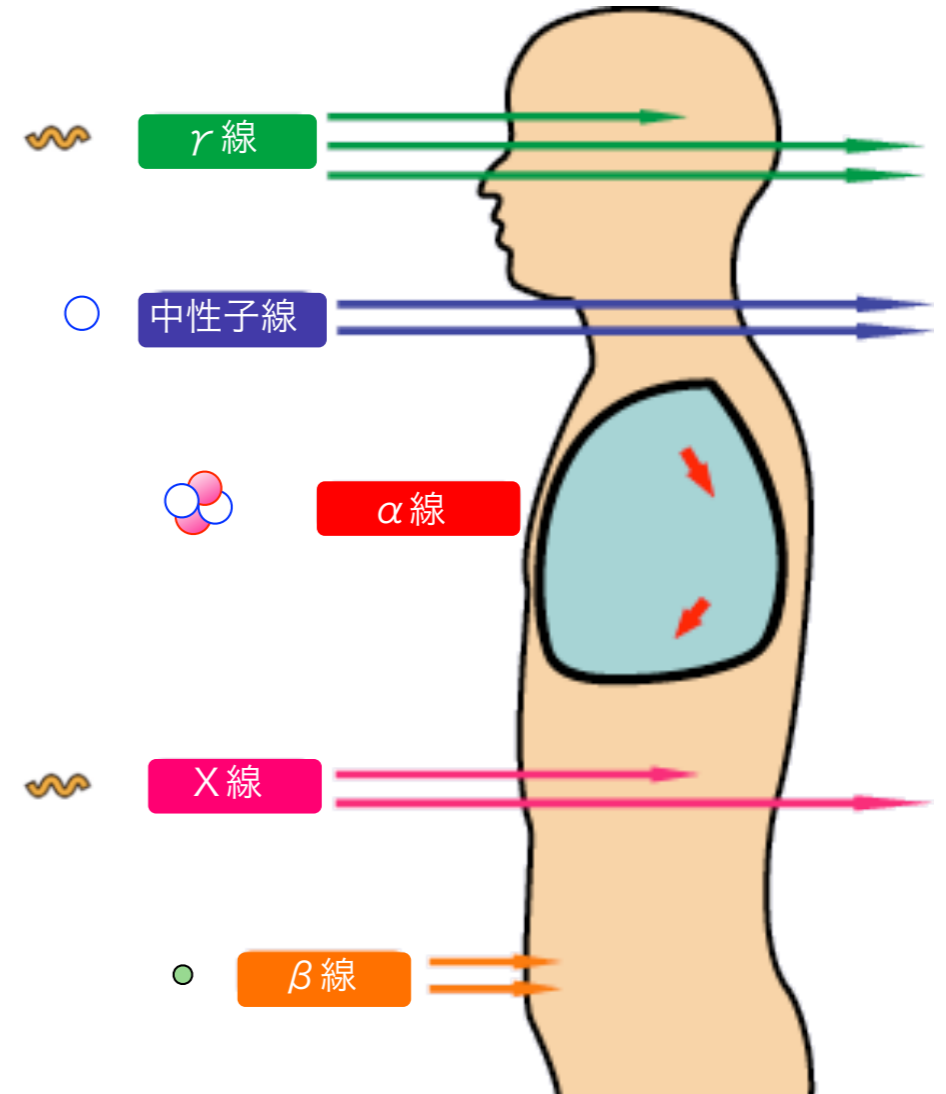


Special lecture for PEAK students, Univ. of Tokyo

# Sciences of Radiation



Mon 10th June 2013

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Assistant Professor

Institute of Physics, Graduate School of Arts & Sciences, UT

# 放射線を科学的に理解する

《教養学部》

**鳥居 寛之** 《物理》  
放射線物理学・原子核物理学



**小豆川 勝見** 《化学》  
放射線計測学・環境放射化学

**渡邊 雄一郎** 《生命》  
放射線生物学

ゲスト講師

**作美 明** 《医病院》  
放射線医療

**森口 祐一** 《都市工》  
環境汚染・廃棄物問題

**藤原 徹** 《農学部》  
放射性物質と農業

**藤垣 裕子** 《教養学部》  
科学技術社会論



【2012年度】

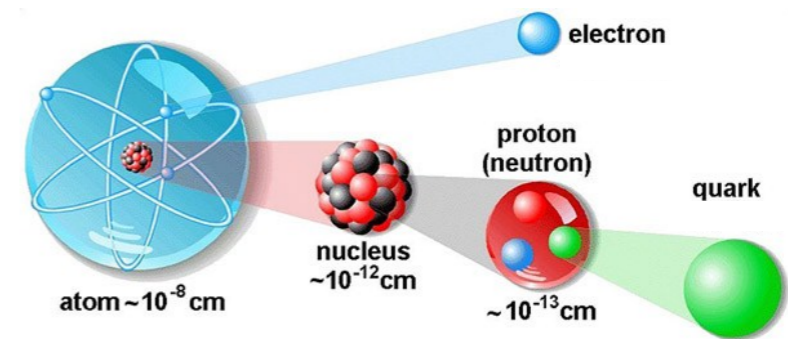
# 東京大学教養学部 放射線講義 スライドのご案内

書籍「放射線を科学的に理解する — 基礎からわかる東大教養の講義 —」

とあわせて、どうぞご利用下さい。 <http://radphys4.c.u-tokyo.ac.jp/~torii/lecture/torii-radio@radphys4.c.u-tokyo.ac.jp>

2011年度夏学期  
自主講義

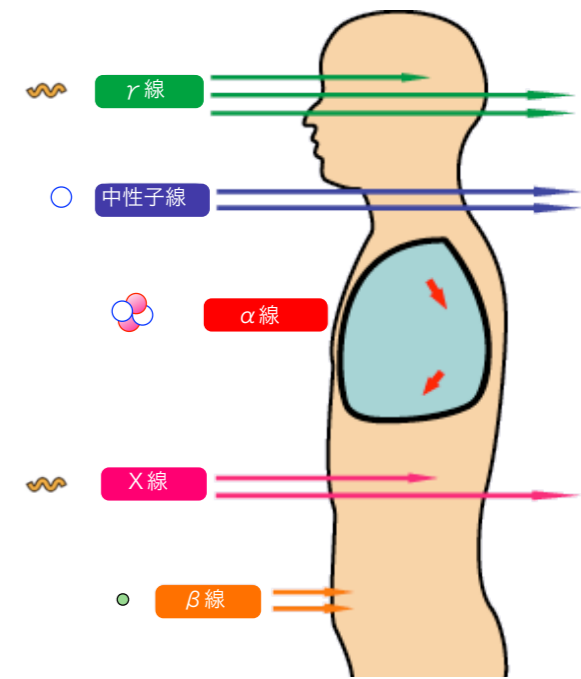
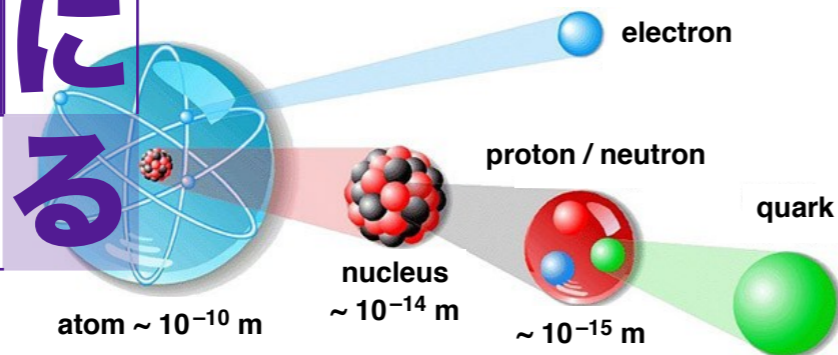
自主講義  
放射線学



2011年度冬学期  
主題科目テーマ講義

2012年度冬学期  
主題科目テーマ講義

放射線を  
科学的に  
理解する







# 放射線

鳥居 寛之  
小豆川勝見  
渡辺雄一郎  
著

中川 恵一  
執筆協力

科学的に  
理解する

基礎からわかる東大教養の講義

丸善出版

## 「放射線を科学的に理解する

— 基礎からわかる東大教養の講義 —

鳥居寛之・小豆川勝見・渡辺雄一郎 著  
中川恵一 執筆協力

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本体 2500円＋税

- 1章 放射線とは？《放射線入門》
  - 2章 放射線の性質《放射線物理学 I》
  - 3章 原子力発電で生み出される放射性物質  
《原子核物理学・原子力工学》
  - 4章 放射線量の評価《放射線物理学 II》
  - 5章 放射線の測り方《放射線計測学》
  - 6章 環境中での放射性物質《環境放射化学》
  - 7章 放射線の細胞への影響《放射線生物学》
  - 8章 放射線の人体への影響《放射線医学》
  - 9章 放射性物質と農業《植物栄養学・土壤肥料学》
  - 10章 放射線の防護と安全《放射線防護学》
  - 11章 役に立つ放射線《放射線の利用・加速器科学》
- Q&A

放射線を理解するには、物理学・化学・生物学・医学・工学など多くの分野の知識が必要です。しかしこれらすべてを網羅することは難しく、系統立てて学べる機会は非常に少ないのが実情です。

本書は東京大学教養学部で行われた講義をもとに、放射線について多角的に学べるよう配慮しています。日常生活や原発事故にかかわる具体的な例を引きながらやさしくていねいに解説しましたので高校生や一般の方にも広く読んでいただきたいと願っています。





on-line lecture on radiation  
for highschool students

Nov. 2011

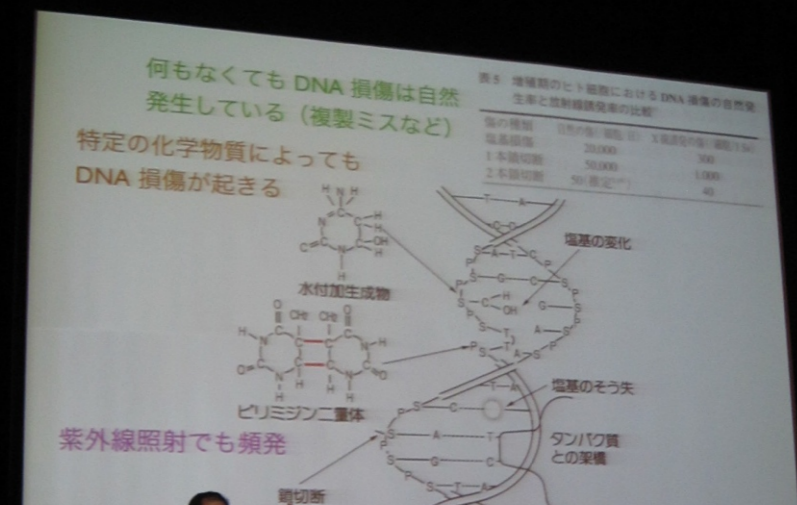




# Public lecture in Fukushima, Nov. 2011



**子どもの笑顔・元気サミット**  
—被災地の子どもたちのために いま私たちができること—





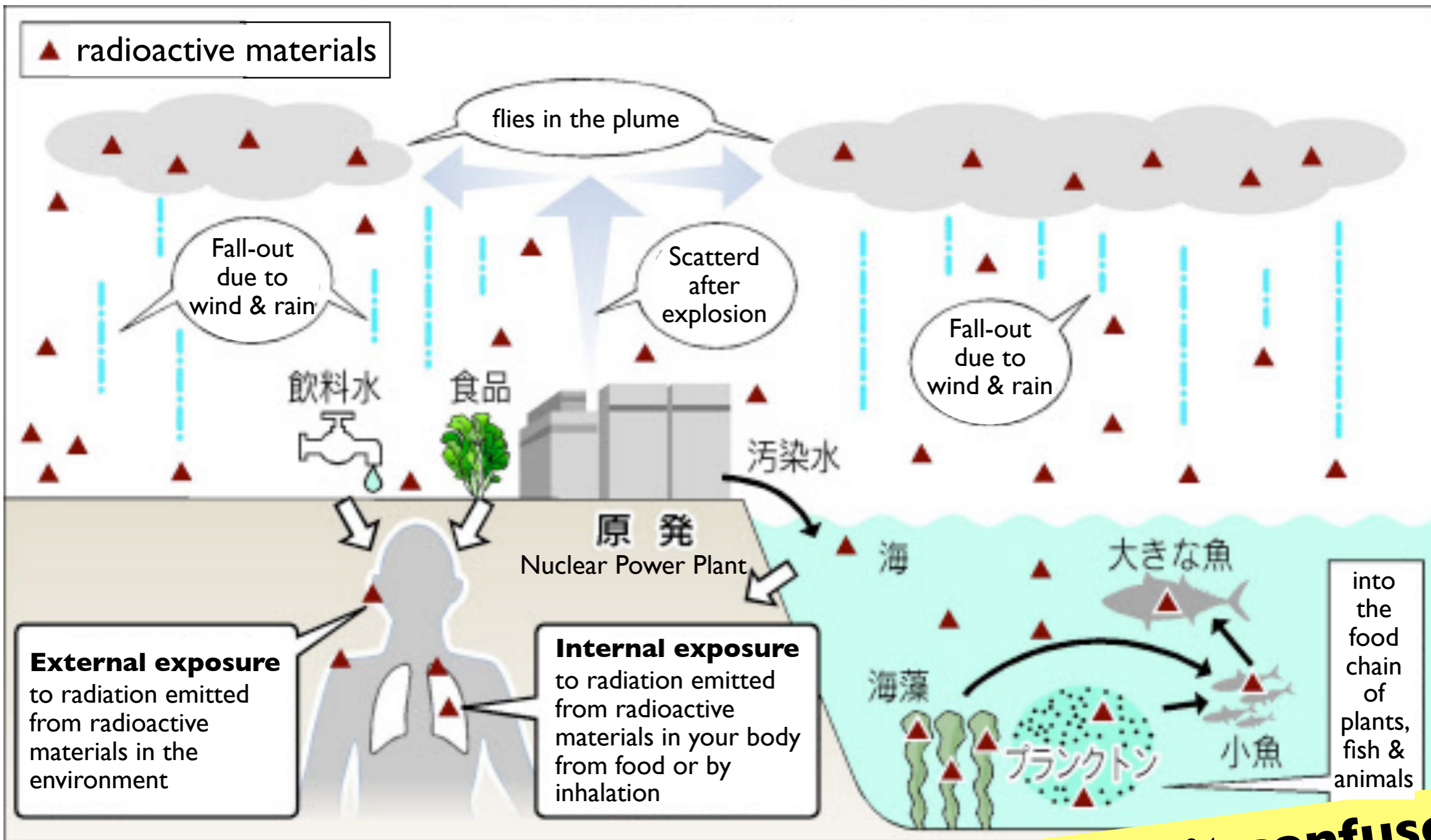
A large pile of earthquake rubble and debris at a construction site. In the background, there are industrial buildings, a blue fence, and a body of water with a boat. Several workers wearing white hard hats and jackets are walking through the debris. Two yellow Komatsu excavators are visible, one in the foreground and one in the background. The scene is filled with brown earth, wood, and various pieces of trash.

**Workshop on the problem  
of earthquake rubbles and  
the public fear of radioactivity**

**Univ. of Tokyo × Hakuhodo × Jiji Press**



**Radiation**  
**Radioactivity**  
**Radioactive materials**



**Don't confuse radioactivity with radiation.**

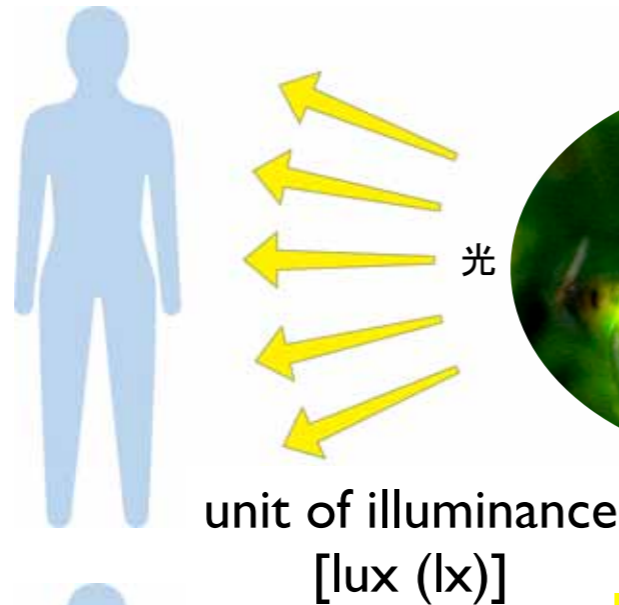
Some **radioactive materials** flew to Tokyo.

