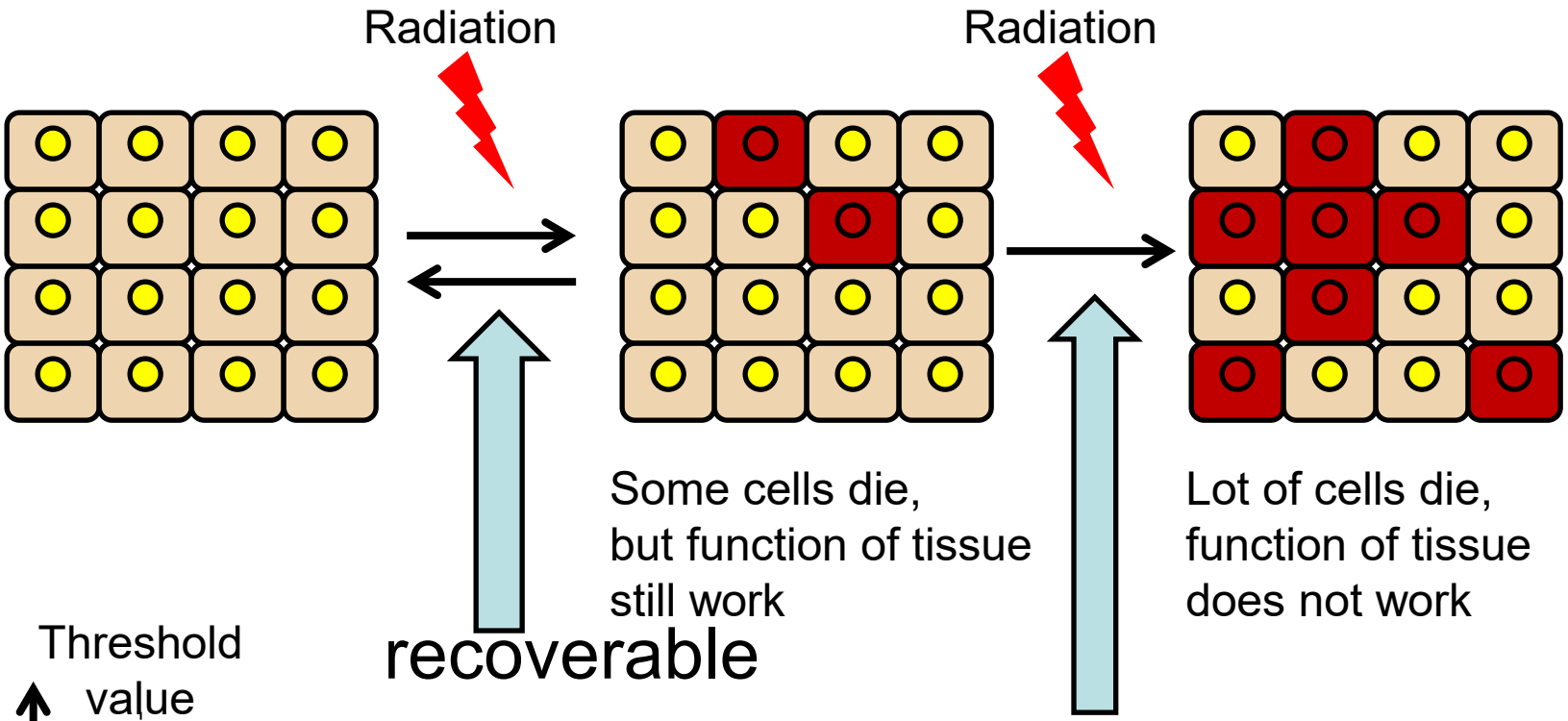
Japanese law

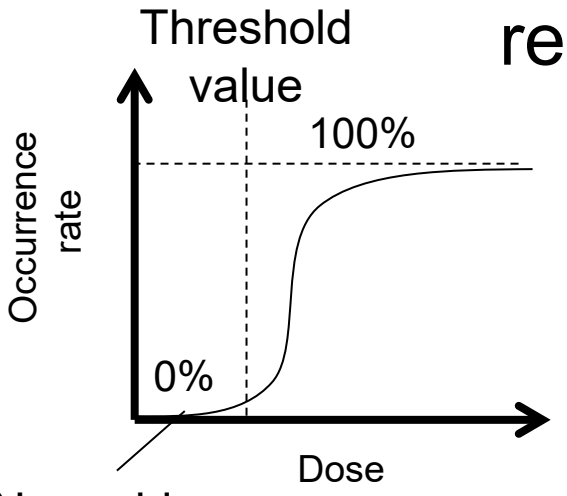
for **Non-Radiation** Workers

Effective dose limit	250 μSv/3 months (1 mSv/year)
	(RIKEN: 50 μSv/year)

3-2, **Deterministic Effects**

Why the threshold exist?





No problem

Deterministic effect確定的影響 (Tissue reaction)

Threshold values (exposure in a short time)

tissue	effect	Threshold（Gy）
Testis睾丸	temporary sterility一時的不妊	0.15
	permanent sterility永久不妊	3.5～6.0
Ovary卵巣	permanent sterility永久不妊	2.5～6.0
eye lens	Cataract白内障	5
bone marrow骨髄	blood-production disorder造血障害	0.5

ICRP Pub.103 (2007) p124

Death by whole body exposure to low LET radiation in a short time

Whole body dose（Gy）	critical organ	period to death (day)
3～5	bone marrow骨髄	30～60
5～15	Stomach胃, intestines腸, lung肺	10～20
＞15	nervous system神経系	1～5

ICRP Pub.60 (1990) p124.

Summary of "Biological effect of radiation dose"

Stochastic effect確率的影響 and
deterministic effect確定的影響 exist.

For X and γ ray, absorbed dose Gy ~ effective dose Sv

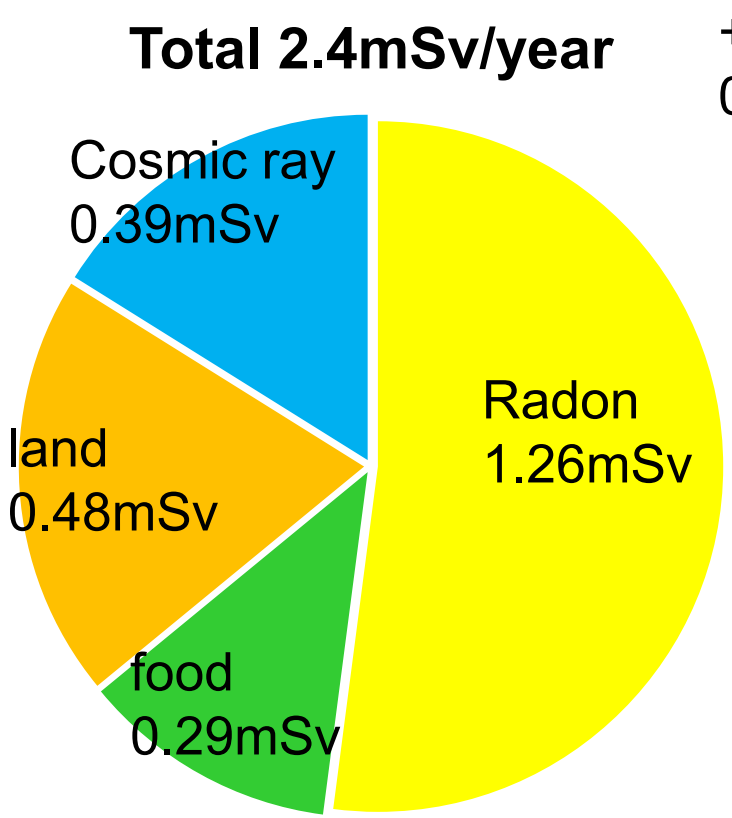
Don't exceed 0.15 Gy (=Sv) for deterministic effect !

There is 0.1% cancer risk by 50 mSv/year exposure.
Don't exceed 1 mSv(/year) for regulation in Japan !

At RIKEN Nishina school, your radiation dose rate
is estimated <1uSv !

4, Natural background of radiation

Natural radiation exposure (global average)
放射線被爆



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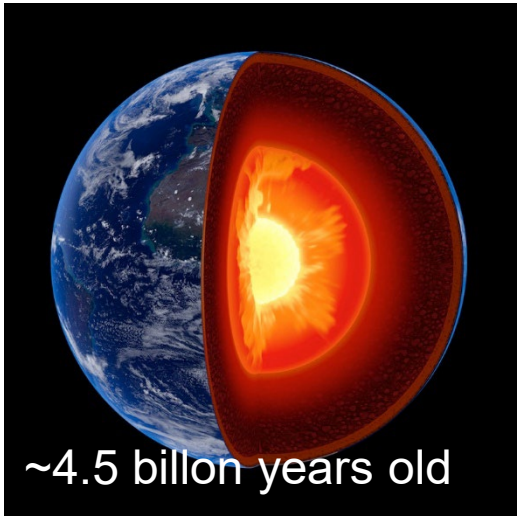
Natural Radiation Source

Generated in universe (stars), contained in Earth

0.25~0.5 of heat in earth comes from this radiation heat.



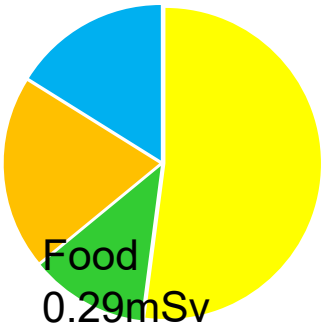
Pict."http://planetpedia.in/nature/earthquake/"

Series
- uranium238 — Half life 4.5 billon years
- thorium232 — Half life 14 billon years