**Radiation** cannot reach Tokyo directly from Fukushima NPP.



# Radioactivity & Radiation

Sievert

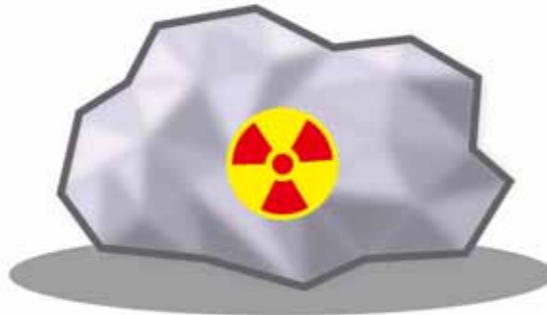
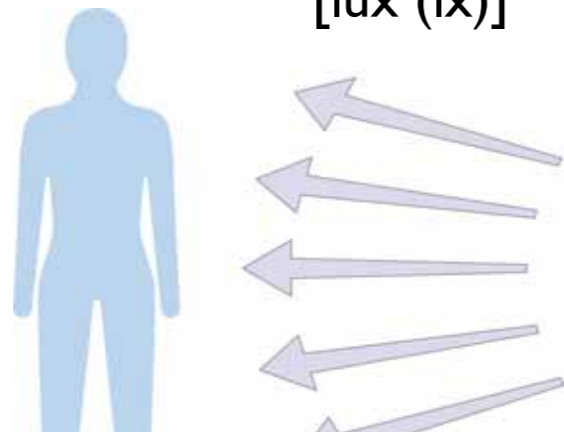


ability to emit light



unit of luminous intensity  
[candela (cd)]

**radioactive material**



radioactivity =  
ability to emit radiation



Unit of **radioactivity**  
**becquerel [Bq]**

Becquerel



Unit of the intensity & effect of **radiation**  
**sievert [Sv]**

## Units of **radioactivity**

**[Bq]** | Bq = 1 dps, **[Ci]** | Ci = 37 GBq

decay/disintegration  
per second

**Curie**

Giga =  $10^9$   
= billion (US) / milliard (UK)

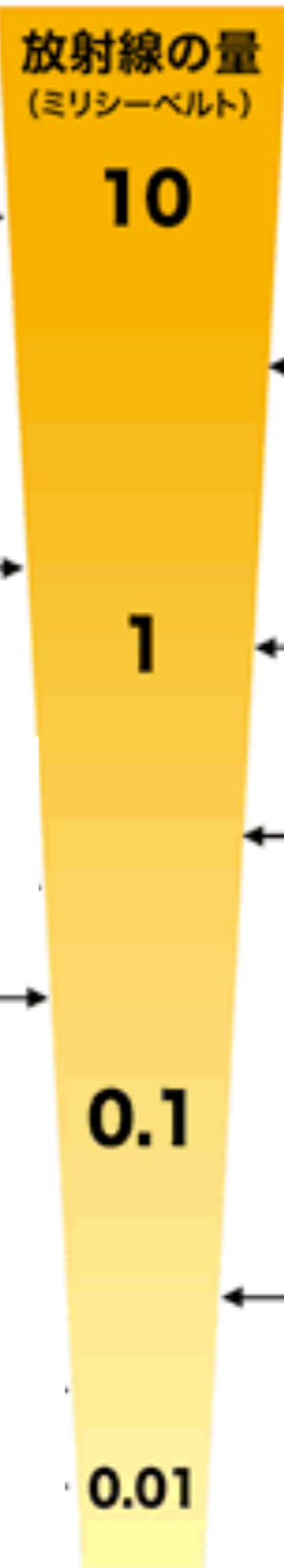




# Natural (environmental) & medical radiation



Dose per year at Guarapari, Brasil **10**



mSv (effective dose)

X-ray CT scan of the chest (once) ★



6.9

Japan average

0.29

cosmic rays

from food

inhalation of radon gas

from the earth

World average

Japan ave. ca. 1.5

mSv / yr

world average of dose per year

2.4



Annual dose limit of the public (excl. medical)

1.0



X-ray medical exam. of the stomach (once)

0.6



Dose for a return trip by airplane between Tokyo – New York

0.2



X-ray medical exam. of the chest (once) ★

0.1



0.05



Targeted annual set-point limit around Japanese nuclear power plants. (Achieved values are well below — except for the accident.)

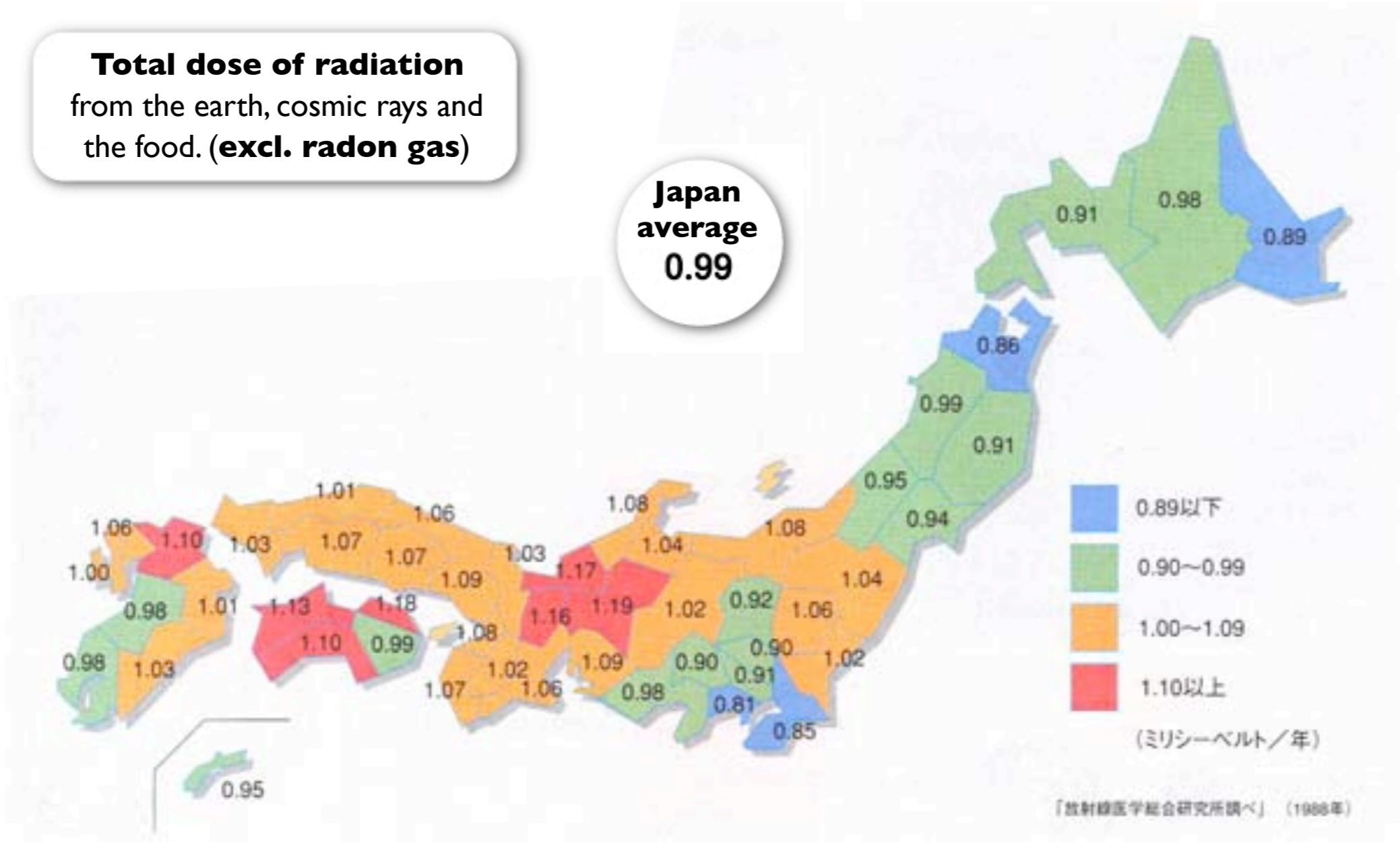
0.01

# Japanese natural dose of radiation

mSv / yr

**Total dose of radiation**  
from the earth, cosmic rays and  
the food. (excl. radon gas)

Japan  
average  
0.99



# higher natural dose in western Japan



## Domestic natural dose of radiation

mSv / yr

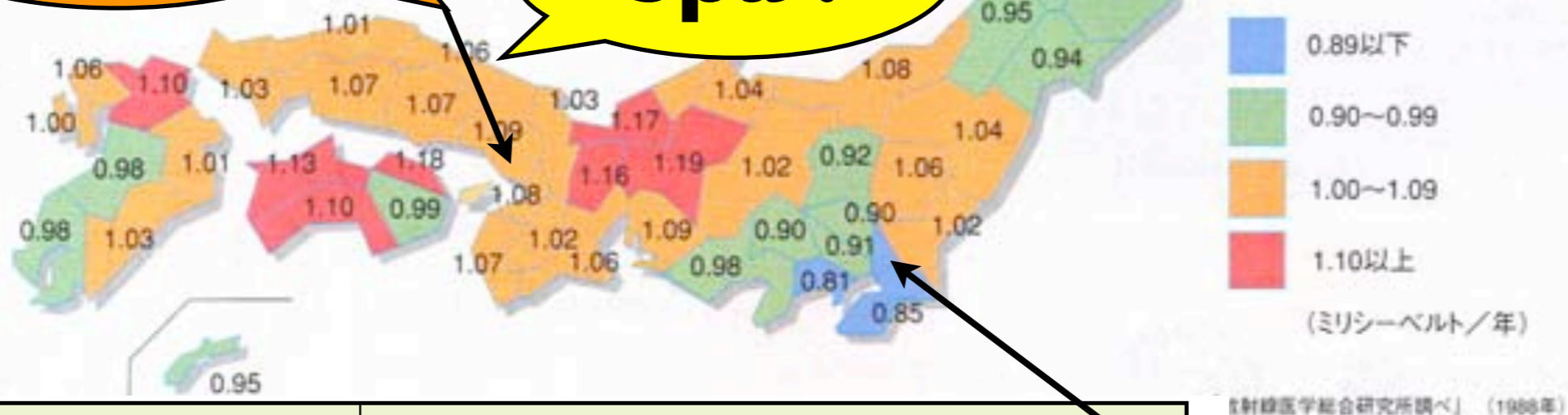
lower natural dose in eastern Japan (Kanto, Tohoku)

**Total dose of radiation**  
from the earth, cosmic rays and the food. (excl. radon gas)

Japan average 0.99

**granite**  
(Mikage-stone)

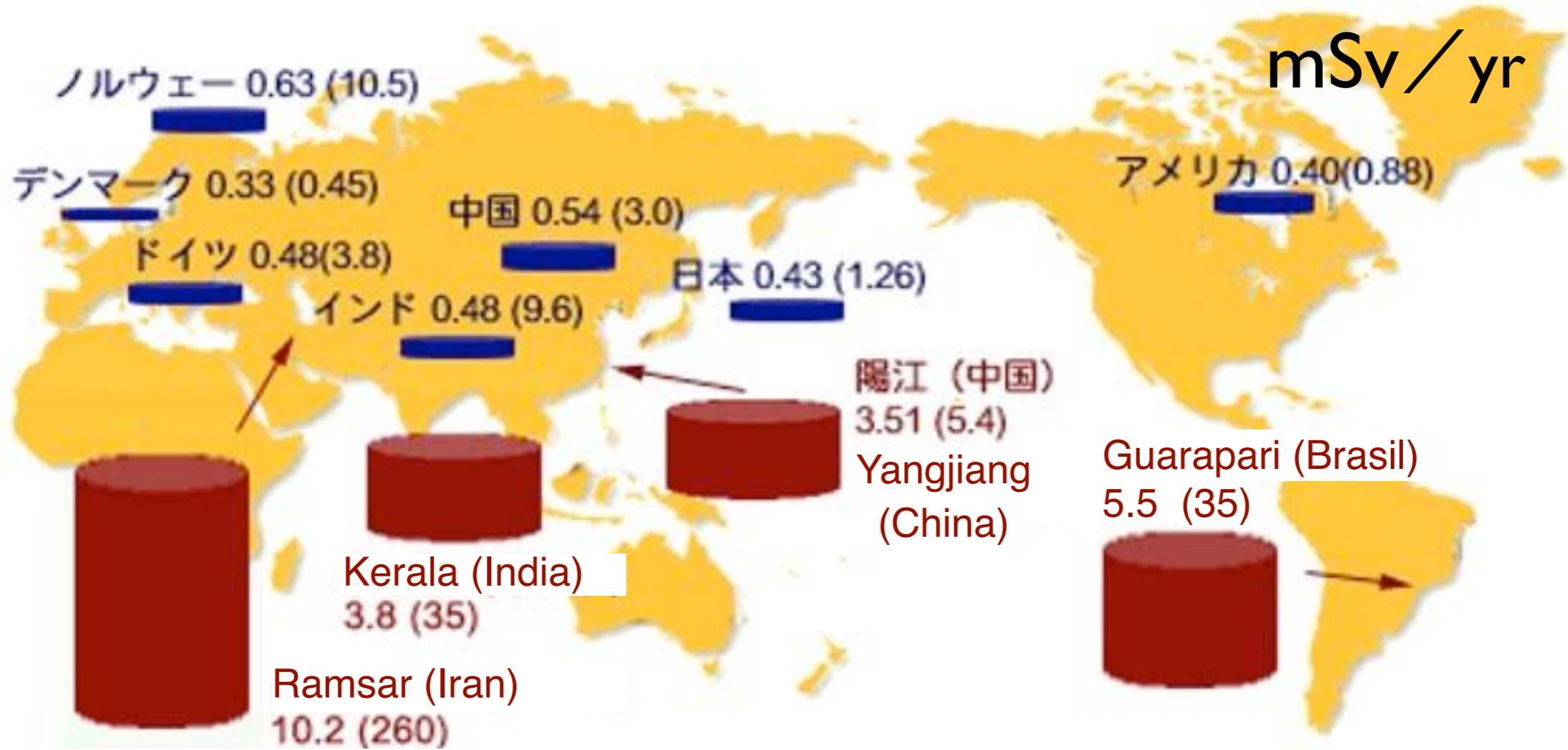
**Spa !**



Radioactive nuclide	Density (Bq / kg)	
	usual rocks & soils	granite
Potassium K-40	100~700	500~1600
Uranium U-238 & daughters	10~50	20~200
Thorium Th-232	7~50	20~200

**Kanto loamy layer**





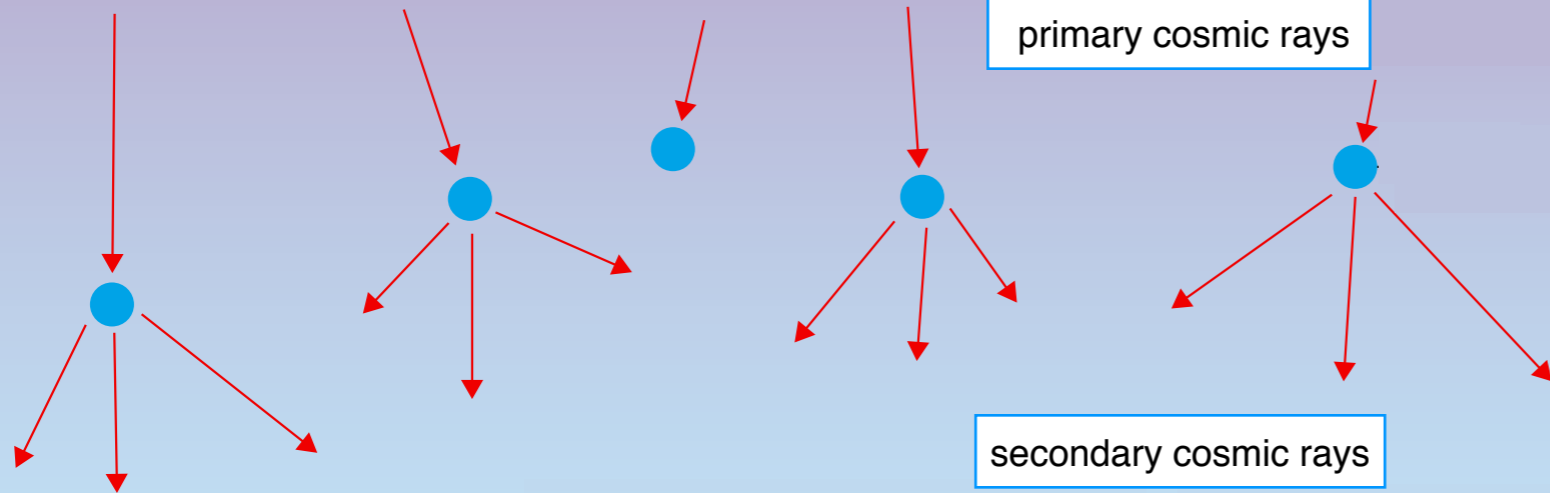
max. value in ( )



表1 高自然放射線地区と対照地区におけるがん死亡率の比較<sup>7,8)</sup>

	高自然放射線地区	対照地区
自然放射線量率 (mSv/年)	5.5	2.1
がん死亡率 (10万人・年)	48.8	51.1
調査人数・年	1,008,769	995,070

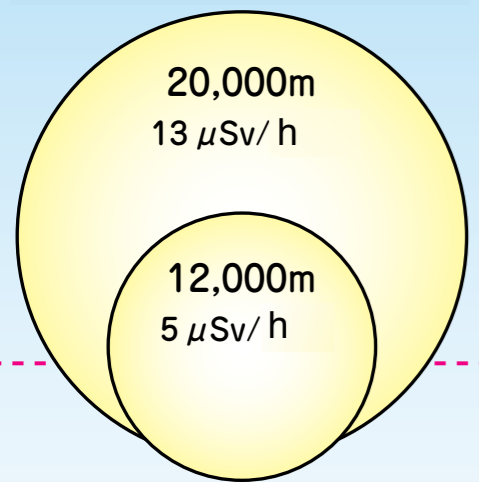
図2 陽江市・恩平県放射線環境調査実施地域



100km

10km

1km

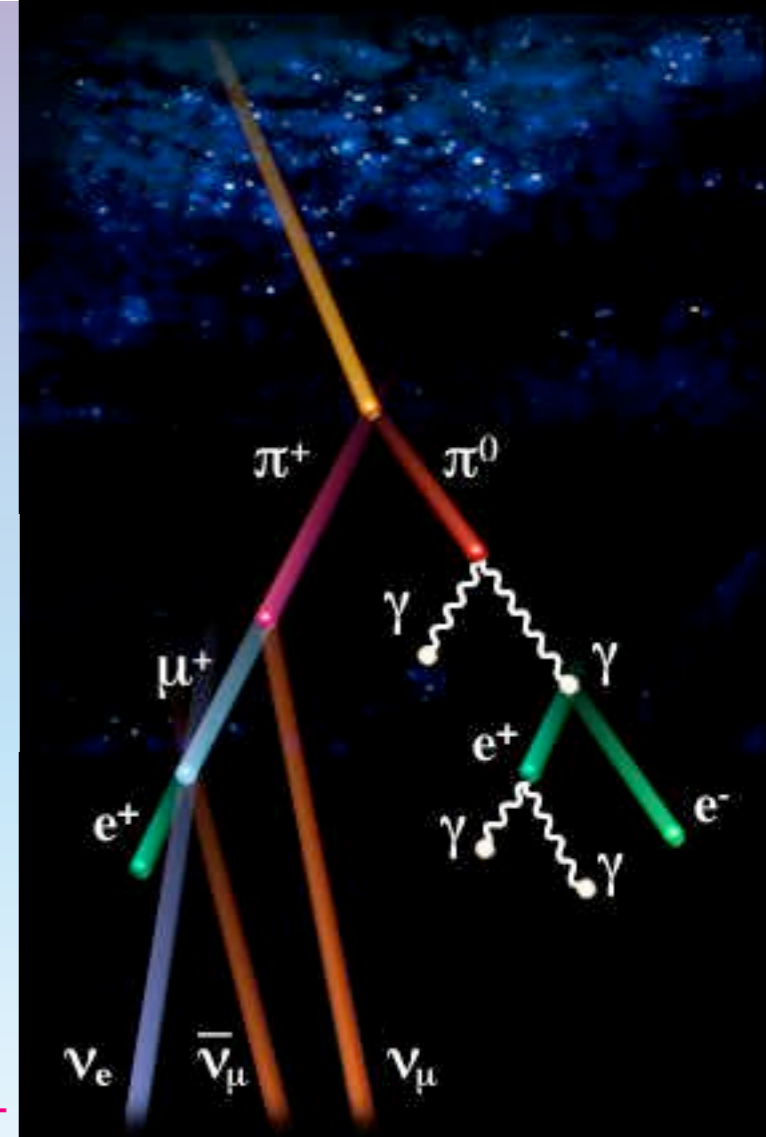
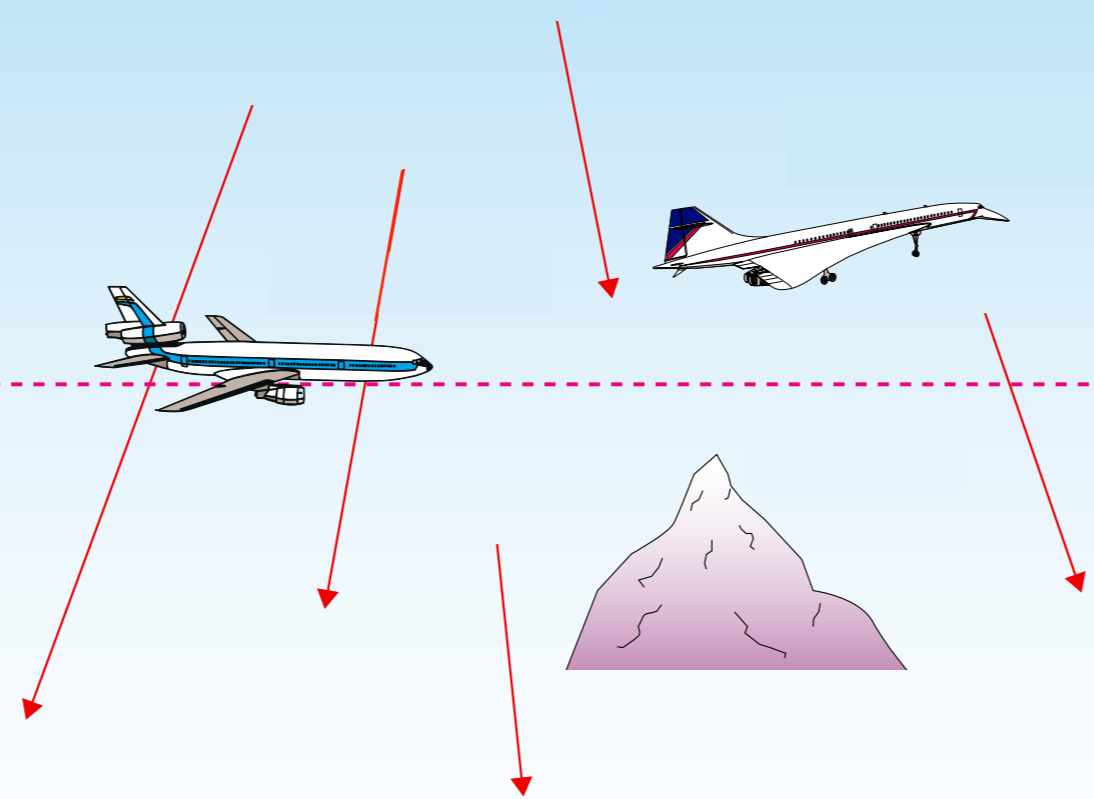


4,000m  $\odot$  0.2  $\mu\text{Sv/h}$

2,000m  $\odot$  0.1  $\mu\text{Sv/h}$

sea level  $\odot$  0.03  $\mu\text{Sv/h}$

$\mu\text{Sv} = \text{microsievert}$



Round-trip by flight  
TYO-NYC  
200  $\mu\text{Sv}$  (max)  
= 0.2 mSv



# Natural radioactivity in the food / body

出典：旧科学技術庁パンフレット

Bq / kg

Bq (60 kg)

● Radioactive materials in our body

Radioactive nuclide	Density (Bq / kg)	Radioactivity per 60-kg body
Potassium K-40	67	4,100
Carbon C-14	41	2,600
Rubidium Ru-87	8.5	520
Lead Pb-210 / Polonium Po-210	0.074~1.5	19
Uranium U-238	—	1.1

● Radioactivity of potassium-40 in Japanese foods

(単位：ベクレル/kg)



Bq / kg

$^{40}\text{K}$   
 isotope abundance = 0.012%  
 half-life 13 billion yrs  
 $^{40}\text{K} \rightarrow ^{40}\text{Ar}$  (EC $\gamma$ ) 11%  
 $^{40}\text{K} \rightarrow ^{40}\text{Ca}$  ( $\beta^-$ ) 89%

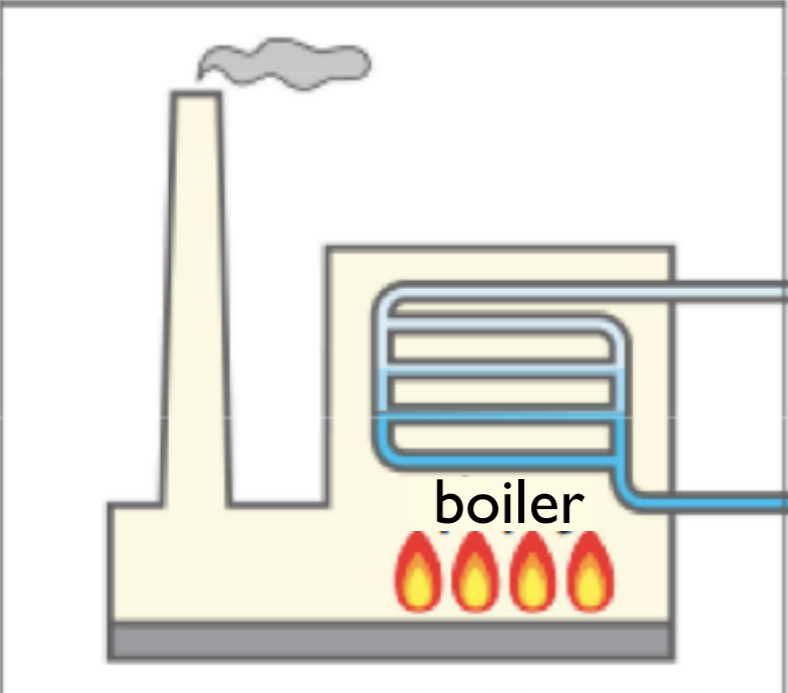
**We ingest 3 g of Potassium = 80 Bq of  $^{40}\text{K}$  every day, egesting the same amount.**



# Nuclear Physics

# Thermal vs. nuclear power generation

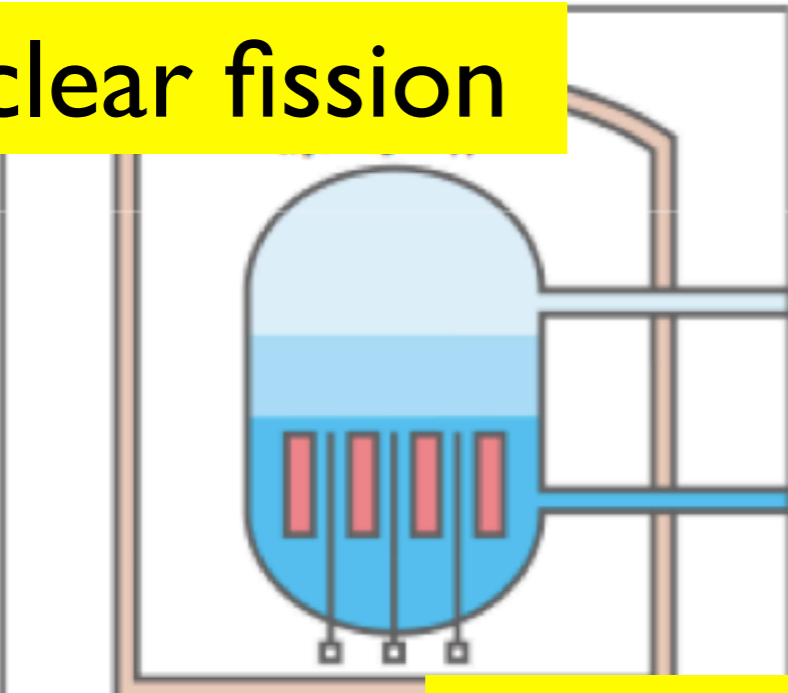
Thermal



Chemical combustion

Nuclear fission

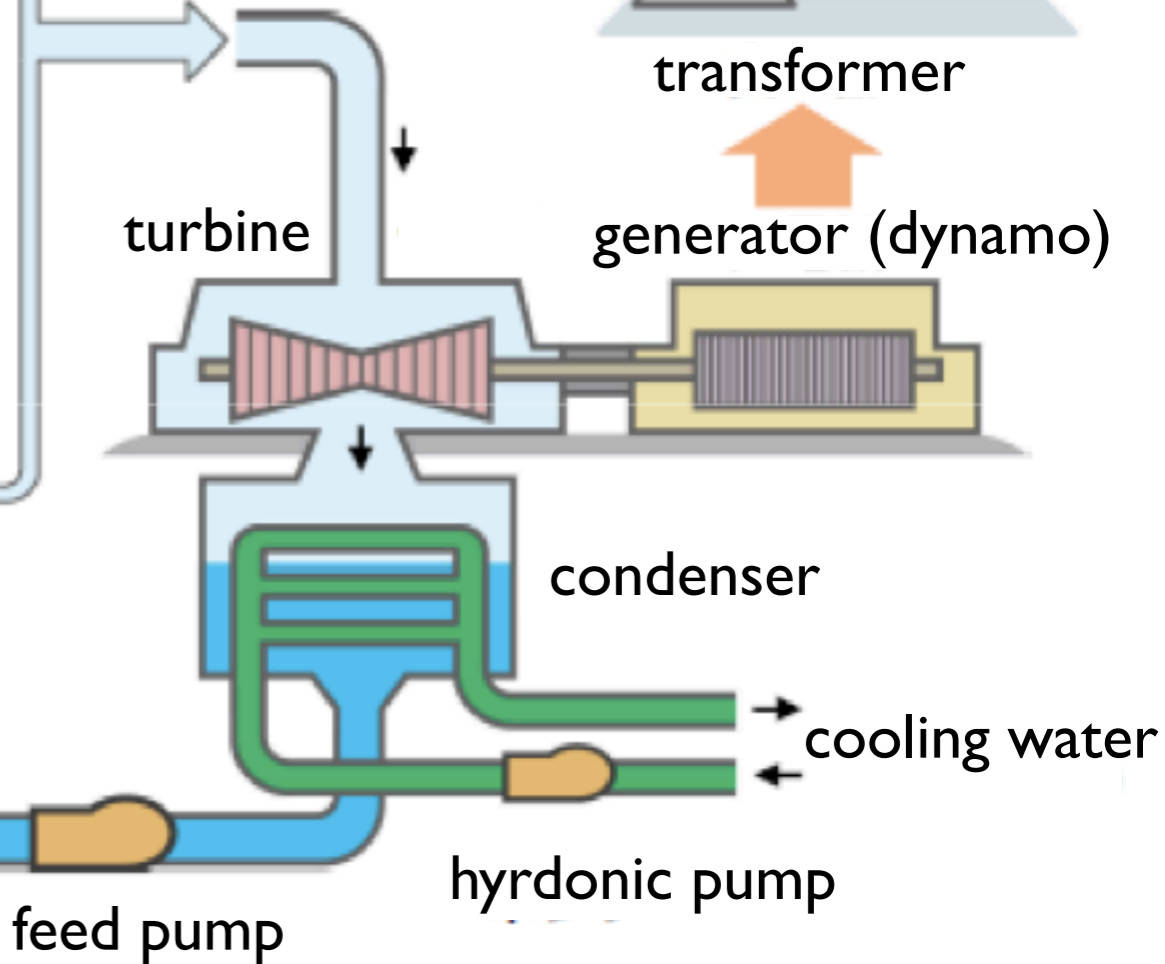
Nuclear



$$E = mc^2$$

vapor  
water

vapor  
water



turbine

transformer

generator (dynamo)

condenser

cooling water

feed pump

hyrdonic pump



分子  
molecule



原子  
atom



原子核  
nucleus



陽子  
proton



クォーク  
quark

nm ( $10^{-9}$  m)

nanometer

**Chemistry**

eV

electronvolt

atom < atomus < ατομος < a- + témnein + -os  
(cannot be cut)

**Atomic Physics**

Å ( $10^{-10}$  m)

Ångström

eV – keV

several electronvolts –  
kiloelectronvolt

# Why did alchemy fail?

**Nuclear Physics**

fm ( $10^{-15}$  m)

femtometer

MeV

megaelectronvolt

**Particle Physics**

am ( $10^{-18}$  m)

attometer

GeV

gigaelectronvolt



# Periodic table

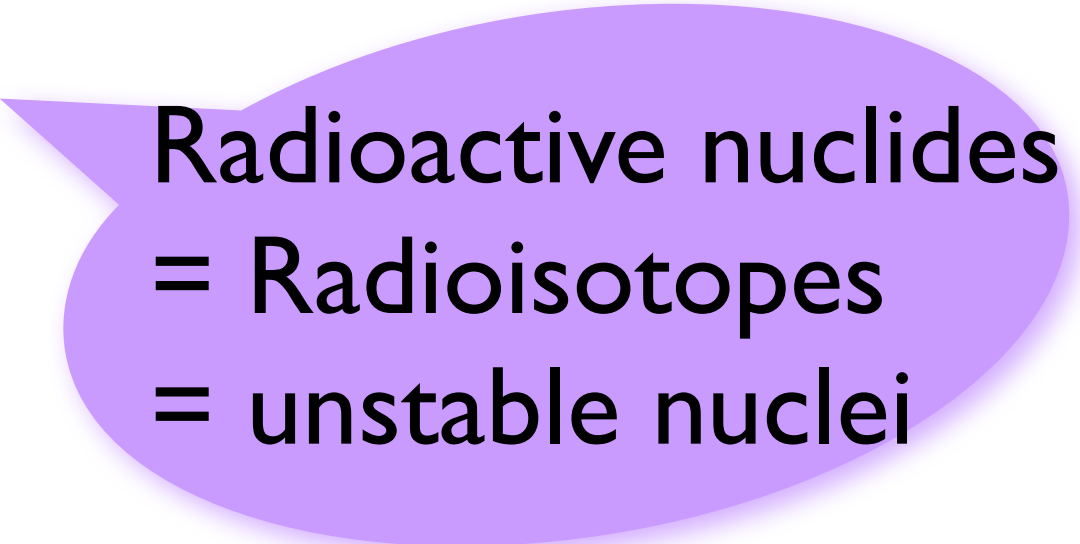
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18														
1	1 <b>H</b> 1.0079	Atomic Sym Mass																2 <b>He</b> 4.0026														
2	3 <b>Li</b> 6.941	4 <b>Be</b> 9.0121	<table border="1"> <tr> <td colspan="5">金属</td> <td colspan="2">非金属元素</td> </tr> <tr> <td>アルカリ金属</td> <td>アルカリ土類金属</td> <td>ランタノイド</td> <td>遷移元素</td> <td>卑金属</td> <td>非金属元素</td> <td>希ガス</td> </tr> </table>										金属					非金属元素		アルカリ金属	アルカリ土類金属	ランタノイド	遷移元素	卑金属	非金属元素	希ガス	5 <b>B</b> 10.811	6 <b>C</b> 12.010	7 <b>N</b> 14.006	8 <b>O</b> 15.999	9 <b>F</b> 18.998	10 <b>Ne</b> 20.179
金属					非金属元素																											
アルカリ金属	アルカリ土類金属	ランタノイド	遷移元素	卑金属	非金属元素	希ガス																										
3	11 <b>Na</b> 22.989	12 <b>Mg</b> 24.305	<table border="1"> <tr> <td>C</td> <td>固体</td> </tr> <tr> <td>Hg</td> <td>液体</td> </tr> <tr> <td>H</td> <td>気体</td> </tr> <tr> <td>Rf</td> <td>Unknown</td> </tr> </table>																C	固体	Hg	液体	H	気体	Rf	Unknown	13 <b>Al</b> 26.981	14 <b>Si</b> 28.085	15 <b>P</b> 30.973	16 <b>S</b> 32.065	17 <b>Cl</b> 35.453	18 <b>Ar</b> 39.948
C	固体																															
Hg	液体																															
H	気体																															
Rf	Unknown																															
4	19 <b>K</b> 39.098	20 <b>Ca</b> 40.078	21 <b>Sc</b> 44.955	22 <b>Ti</b> 47.867	23 <b>V</b> 50.941	24 <b>Cr</b> 51.996	25 <b>Mn</b> 54.938	26 <b>Fe</b> 55.845	27 <b>Co</b> 58.933	28 <b>Ni</b> 58.693	29 <b>Cu</b> 63.546	30 <b>Zn</b> 65.38	31 <b>Ga</b> 69.723	32 <b>Ge</b> 72.64	33 <b>As</b> 74.921	34 <b>Se</b> 78.96	35 <b>Br</b> 79.904	36 <b>Kr</b> 83.798														
5	37 <b>Rb</b> 85.467	38 <b>Sr</b> 87.62	39 <b>Y</b> 88.905	40 <b>Zr</b> 91.224	41 <b>Nb</b> 92.906	42 <b>Mo</b> 95.96	43 <b>Tc</b> (97.907)	44 <b>Ru</b> 101.07	45 <b>Rh</b> 102.90	46 <b>Pd</b> 106.42	47 <b>Ag</b> 107.86	48 <b>Cd</b> 112.41	49 <b>In</b> 114.81	50 <b>Sn</b> 118.71	51 <b>Sb</b> 121.76	52 <b>Te</b> 127.60	53 <b>I</b> 126.90	54 <b>Xe</b> 131.29														
6	55 <b>Cs</b> 132.90	56 <b>Ba</b> 137.32	57-71	72 <b>Hf</b> 178.49	73 <b>Ta</b> 180.94	74 <b>W</b> 183.84	75 <b>Re</b> 186.20	76 <b>Os</b> 190.23	77 <b>Ir</b> 192.21	78 <b>Pt</b> 195.08	79 <b>Au</b> 196.96	80 <b>Hg</b> 200.59	81 <b>Tl</b> 204.38	82 <b>Pb</b> 207.2	83 <b>Bi</b> 208.98	84 <b>Po</b> (208.98)	85 <b>At</b> (209.98)	86 <b>Rn</b> (222.01)														
7	87 <b>Fr</b> (223)	88 <b>Ra</b> (226)	89-103	104 <b>Rf</b> (261)	105 <b>Db</b> (262)	106 <b>Sg</b> (266)	107 <b>Bh</b> (264)	108 <b>Hs</b> (277)	109 <b>Mt</b> (268)	110 <b>Ds</b> (271)	111 <b>Rg</b> (272)	112 <b>Cn</b> (285)	113 <b>Uut</b> (284)	114 <b>F1</b> (289)	115 <b>Uup</b> (288)	116 <b>Lv</b> (292)	117 <b>Uus</b>	118 <b>Uuo</b> (294)														