Potassium40(=kalium, ^{40}K) → food

Half life 1.3 billon years

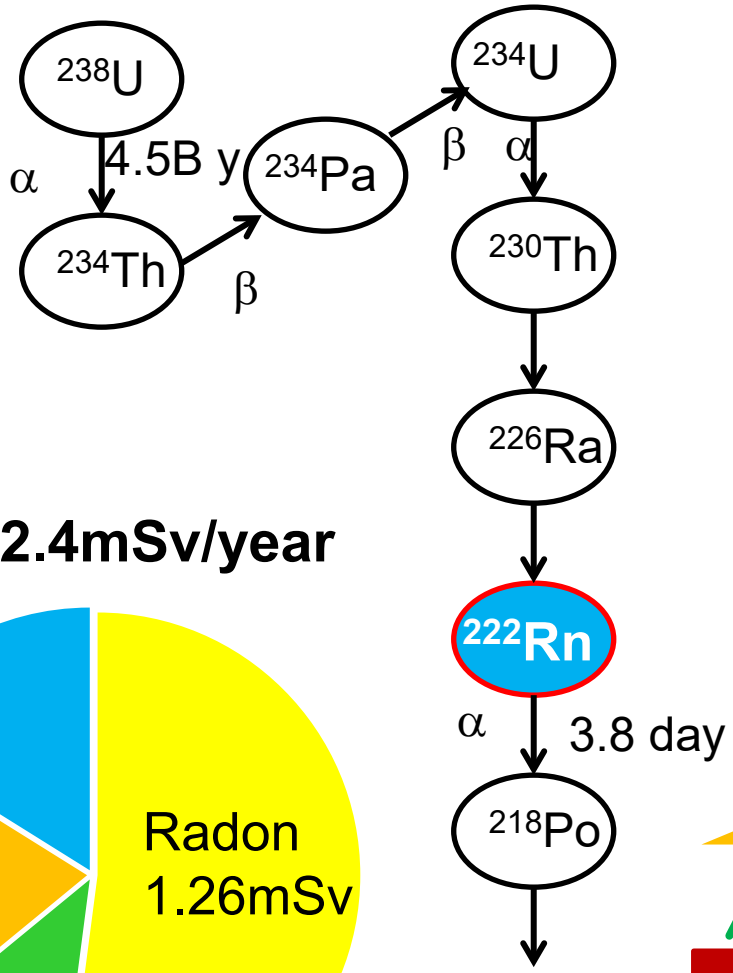
Total 2.4mSv/year



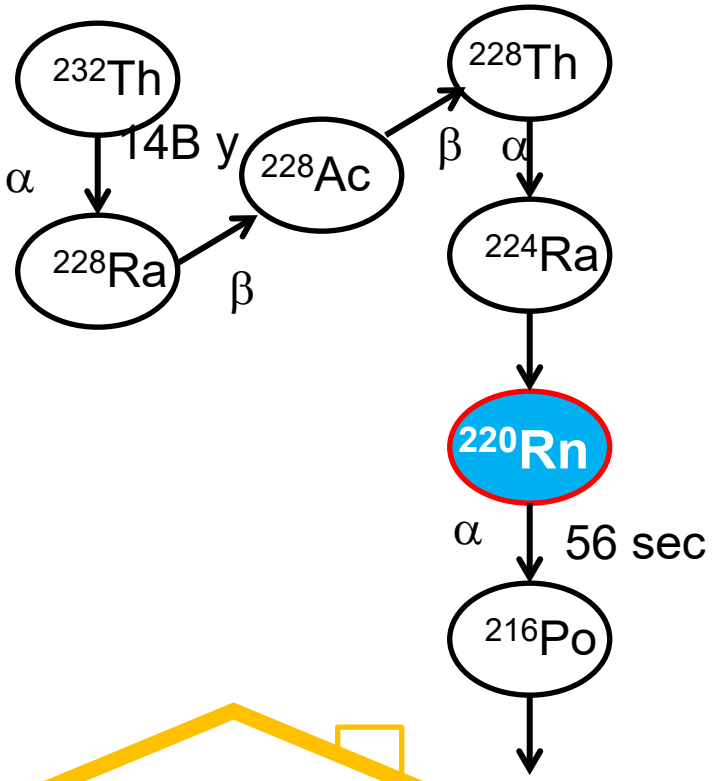
You have radiation dose with this breakfast, lunch, denner, etc.

Radon (Rn, rare gas!) generation

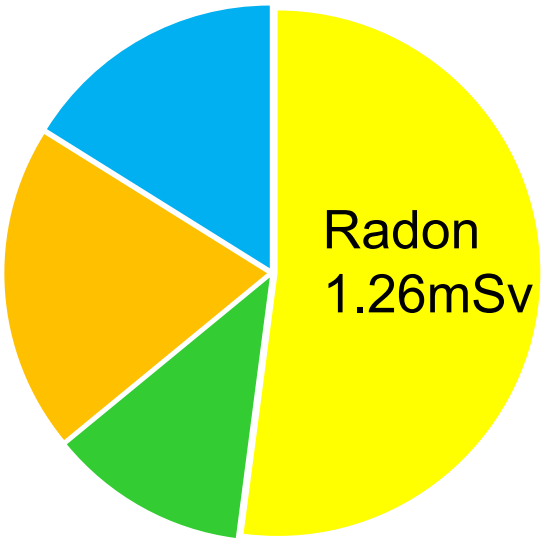
Uranium series

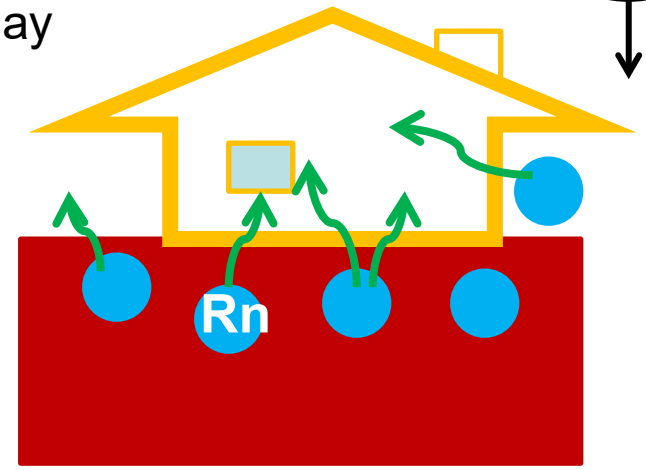


Thorium series

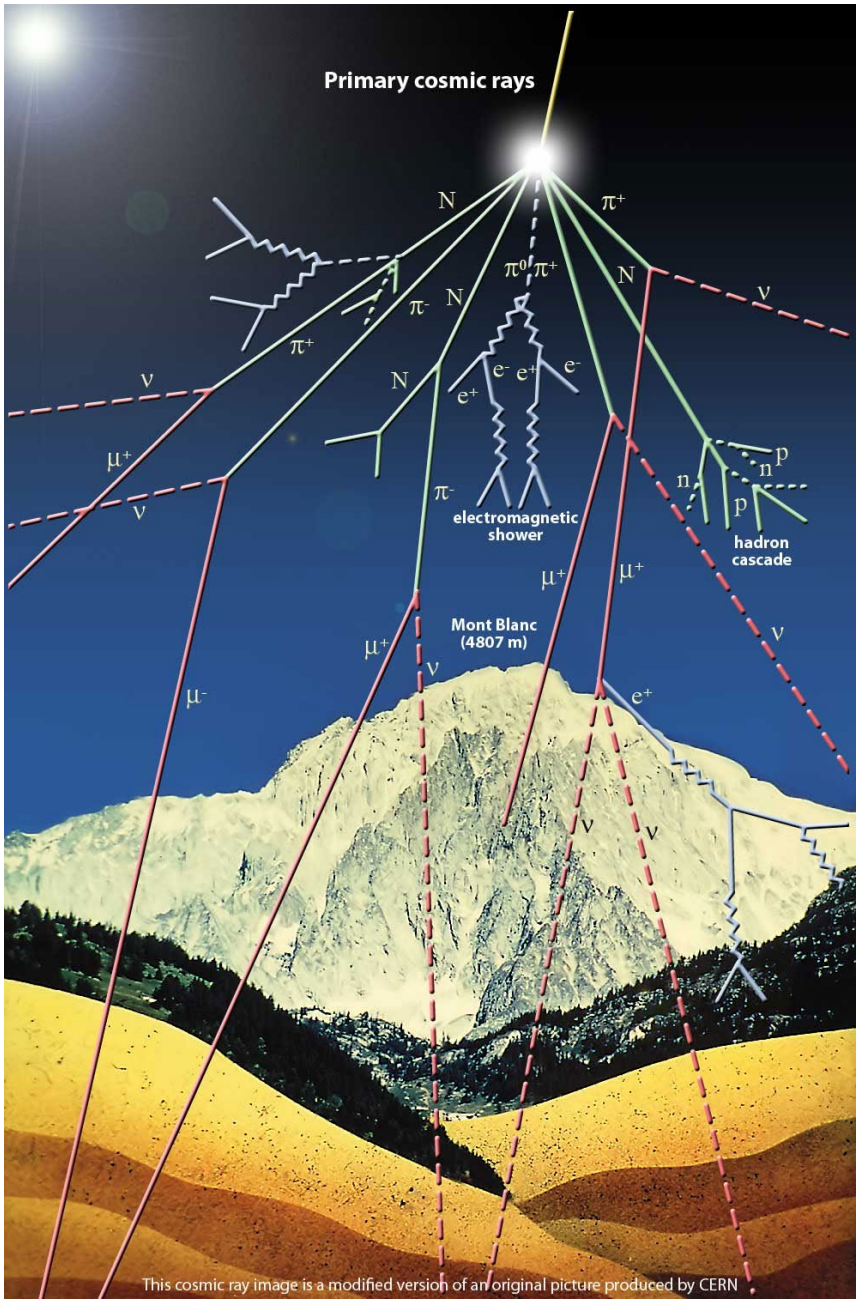


Total 2.4mSv/year





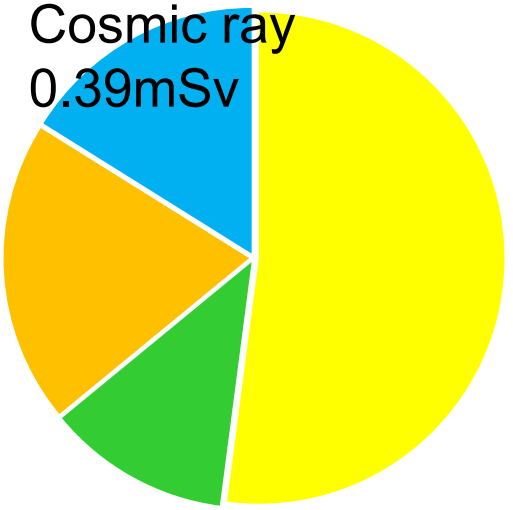
Cosmic ray（宇宙線）



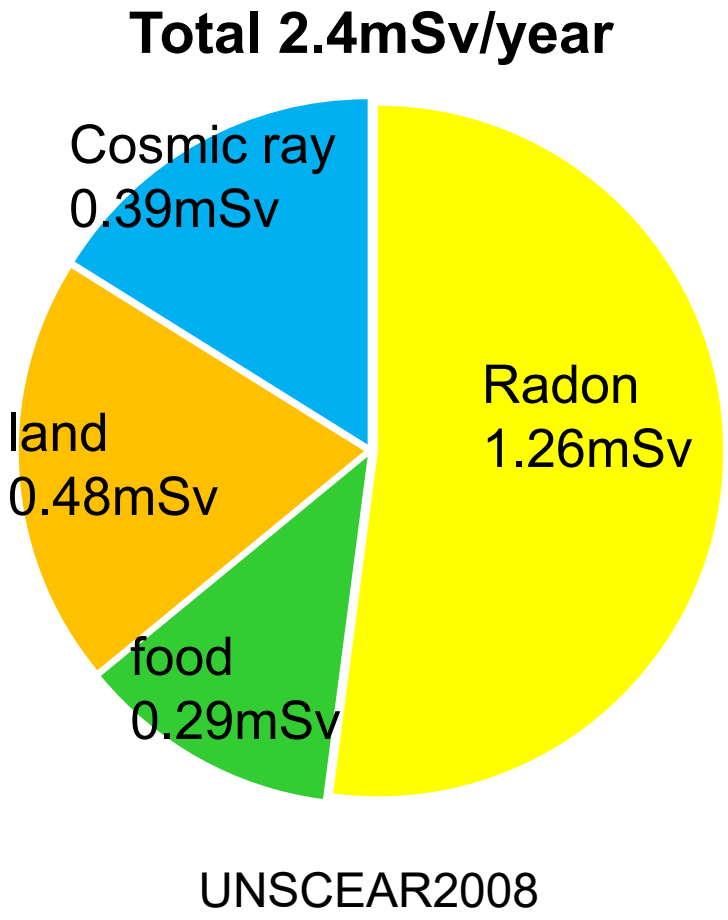
High energy particles (mainly proton) travel in universe. It strike earth atmosphere and generate lot of particles via nuclear reaction.

These particles expand as shower, the area is several handled m^2 at the ground level. In average, a cosmic ray penetrate your palm every second.