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

周期表 Design and Interface Copyright © 1997 Michael Dayah. <http://www.ptable.com/> Last updated: May 30, 2008

57 <b>La</b> 138.90	58 <b>Ce</b> 140.11	59 <b>Pr</b> 140.90	60 <b>Nd</b> 144.24	61 <b>Pm</b> (145)	62 <b>Sm</b> 150.36	63 <b>Eu</b> 151.96	64 <b>Gd</b> 157.25	65 <b>Tb</b> 158.92	66 <b>Dy</b> 162.50	67 <b>Ho</b> 164.93	68 <b>Er</b> 167.25	69 <b>Tm</b> 168.93	70 <b>Yb</b> 173.05	71 <b>Lu</b> 174.96
89 <b>Ac</b> (227)	90 <b>Th</b> 232.03	91 <b>Pa</b> 231.03	92 <b>U</b> 238.02	93 <b>Np</b> (237)	94 <b>Pu</b> (244)	95 <b>Am</b> (243)	96 <b>Cm</b> (247)	97 <b>Bk</b> (247)	98 <b>Cf</b> (251)	99 <b>Es</b> (252)	100 <b>Fm</b> (257)	101 <b>Md</b> (258)	102 <b>No</b> (259)	103 <b>Lr</b> (262)

**Radioactive materials** are  
materials composed of atoms with



Radioactive nuclides  
= Radioisotopes  
= unstable nuclei



# Radioactive materials are

materials composed of atoms with

$$\text{mass number } A = Z + N$$

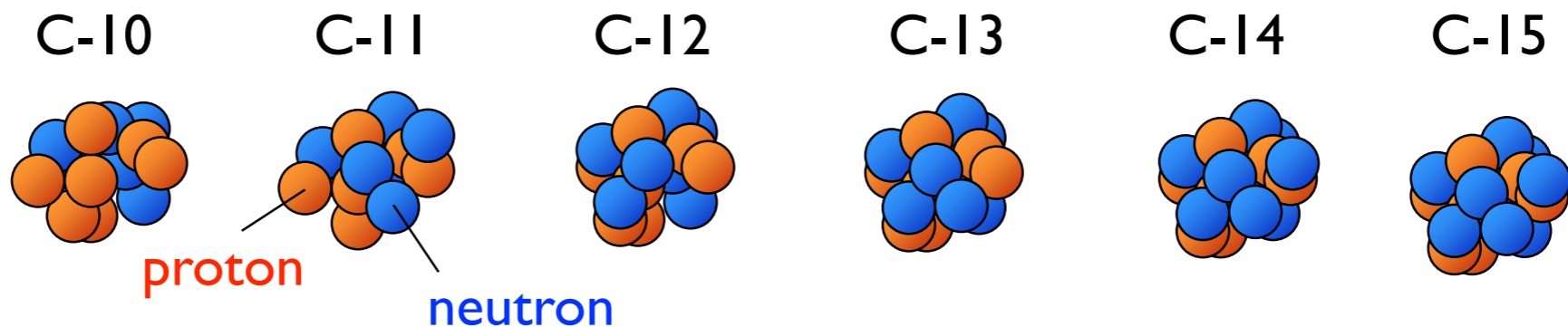
Radioactive nuclides  
= Radioisotopes  
= unstable nuclei

Same chemical element for the same proton number  $Z$

Different nuclides for different neutron number  $N$

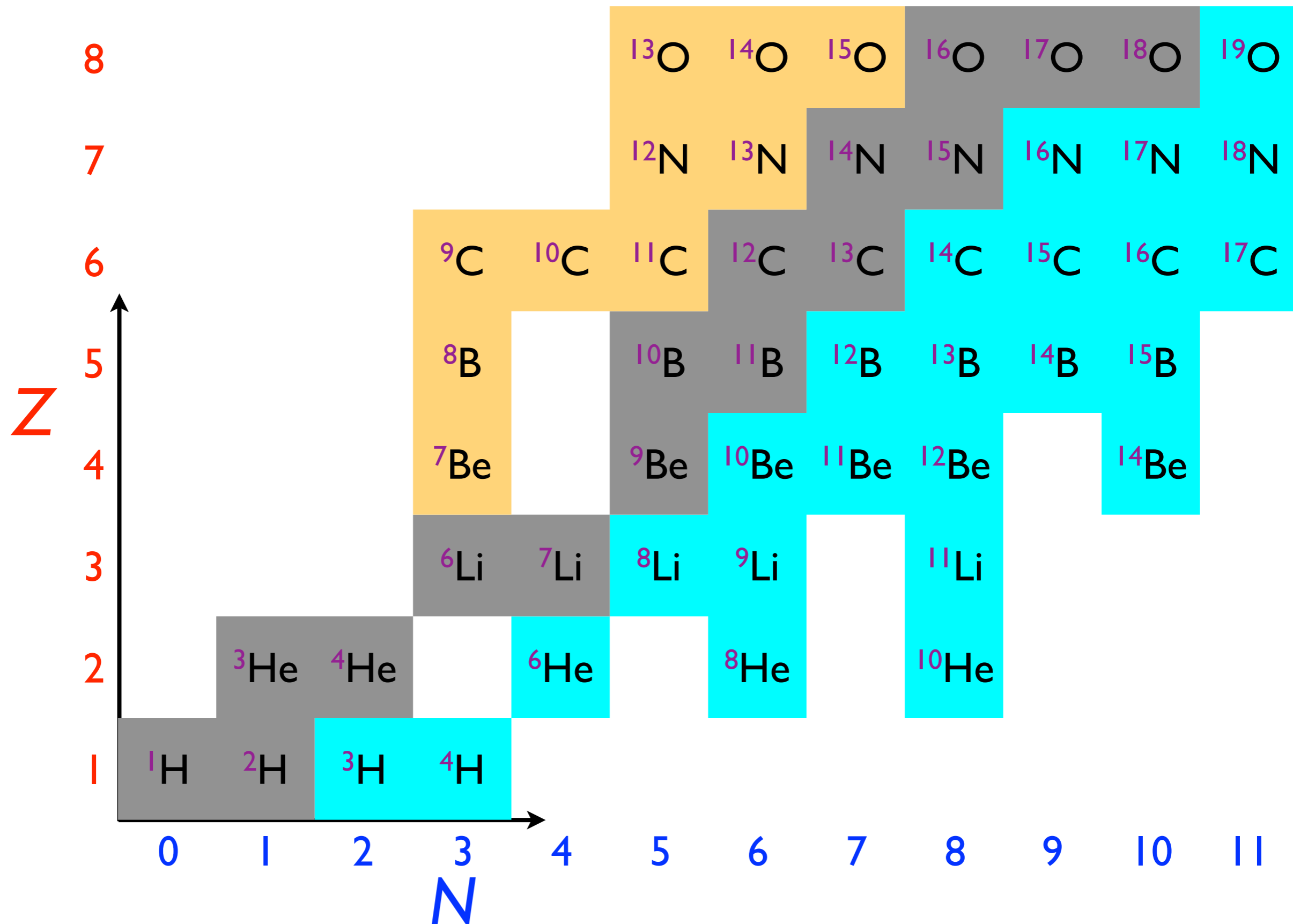


example:  
Carbon



← radioisotopes (unstable)      stable isotopes (infinite lifetimes)      radioisotopes (unstable) →

# Nuclear chart





# Nuclear Science

**Nuclear Science** is the study of the structure, properties, and interactions of the atomic nuclei. Nuclear scientists calculate and measure the masses, shapes, sizes, and decays of nuclei at rest and in collisions. They ask questions, such as "Why do nucleons stay in the nucleus? What combinations of protons and neutrons are possible? What happens when nuclei are compressed or rapidly cooled? What is the origin of the nuclei found on Earth?"

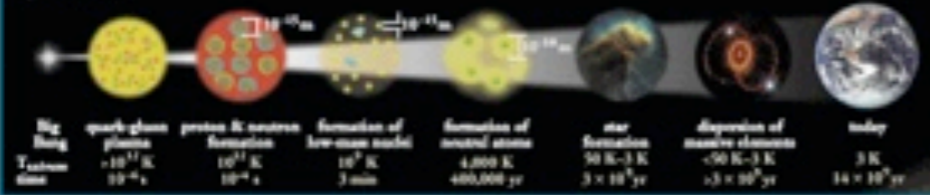
**Legend**

- electron ( $e^-$ )
- quark
- photon ( $\gamma$ )
- proton ( $p^+$ )
- positron ( $e^+$ )
- gluon field
- neutrino ( $\nu$ )
- gluon
- antineutrino ( $\bar{\nu}$ )
- photon ( $\gamma$ )

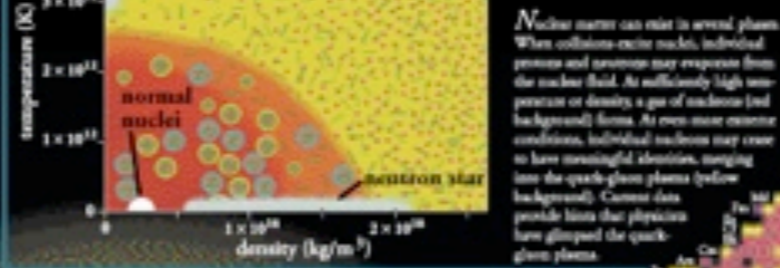
$A_{max} = 118$   
 $Z_{max} = 118$   
 $N_{max} = A - Z$

## Expansion of the Universe

After the Big Bang, the universe expanded and cooled. At about  $10^{-35}$  second, the universe consisted of a soup of quarks, gluons, electrons, and neutrinos. When the temperature of the Universe,  $T_{univ}$ , cooled to about  $10^9$  K, this soup condensed into protons, neutrons, and electrons. As time progressed, some of the protons and neutrons formed deuterium, helium, and lithium nuclei. Still later, electrons combined with protons and these low-mass nuclei to form neutral atoms. Due to gravity, clouds of atoms condensed into stars, where hydrogen and helium fused into more massive chemical elements. Expanding stars (supernovae) from the most massive elements and disperse them into space. Our earth was formed from supernova debris.



## Phases of Nuclear Matter



## Unstable Nuclei

Stable nuclei form a narrow white band on the Chart of the Nuclides. Scientists produce unstable nuclei for from this band and study their decays, thereby learning about the extremes of nuclear conditions. In its present form, this chart contains about 2500 different nuclides. Nuclear theory predicts that there are at least 4000 more to be discovered with  $Z \leq 112$ .

Scientists first synthesized Element 112 in a particle accelerator experiment. They identified it by observing its characteristic alpha particle decay chain.

## Radioactivity

**Alpha Decay:**  $^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th} + ^4_2\text{He}$

**Beta Minus Decay:**  $^{14}_6\text{C} \rightarrow ^{14}_7\text{N} + e^- + \bar{\nu}_e$

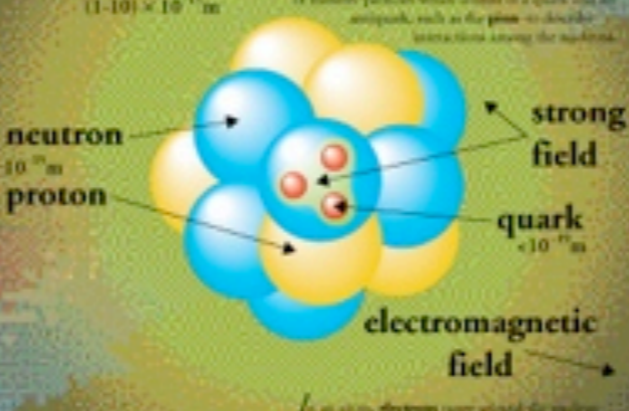
**Beta Plus Decay:**  $^{11}_6\text{C} \rightarrow ^{11}_5\text{B} + e^+ + \nu_e$

**Gamma Decay:**  $^{60}_{27}\text{Co} \rightarrow ^{60}_{27}\text{Co} + \gamma$

Radioactive decay transforms a nucleus by emitting different particles. In alpha decay, the nucleus releases a  $^4_2\text{He}$  nucleus—an alpha particle. In beta decay, the nucleus either emits an electron and antineutrino for a proton and neutrino or captures an atomic electron and emits a positron and antineutrino. Antineutrino is composed of anti-particles. Both alpha and beta decays change the original nucleus into a nucleus of a different chemical element. In gamma decay, the nucleus lowers its internal energy by emitting a photon—a gamma ray. This decay does not modify the chemical properties of the atom.

## The Nucleus

$(1-10) \times 10^{-17}\text{m}$



As the source of the element's name, helium from nucleons—protons and neutrons. Each nucleon is made from three quarks held together by gluon strong interactions, which are mediated by gluons. In turn, the nucleus is held together by the strong interaction between the protons and neutrons themselves. Nuclear physicists often use the term "strong field" to describe the interactions among the nucleons.

In an alpha emission event, the nucleus of uranium ( $^{238}_{92}\text{U}$ ) loses the nucleus of helium ( $^4_2\text{He}$ ) and the nucleus of thorium ( $^{234}_{90}\text{Th}$ ) is left behind.

## Nuclear Energy

**Fission:**  $^{235}_{92}\text{U} + n \rightarrow ^{141}_{54}\text{Xe} + ^{90}_{38}\text{Sr} + 2n$

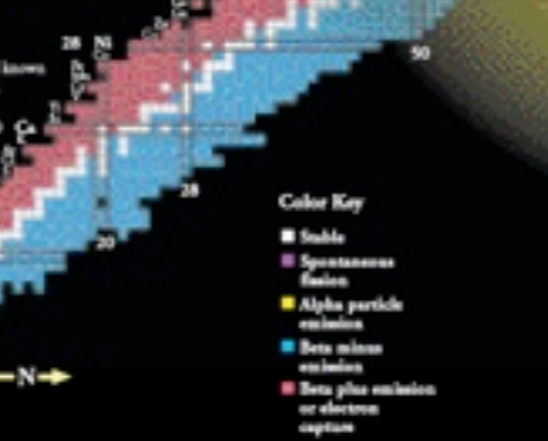
**Fusion:**  $^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + n$

**Sun:** photon

In the early stages of nuclear evolution, our sun and other stars, hydrogen fuses to form helium, releasing energy in the form of photons (light) and neutrinos. During the later stages of nuclear evolution, more massive nuclei up to and beyond uranium are synthesized by fusion. By measuring the number of reactions that come from the Sun, scientists recently have demonstrated that reactions must have a mass greater than zero.

## Chart of the Nuclides

The Chart of the Nuclides presents in graphic form all known nuclei with atomic number, Z, and neutron number, N. Each nuclide is represented by a box colored according to its predominant decay mode. Magic numbers (2, 8, 20, 28, 50, 82 and 126) are indicated by a rectangle on the chart. They correspond to major shell gaps and show regions of greater nuclear binding energy.



## Applications

**Radioactive Dating:** Nearly every radioactive isotope such as  $^{14}\text{C}$  is used to date objects that were once living, such as wood. For example, from a study of carbon found at the site, scientists determined that Pompeii was built nearly 4,000 years ago.

**Smoke Detectors:** Many smoke detectors use a small amount of the alpha emitter  $^{241}\text{Am}$  to ionize the air. Smoke entering the detector reduces the current and sets off the alarm.

**Nuclear Medicine:** Radioactive isotopes, such as  $^{201}\text{Tl}$ ,  $^{99\text{m}}\text{Tc}$ , and  $^{131}\text{I}$ , are commonly used in the diagnosis and treatment of disease. Positron emission tomography (PET) is a common use of beta emitters.

**Space Exploration:** Uranium and alpha particles in naturally occurring uranium present in Martian rocks. On Earth, nuclear reactors are used in many ways from electrical power generation to an orbiter.

**Nuclear Reactors:** Nuclear reactors are the source of  $^{235}\text{U}$  or  $^{239}\text{Pu}$  nuclei to produce electric power. Reactors and other nuclear applications generate radioactive waste, disposal of the waste is a subject of current research.