Total 2.4mSv/year



Summery of natural radiation exposure



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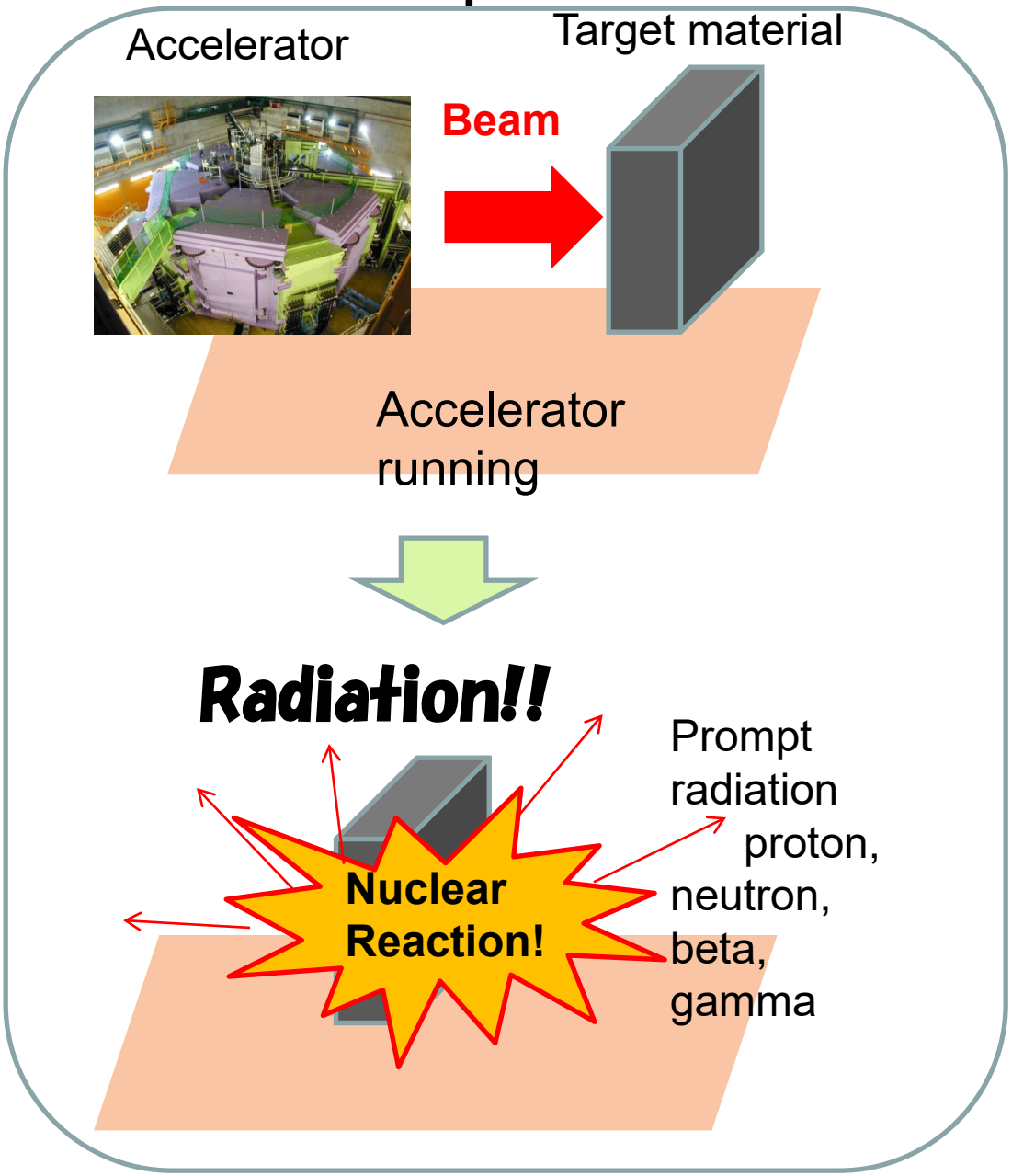
There is 0.1% cancer risk
by 50 mSv/year exposure.

In Japanese regulation, additional
1 mSv/year is allowed.

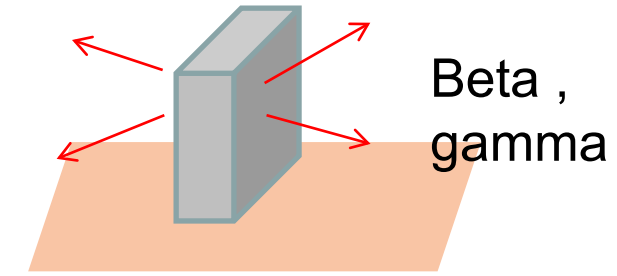
At RIKEN Nishina school, your radiation dose rate is estimated <1uSv !

5, Safety in RIBF

Prompt and residual radiation



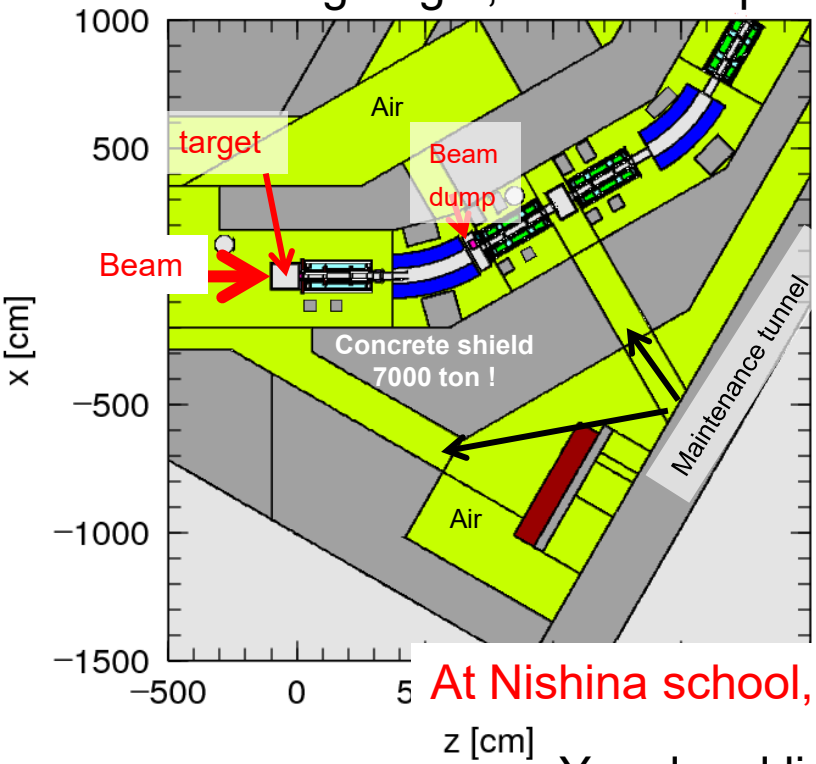
Radiation come from radioactive material after the accelerator is stopped. (residual radioactivity)



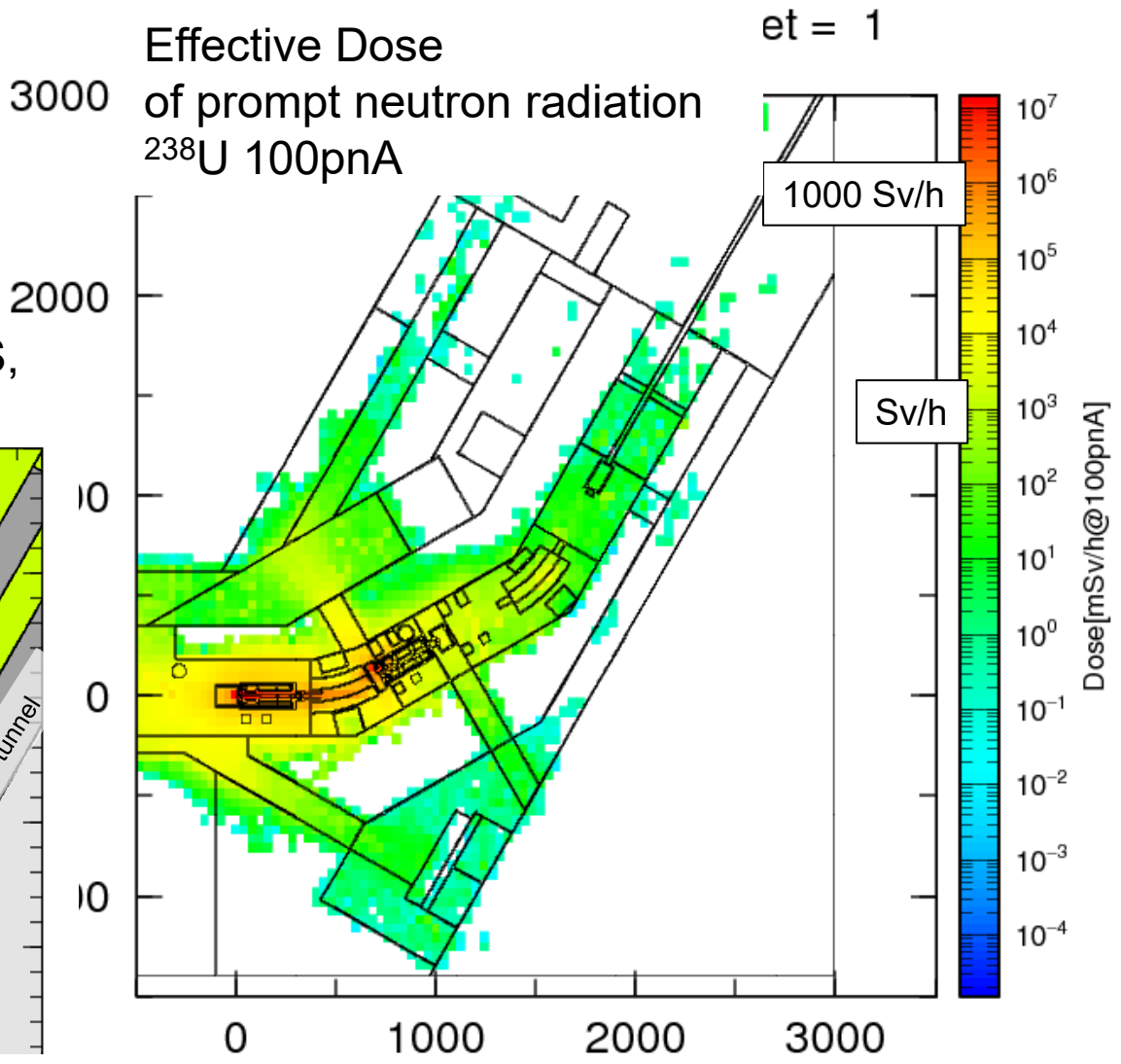
Simulation of nuclear reaction for RIBF facility

Super computer:
200 core cps, 0.5~1 day
>1 million injected

Calculation model of BigRIPS, containing target, beam dump



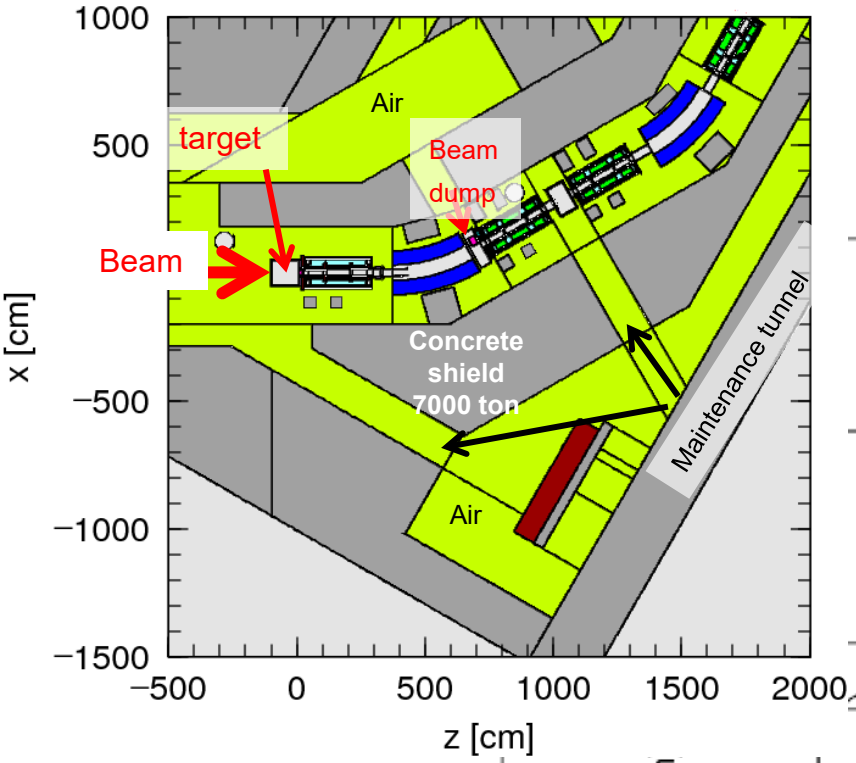
Effective Dose
of prompt neutron radiation
^{238}U 100pnA