**Magnetic Resonance Imaging:** Magnetic Resonance Imaging (MRI) utilizes use of atomic transitions involving the magnetic field of a nucleus to study the local chemical environment. This technique accurately maps the density of hydrogen to produce three-dimensional images of the human body.

www.CPEPweb.org



# Number of nuclides

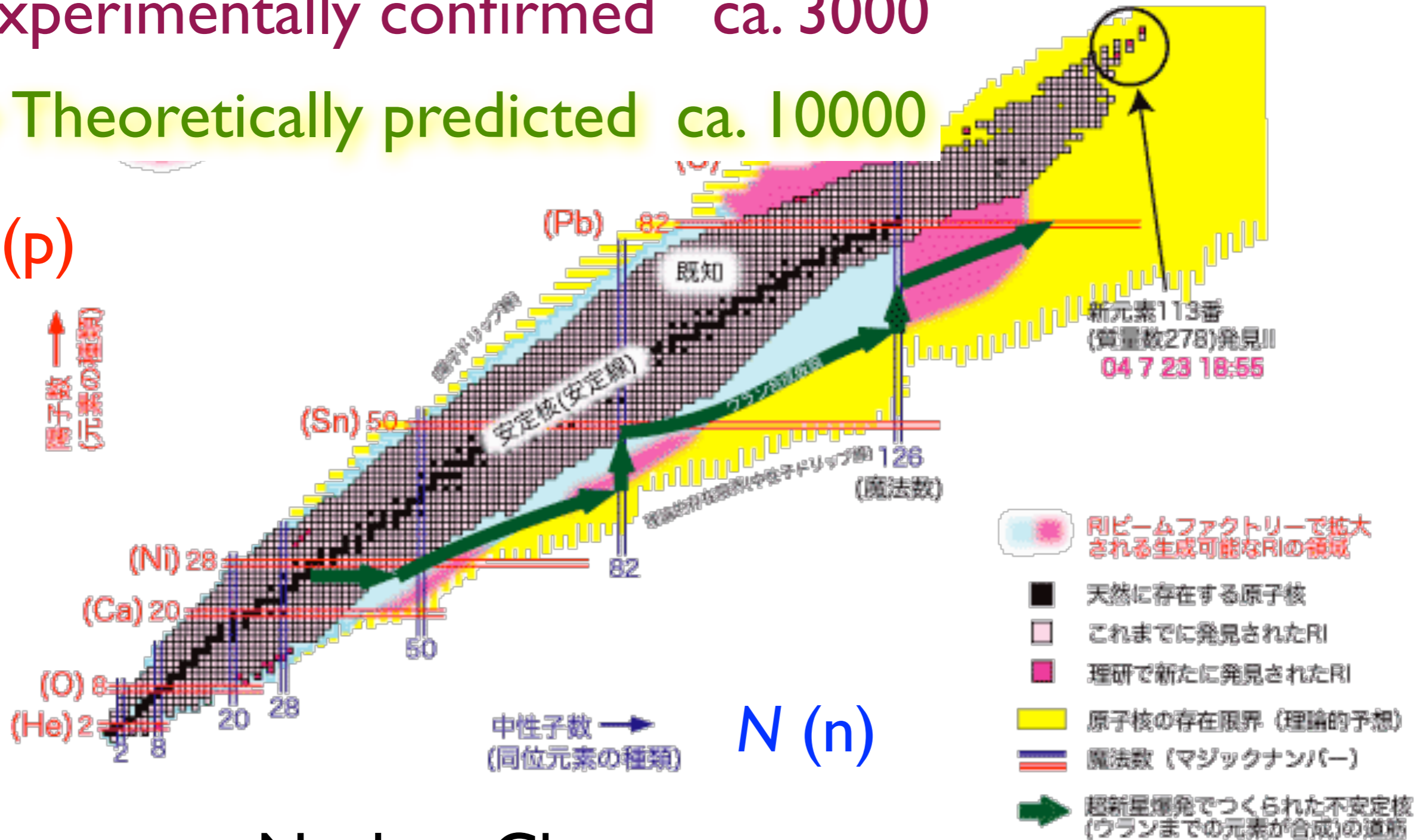
# Nuclear Physics

Stable nuclides ca. 300 species

Experimentally confirmed ca. 3000

+ Theoretically predicted ca. 10000

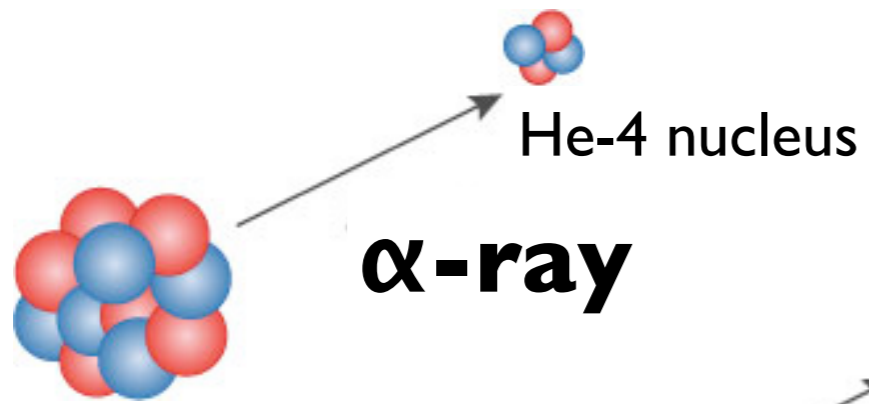
$Z (p)$



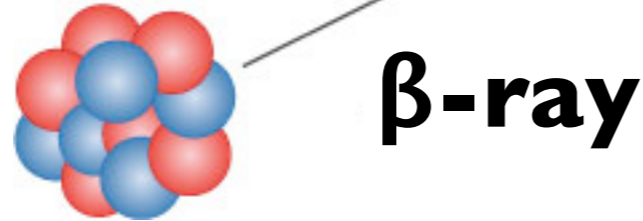
## Nuclear Chart



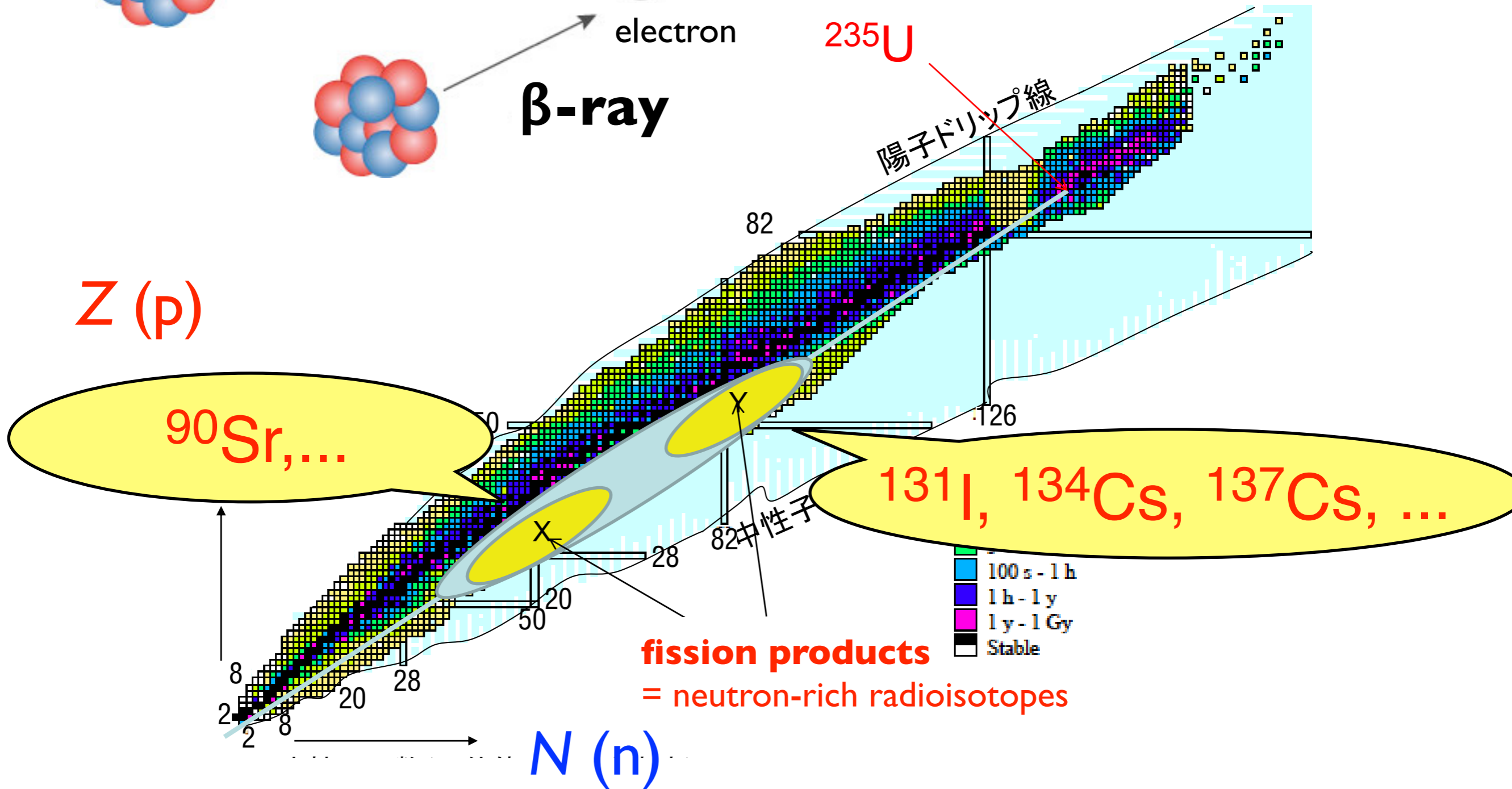
**Radioactivity** is the ability of radioactive materials to emit radiation



$\alpha$ -ray



$\beta$ -ray



Nuclear Chart

Upto 50 million terabecquerels (TBq) of iodine-131 has been released from the Fukushima NPP (nuclear power plant) and scattered all over East Japan.

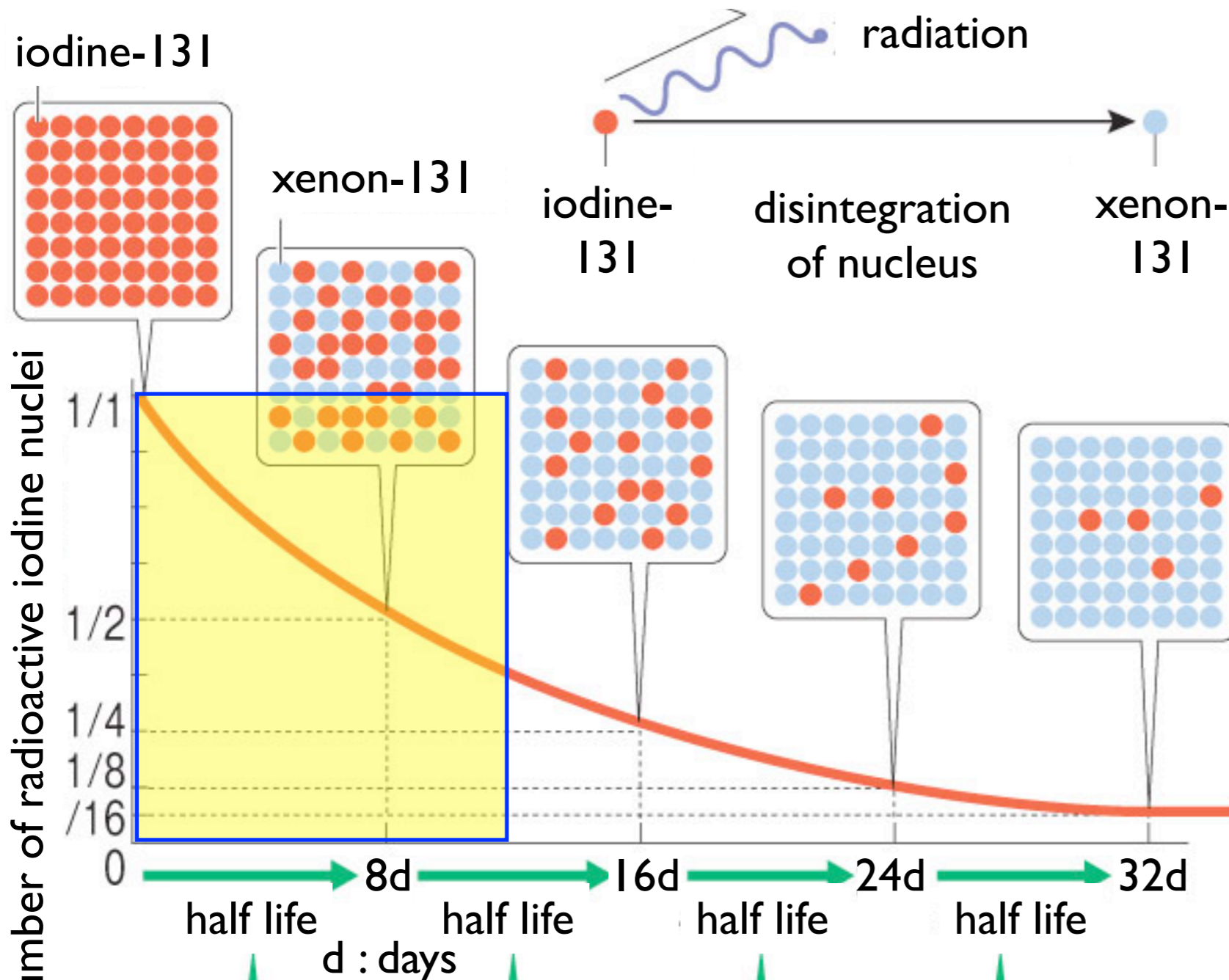
What is the total mass of the radioactive iodine-131 ?

Roughly 100 tons / 100 kg / 100 g / 100 mg ??



What is the total mass of the radioactive iodine-131 ?  
Roughly 100 tons / 100 kg / 100 g / 100 mg ??

### Half life of radioactive materials (iodine-131)



Radioactivity is reduced by half for each half-life period.

# Various types of radiation





Billet de 500 Francs Français en circulation: 1993–1999



- $\alpha$ -ray** helium nucleus
- $\beta$ -ray** electron
- $\gamma$ -ray** photon (EM wave)
- X-ray** photon (EM wave)



**VIDEO**

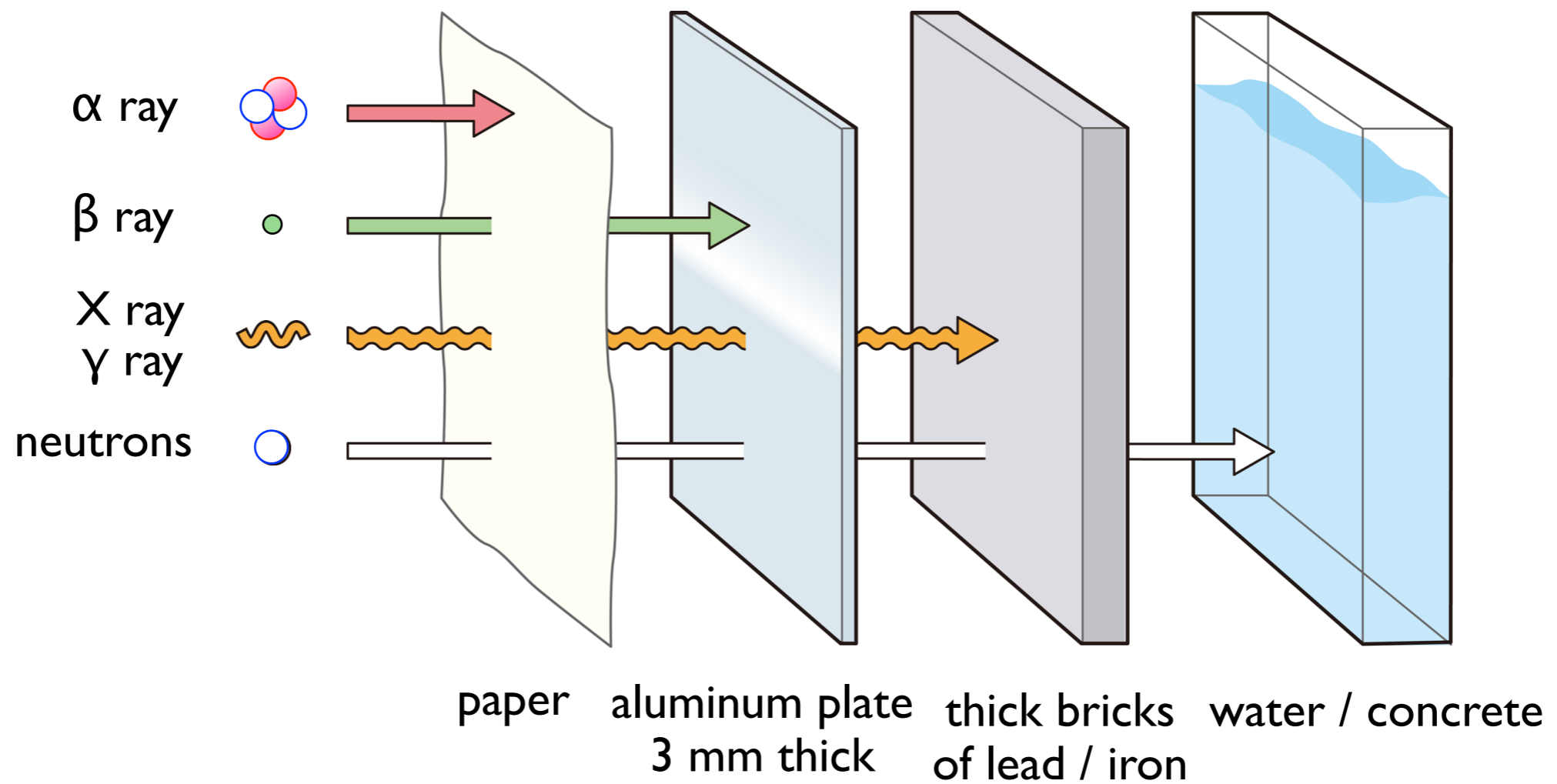
# **Introduction to Radiation**

日本原子力文化振興財団：エネコチャンネルのビデオ映像「探検！身近な放射線」より抜粋

<http://eneco.jaero.or.jp/20110322/>



# Penetration of radiation



# **Interaction between Radiation and matter**

**Slowing-down of charged particles**



# Energy loss of charged particles

electric charge:  
**Coulomb  
force**

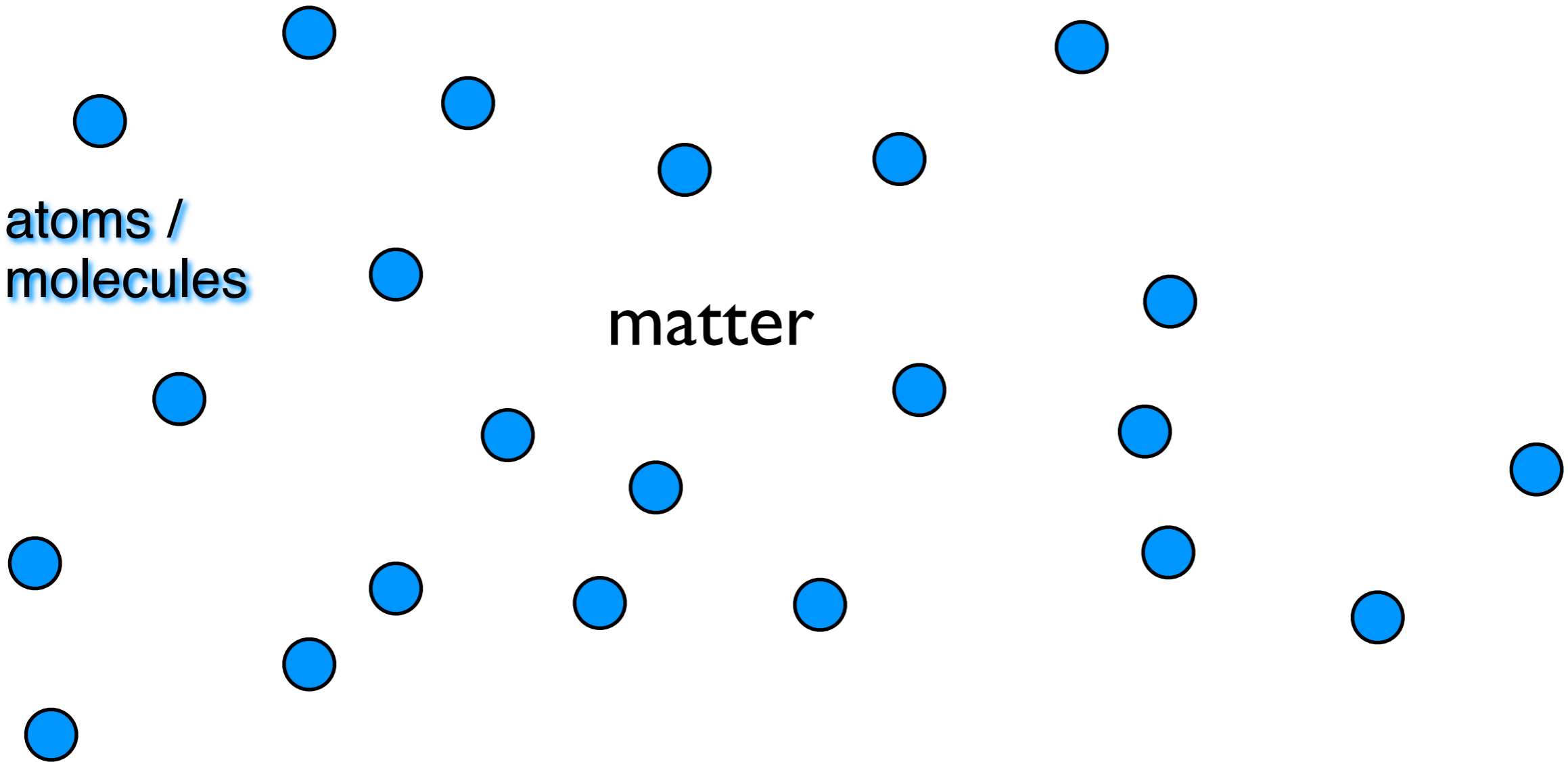
Kinetic energy of the particle is transferred to electrons through **ionization** or **excitation** of atoms and molecules in the matter.

The particle loses its energy and is slowed down.

**Stopping power** =  $-dE / dx$

atoms /  
molecules

matter



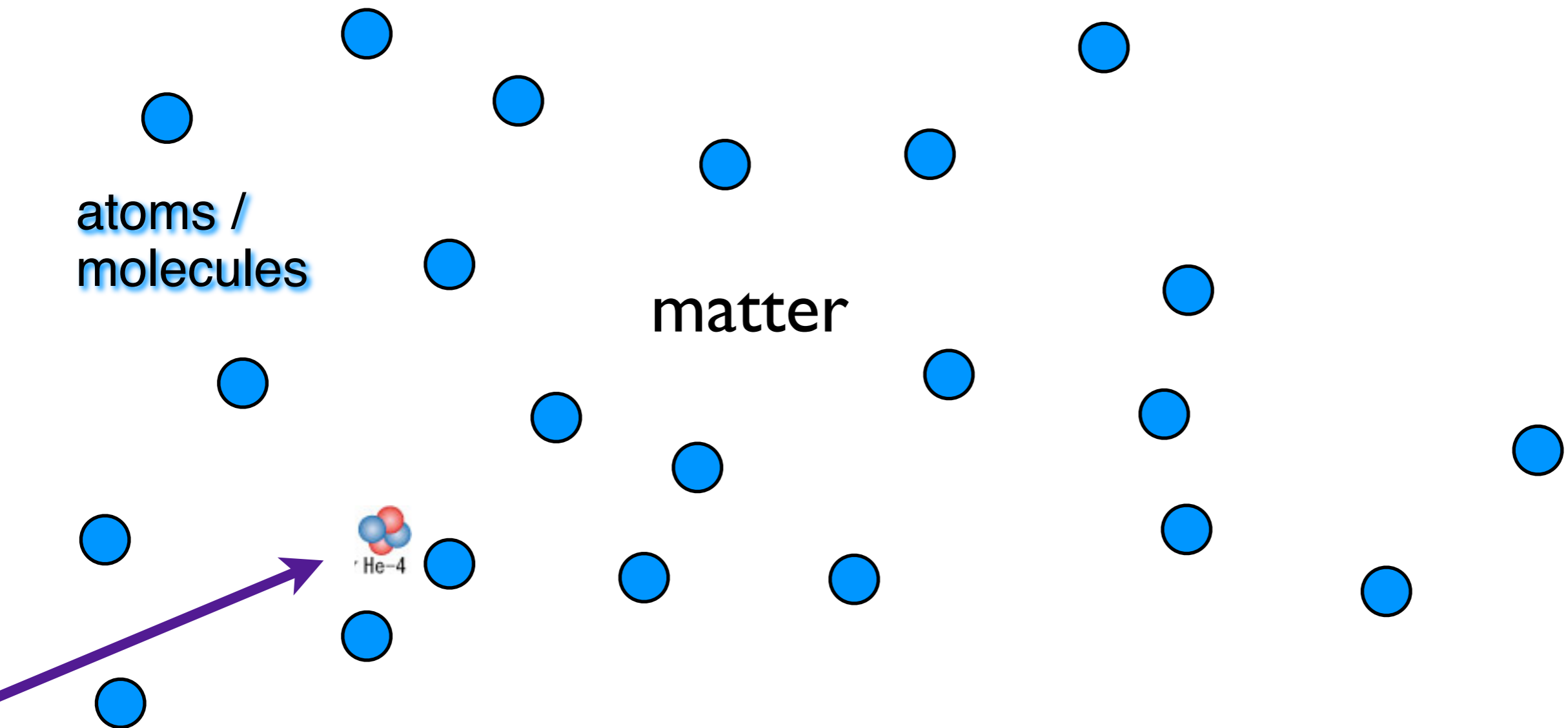
# Energy loss of charged particles

electric charge:  
**Coulomb  
force**

Kinetic energy of the particle is transferred to electrons through **ionization** or **excitation** of atoms and molecules in the matter.

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**Stopping power** =  $-dE / dx$





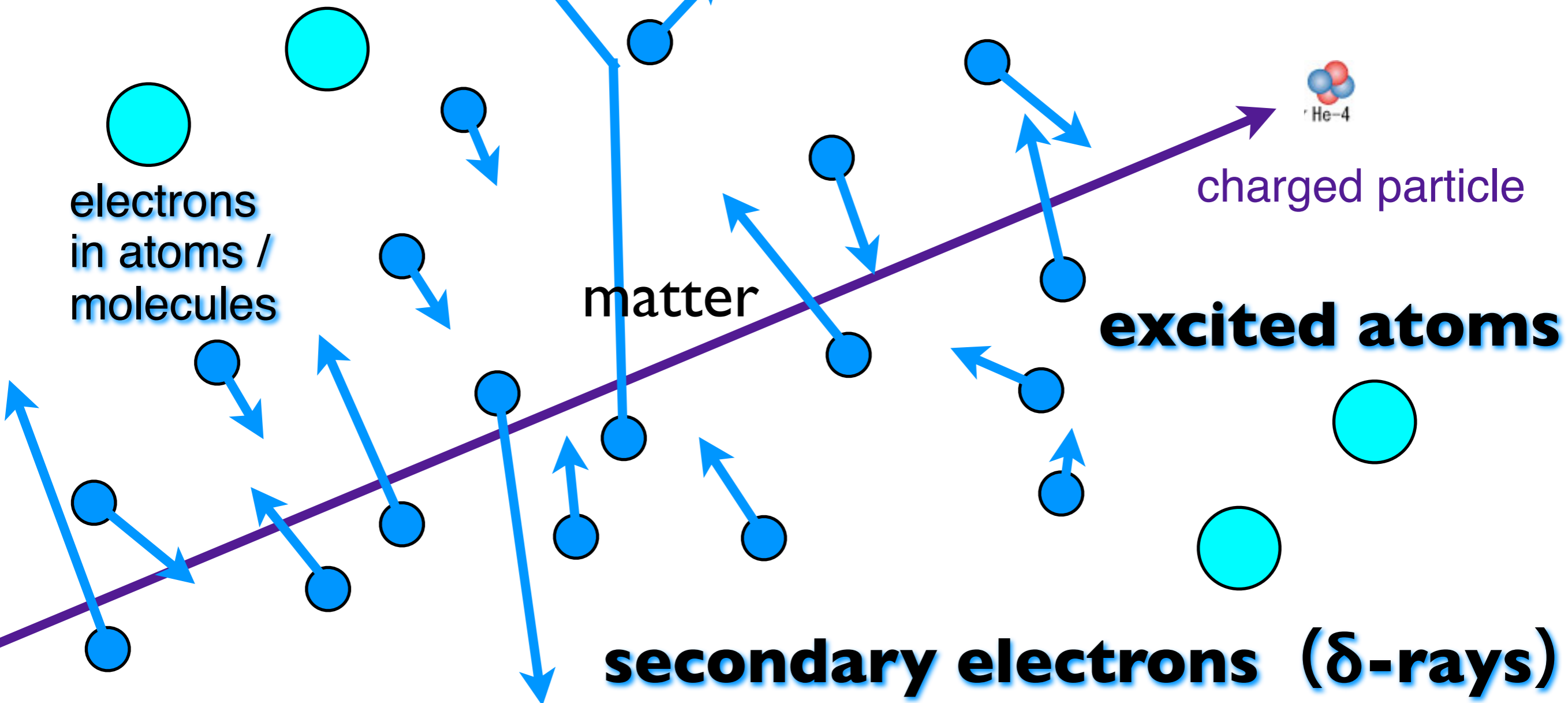
# Energy loss of charged particles

electric charge:  
**Coulomb force**

Kinetic energy of the particle is transferred to electrons through **ionization** or **excitation** of atoms and molecules in the matter.

The particle loses its energy and is slowed down.

$$\text{Stopping power} = -dE / dx$$



# Along the track after passage of charged particles

**Ions** and **excited atoms** are produced, while energetic **secondary electrons** can ionize other atoms. **X-rays** are emitted after atomic **recombination** or **deexcitation**.

**excited atoms**

**X-ray**

**Recombination**

**deexcitation**

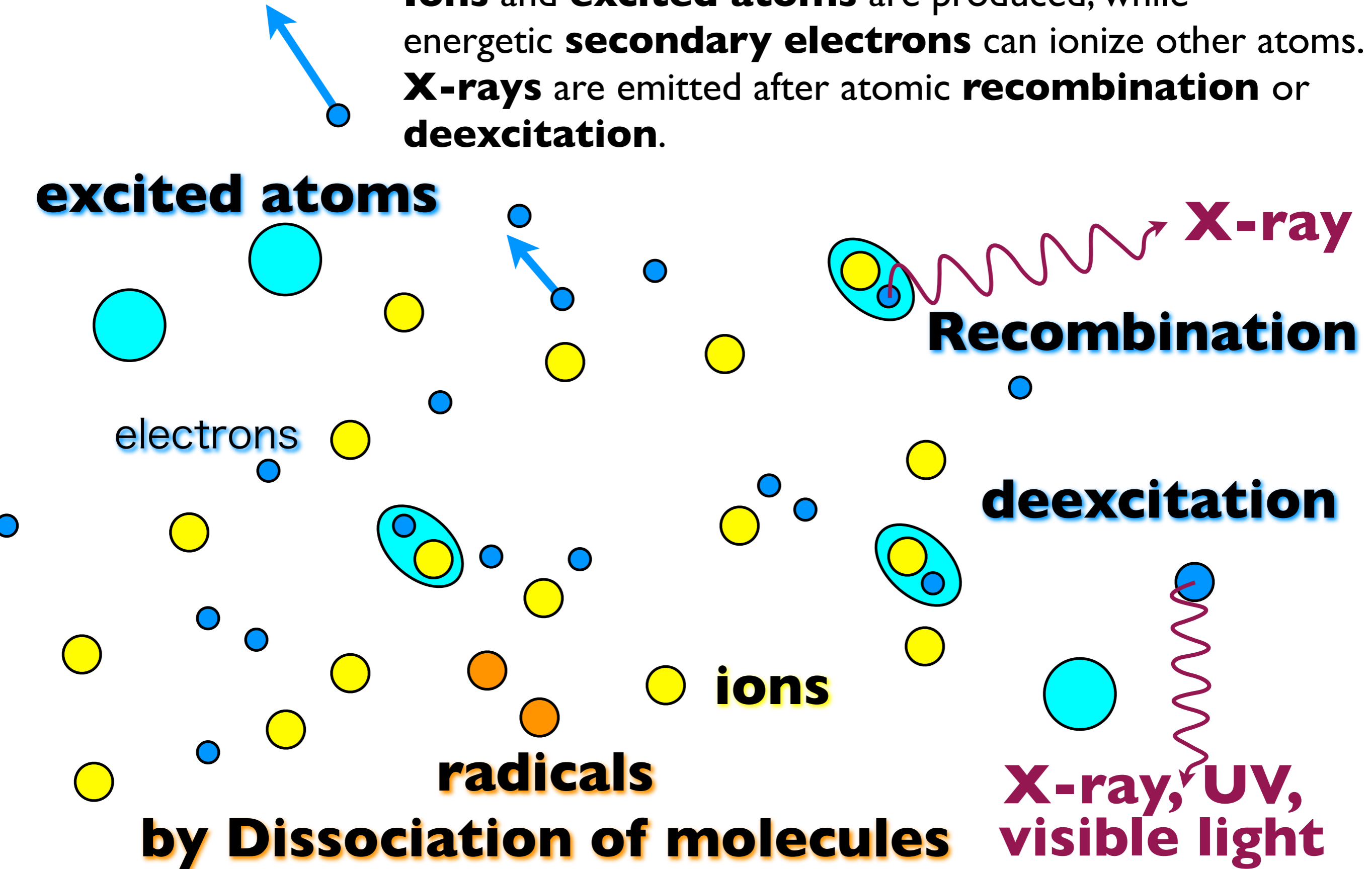
**X-ray, UV,  
visible light**

**ions**

**radicals**

**by Dissociation of molecules**

electrons





# **Interaction between Radiation and matter**

## **Attenuation of photons**

## **Slowing-down and energy loss of charged particles ( $\alpha$ ray, $\beta$ ray etc.)**

Step-by-step energy loss due to ionization and excitation of atoms / molecules

**Stopping power** = energy loss per unit length =  $-\left\langle \frac{dE}{dx} \right\rangle$

## **Attenuation of photons (X ray, $\gamma$ ray)**

Stochastic process of photon loss (absorption or scattering), but the rest remains intact thru.

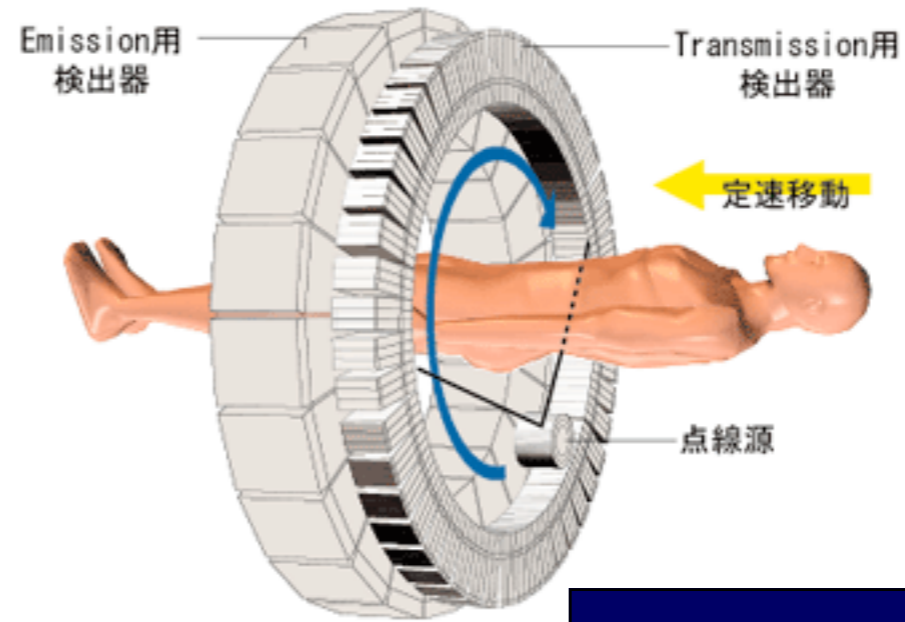
👉 **Exponential decrease of photon number**  
**reaction cross section  $\sigma$**  gives the reaction probability per unit length.