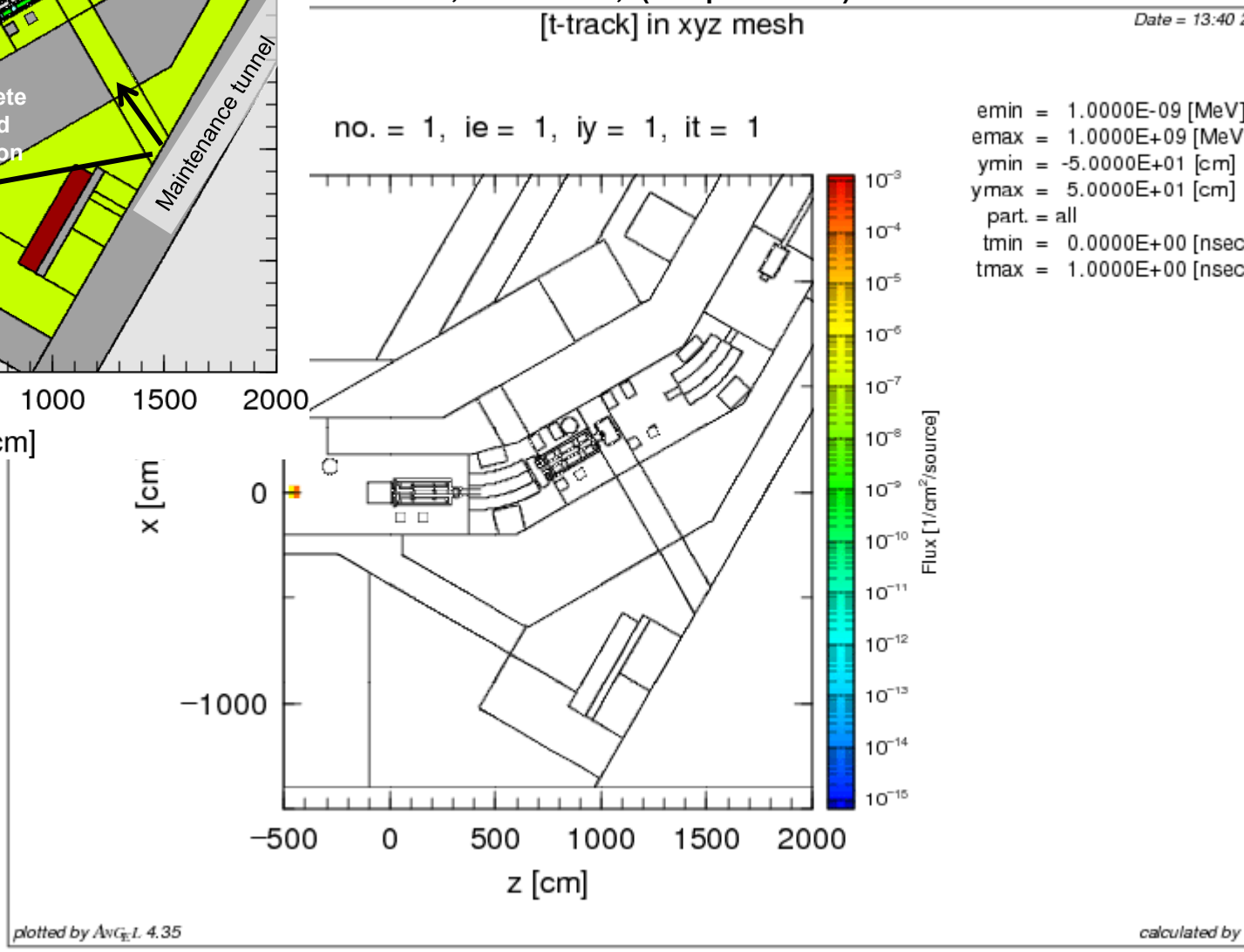
At Nishina school, your radiation exposure is estimated <1uSv !

Your legal limit 1 mSv/year and RIKEN limit 50 μSv/year.