## 胸部単純X線撮影

### 胸部正面像

- ・立位
- ・吸気呼吸停止
- ・管電圧120kVp程度
- ・撮影時間～50ミリ秒
- ・X線投影：背→腹

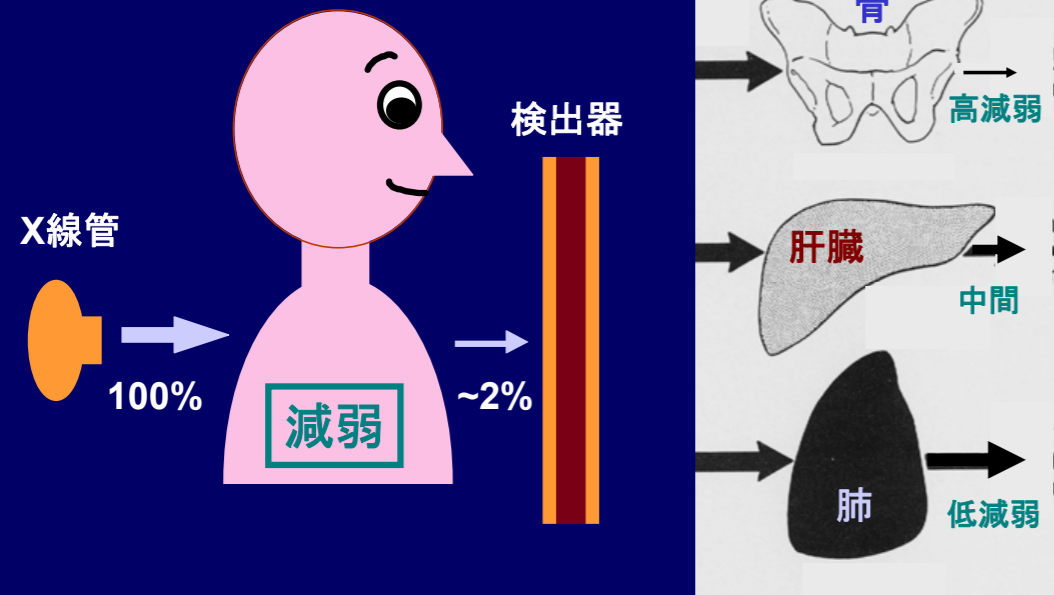
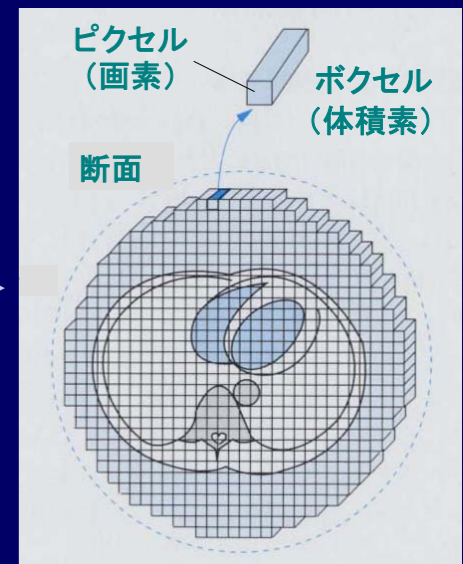
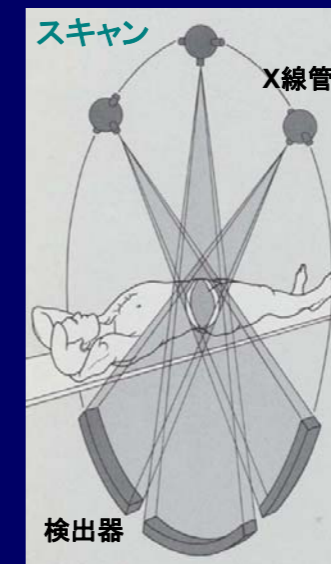


# X-ray CT

# Röntgen radiography

国立循環器病センター 内藤博昭先生のスライドより借用

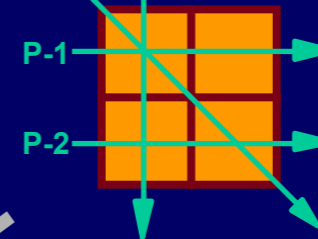
## X線コンピュータ断層撮影法：CT



### 未知の線減弱係数

$\mu_1$	$\mu_2$
$\mu_3$	$\mu_4$

### X線投影



### 連立方程式

- P-1;  $\mu_1 + \mu_2 = 8$
- P-2;  $\mu_3 + \mu_4 = 9$
- P-3;  $\mu_1 + \mu_3 = 6$
- P-4;  $\mu_1 + \mu_4 = 5$

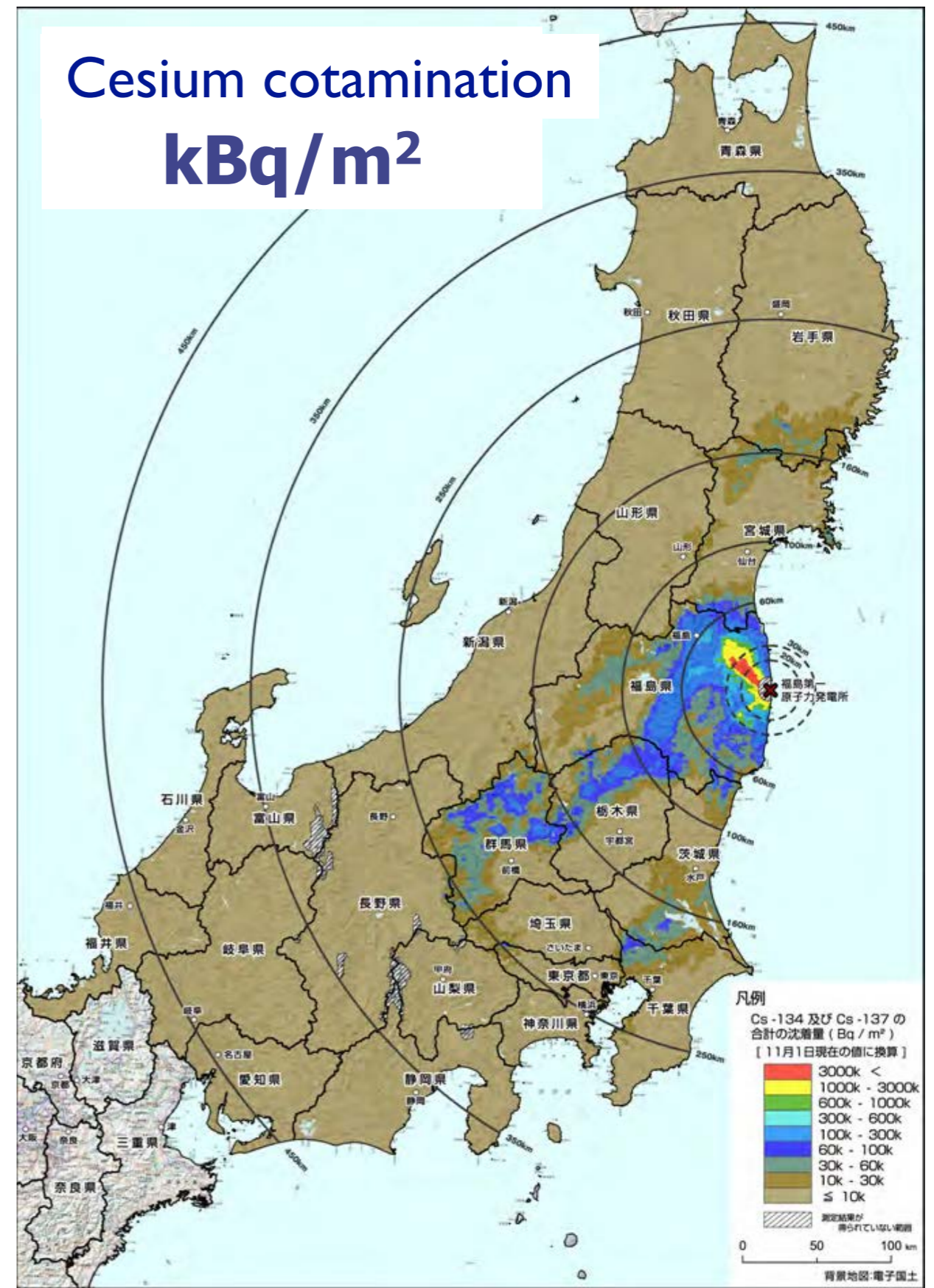
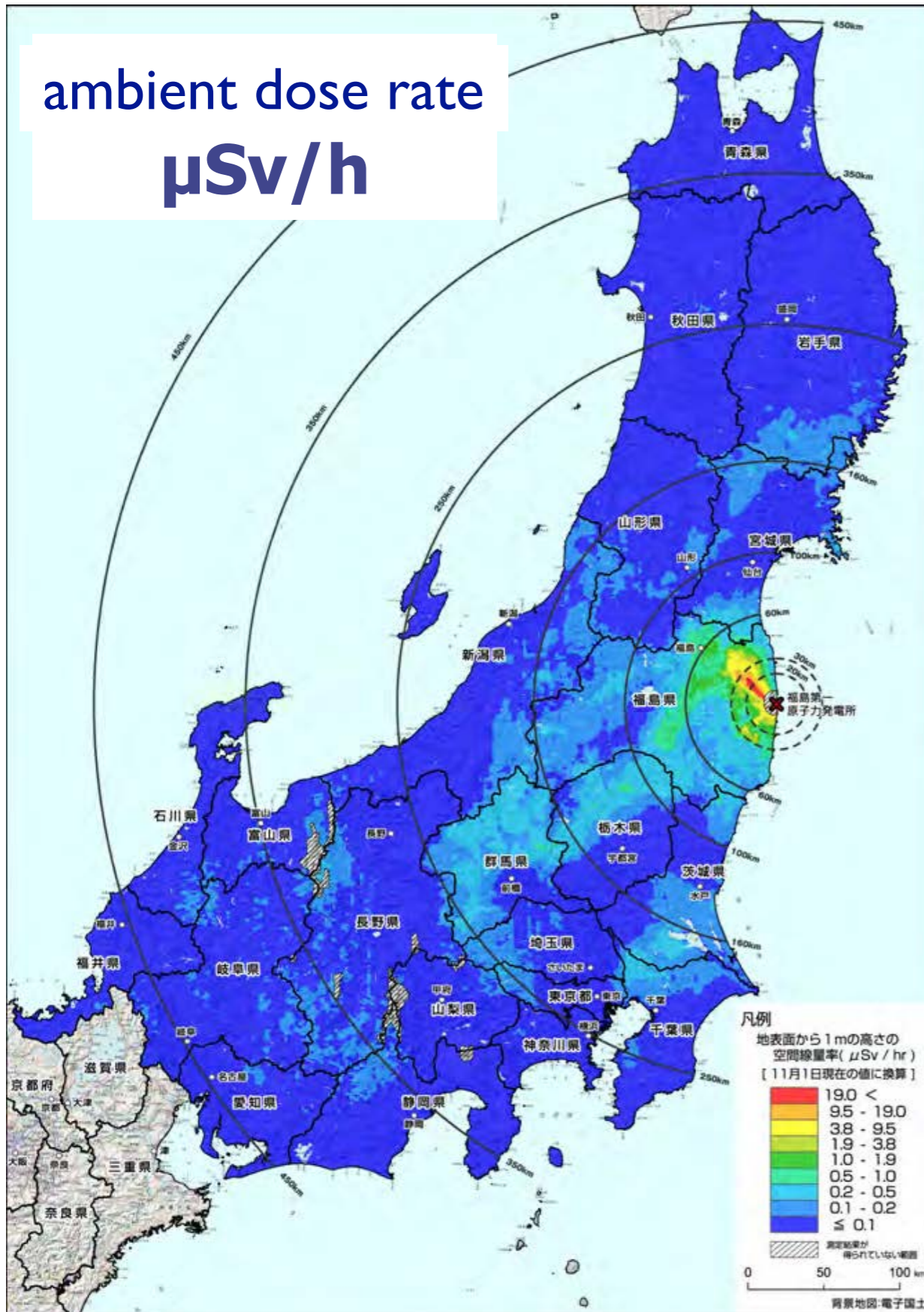
### 解答

1	7
5	4

# Environmental Radiochemistry



# Radioactive contamination map : aerial monitoring by MEXT





# Radioactive contamination map

## 福島第一原発から漏れた放射能の広がり Radiation contour map of the Fukushima Daiichi accident

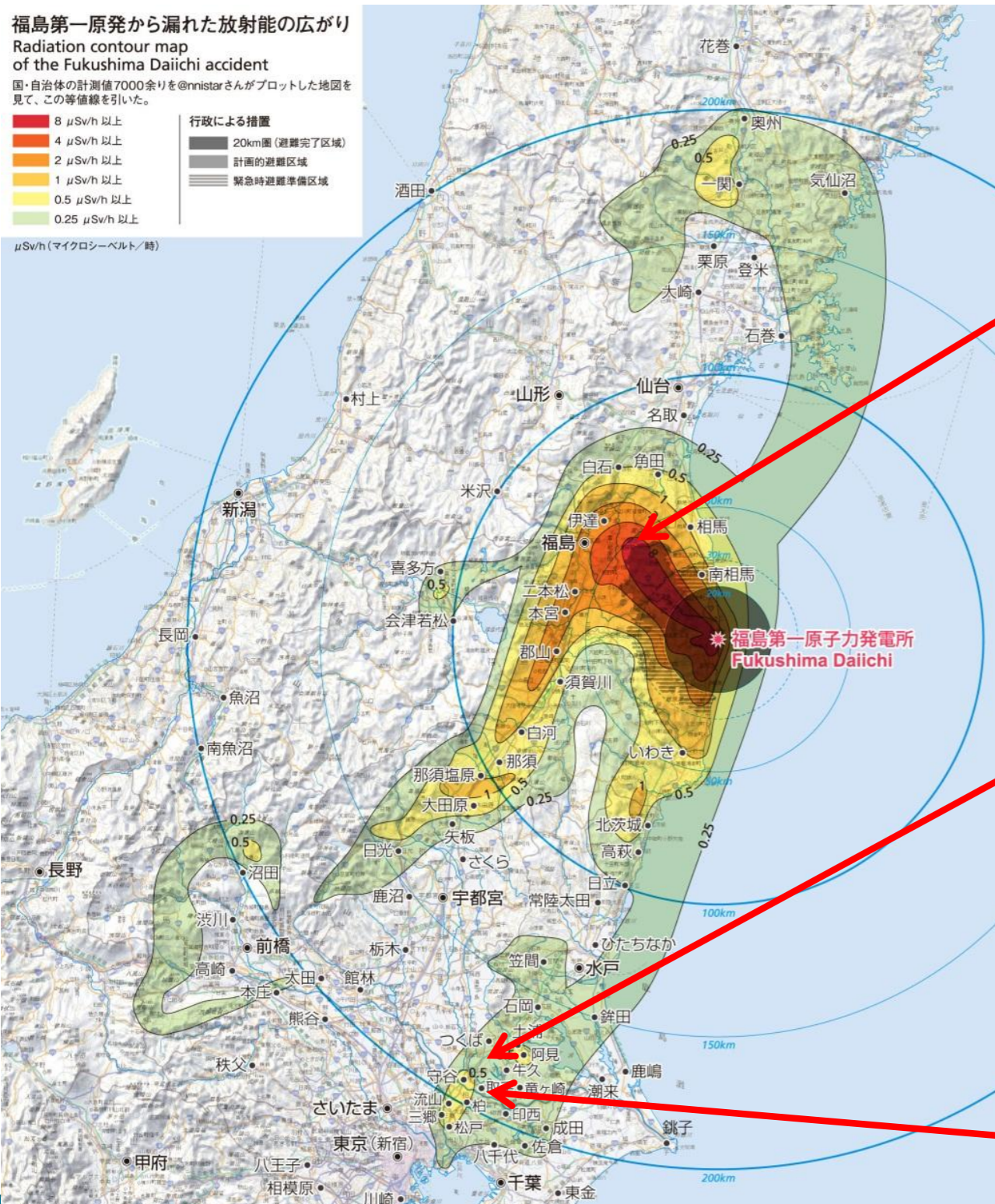
国・自治体の計測値7000余りを@nnistarさんがプロットした地図を見て、この等値線を引いた。

- 8  $\mu\text{Sv/h}$  以上
- 4  $\mu\text{Sv/h}$  以上
- 2  $\mu\text{Sv/h}$  以上
- 1  $\mu\text{Sv/h}$  以上
- 0.5  $\mu\text{Sv/h}$  以上
- 0.25  $\mu\text{Sv/h}$  以上

### 行政による措置

- 20km圏 (避難完了区域)
- 計画的避難区域
- 緊急時避難準備区域

$\mu\text{Sv/h}$  (マイクロシーベルト/時)



早川由紀夫教授(群馬大学)作成、7月26日版

三訂版7月26日(初版4月21日)  
等値線作成: 早川由紀夫(群馬大学) (kipuka.blog70.fc2.com/  
@nnistarさんの地図 (www.nnistar.com/gmap/fukushima.html)  
Contour lines drawn by Yukio Hayakawa (Gunma Univ.),  
Source: @nnistar  
地図製図: 萩原佐知子  
背景地図には電子国土ポータル(portal.cyberjapan.jp)の地図を使用しました。



2011

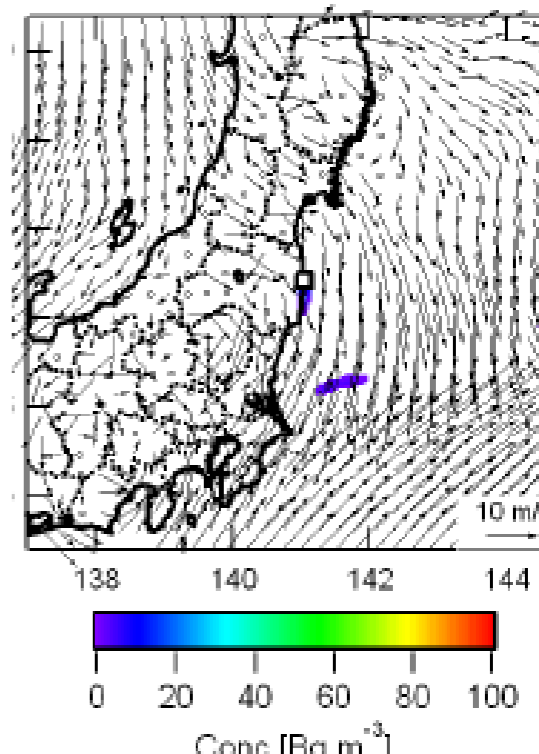
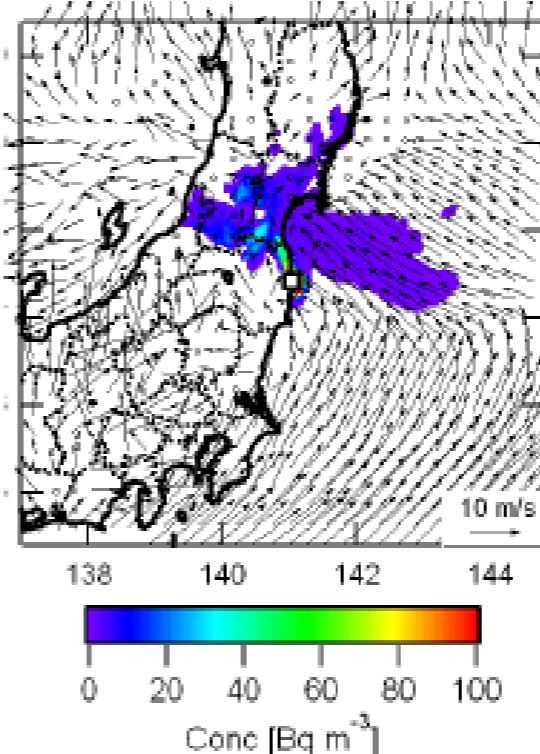
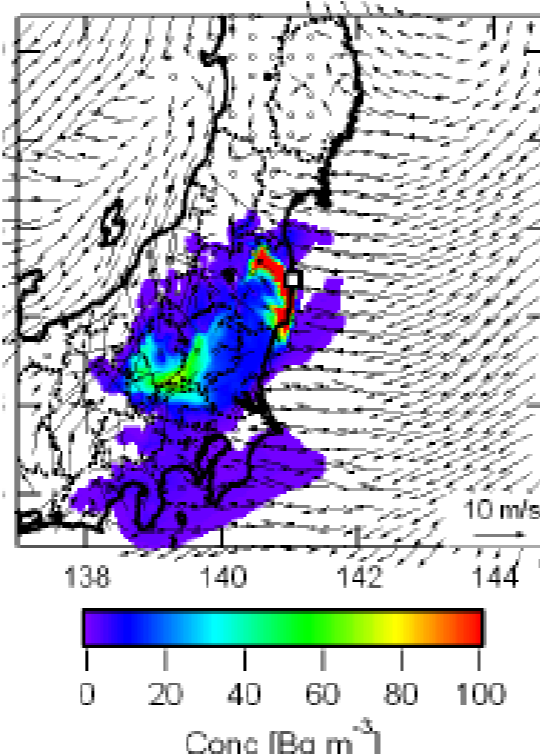
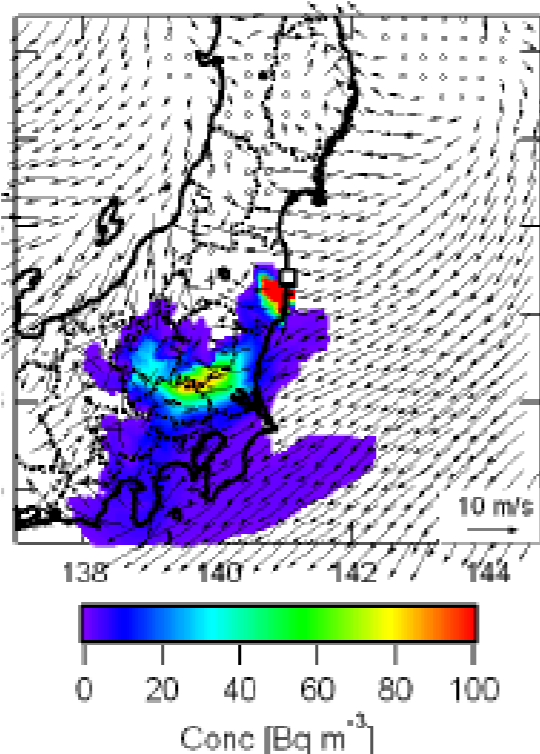
15h, 15th March