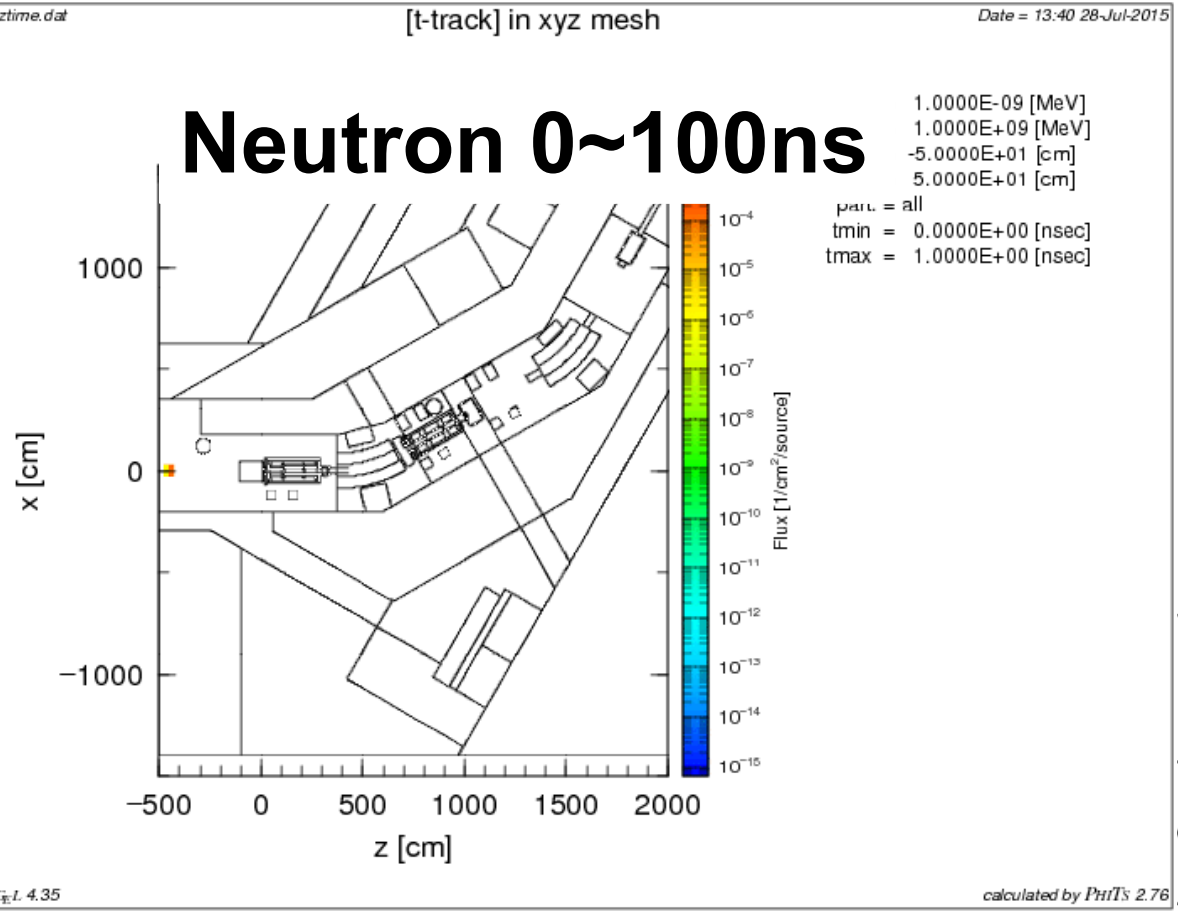
Nuclear reaction in RIBF 0~100ns



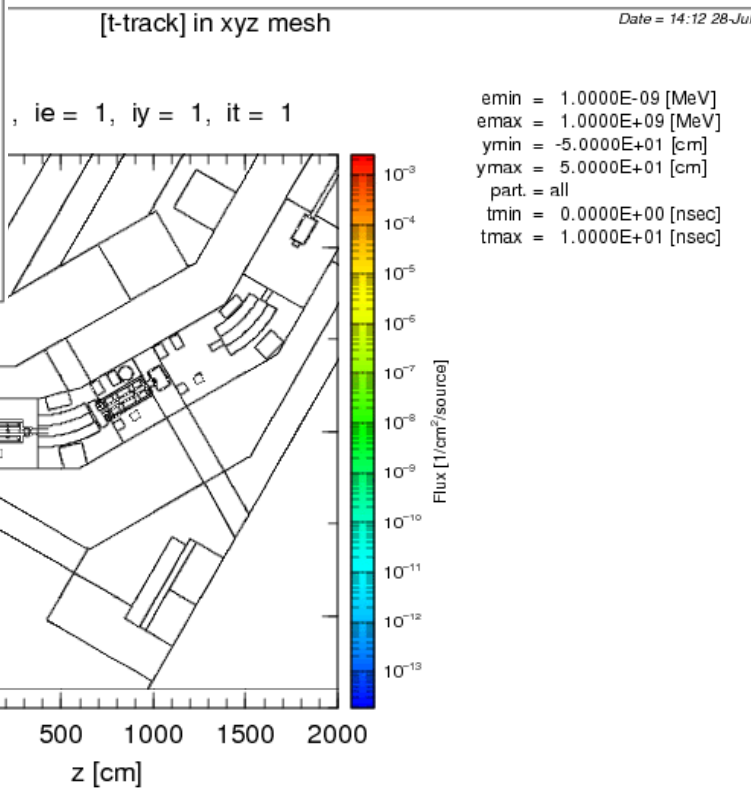
Beam, neutron, (all particle)

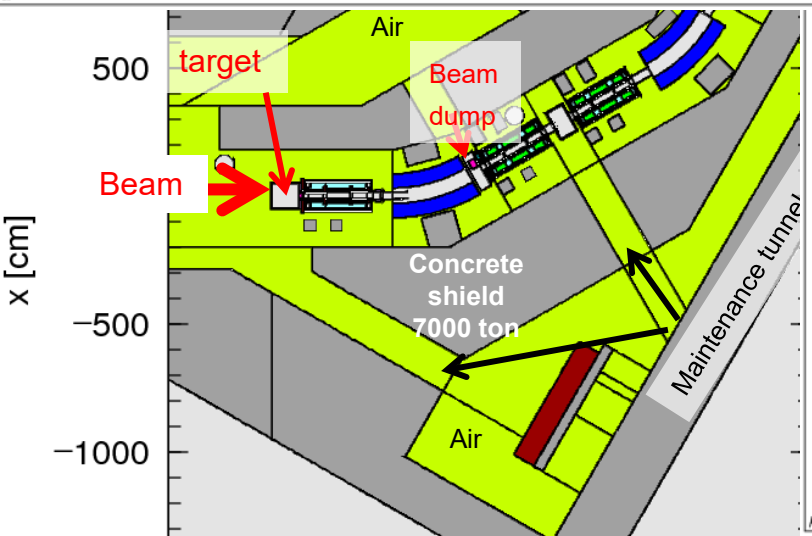


Neutron 0~100ns



Neutron 0-1000ns

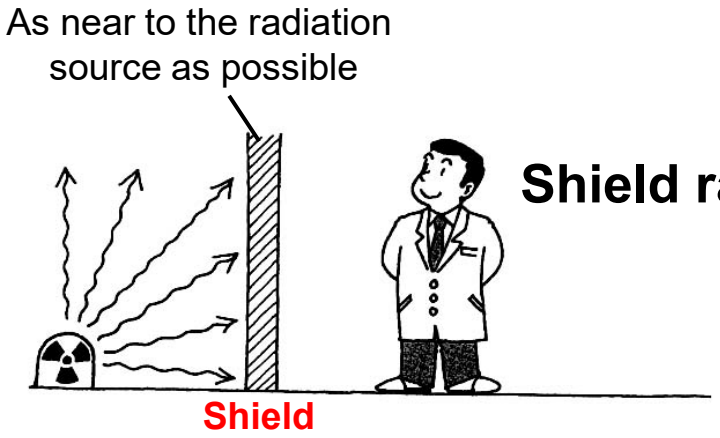




Protecting Against External Exposure(外部被爆防止)

3 principles

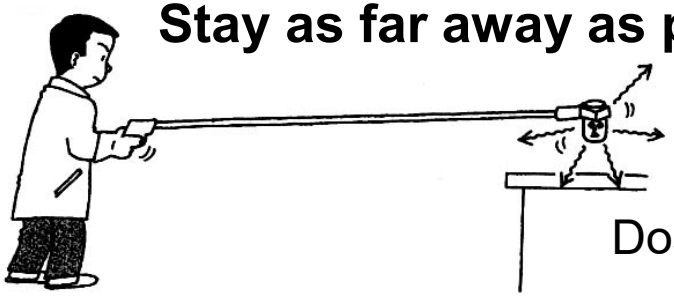
Shielding



Shield radiation sources.

Distance

Stay as far away as possible.



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

Time

Keep exposure time short !

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Protecting Against Internal Exposure内部被爆防止

Prohibited Matters in Radiation Controlled Area

Eating or drinking

Smoking

Makeup

END