19h, 15th March

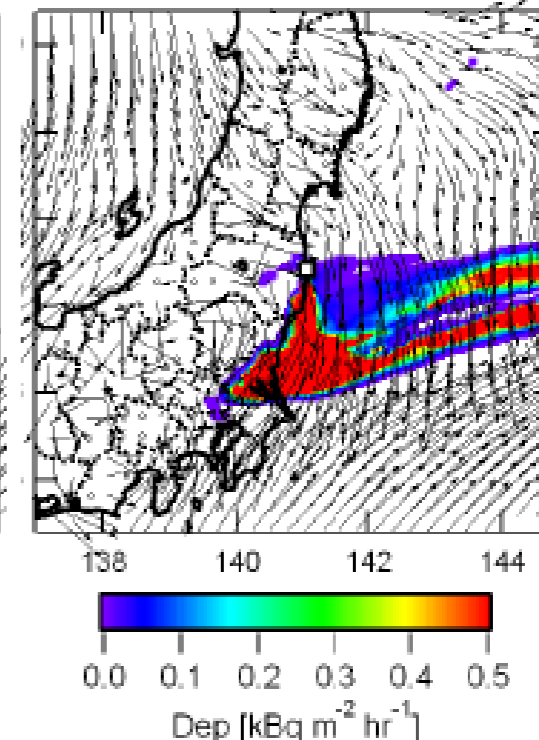
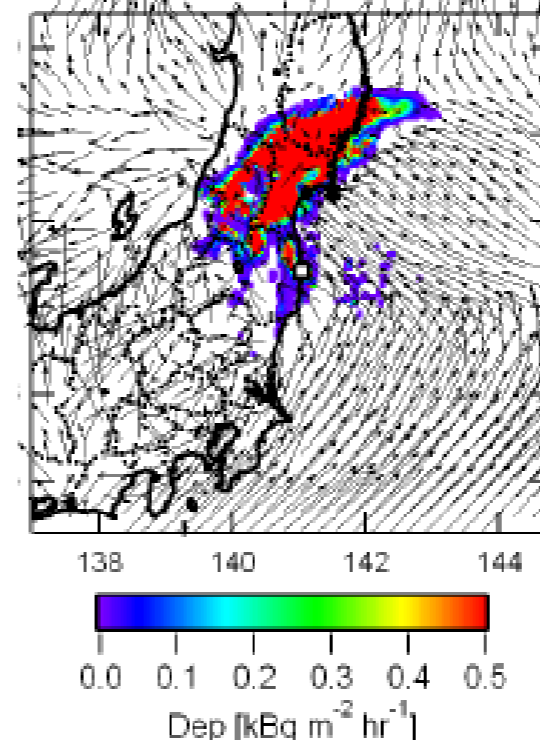
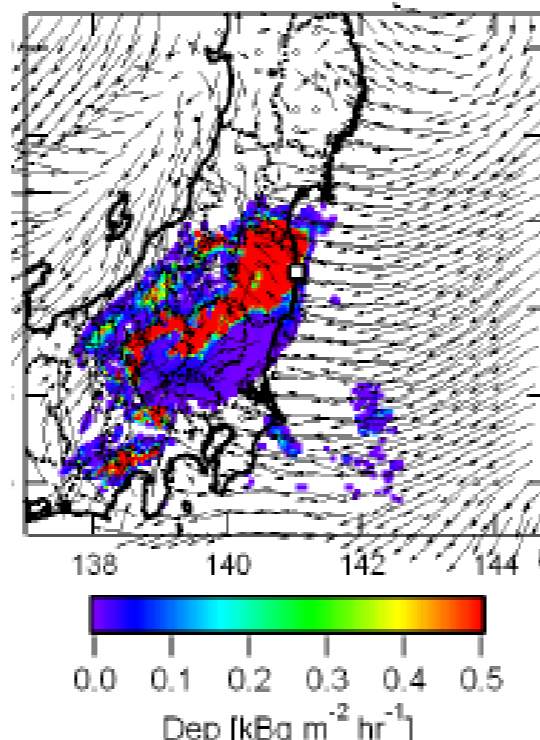
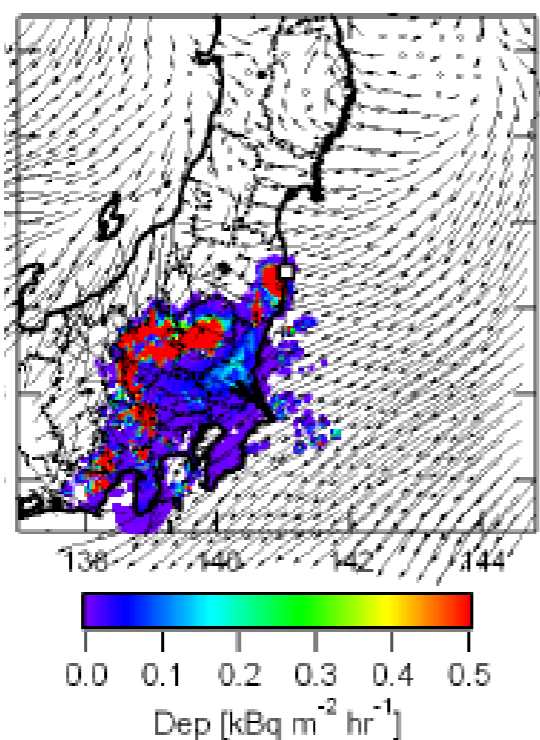
18h, 20th March

8h, 21st March

density  
in the air



fall-out



関東への最初の影響

福島 of 深刻な汚染、  
北関東の汚染

宮城県北部の稲藁汚染

水道水汚染、千葉北西部  
のホットスポット



# Radiation detectors



What does protective clothing protect ?



早川由紀夫教授(群馬大学)作成、7月26日版



三訂版7月26日(初版4月21日)  
等値線作成: 早川由紀夫(群馬大学) (kipuka.blog70.fc2.com/)  
@nnistarさんの地図 (www.nnistar.com/gmap/fukushima.html)  
Contour lines drawn by Yukio Hayakawa (Gunma Univ.),  
Source: @nnistar  
地図製図: 萩原佐知子  
背景地図には電子国土ポータル (portal.cyberjapan.jp) の地図を使用しました。



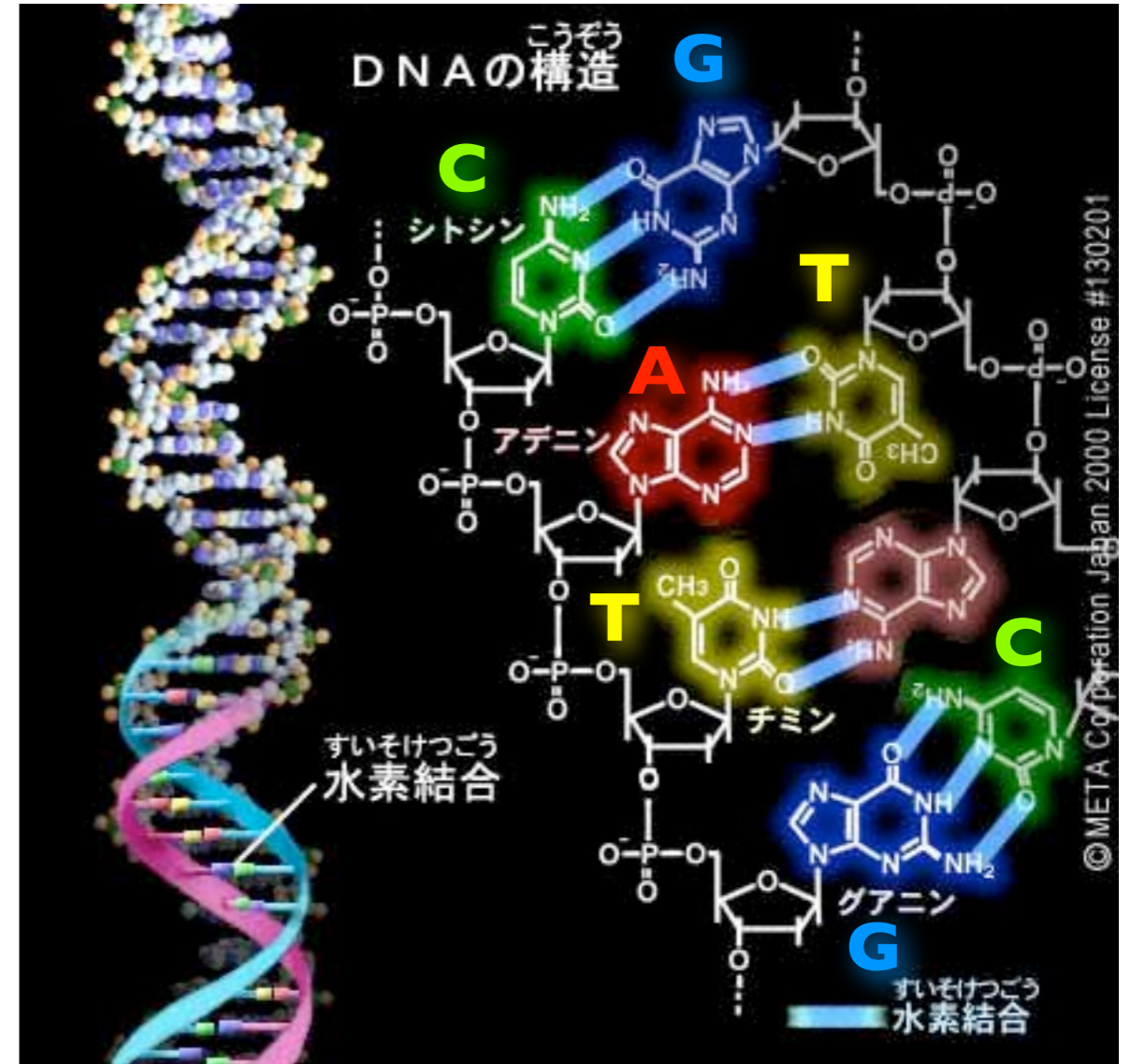
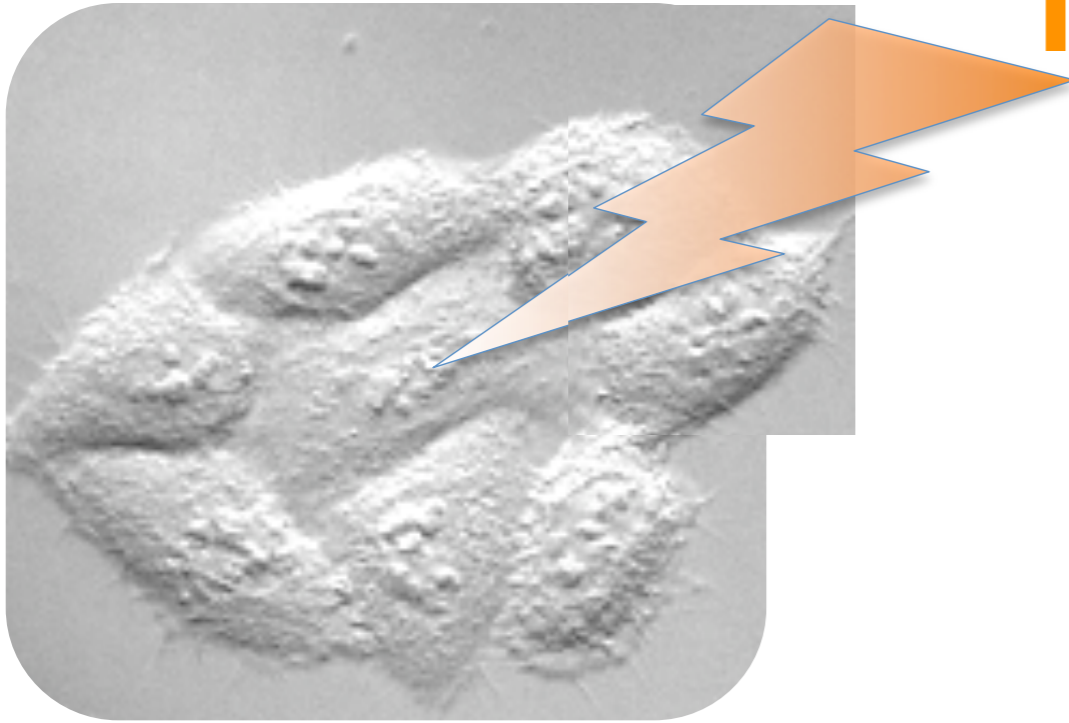


# **Radiation biology**



# irradiation to cell nuclei

## DNA



出典：IPA「教育用画像素材集サイト」 <http://www2.edu.ipa.go.jp/gz/>



A diagram illustrating the hierarchy of genetic material. It starts with a whole cell containing a nucleus. An arrow points from the nucleus to a chromosome, then to a DNA double helix, and finally to the genome. The text '60 trillion cells in a human body' is on the left, and 'genom' is on the right. The word 'DNA' is written in large letters in the center. The caption '図1 核、染色体、遺伝子' (Figure 1: Nucleus, Chromosome, Gene) is at the bottom. The source information '(c) Hironao NUMABE, M.D., D.M.Sc., Kyoto University Graduate School of Medicine' is at the very bottom.

60 trillion cells  
in a human body

chromosome

DNA

genom

図1 核、染色体、遺伝子



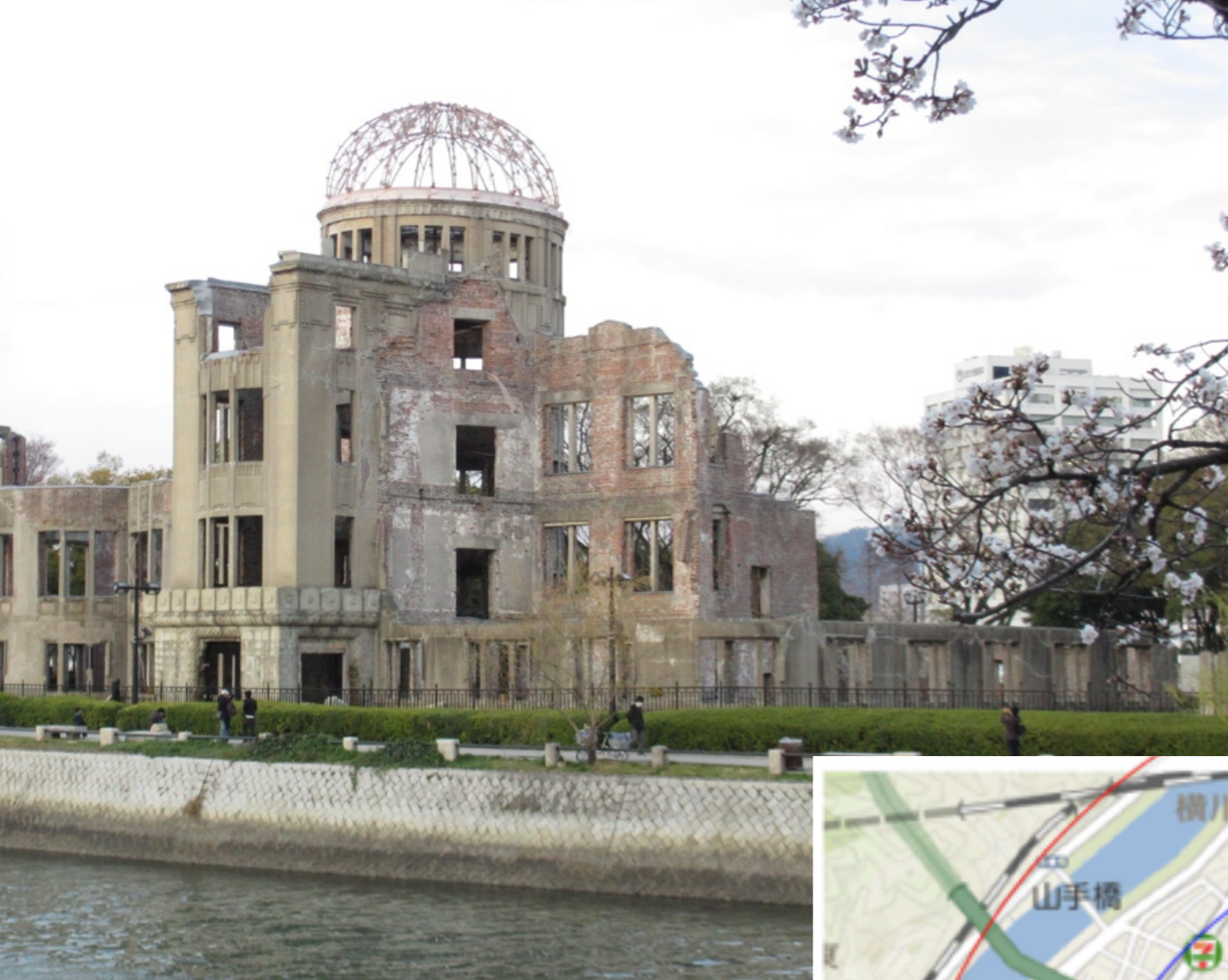
# Atomic Bomb Dome in Hiroshima





# Atomic Bomb Dome in Hiroshima

Estimated dose due to  $\gamma$  rays  
(mGy) **due to neutrons**

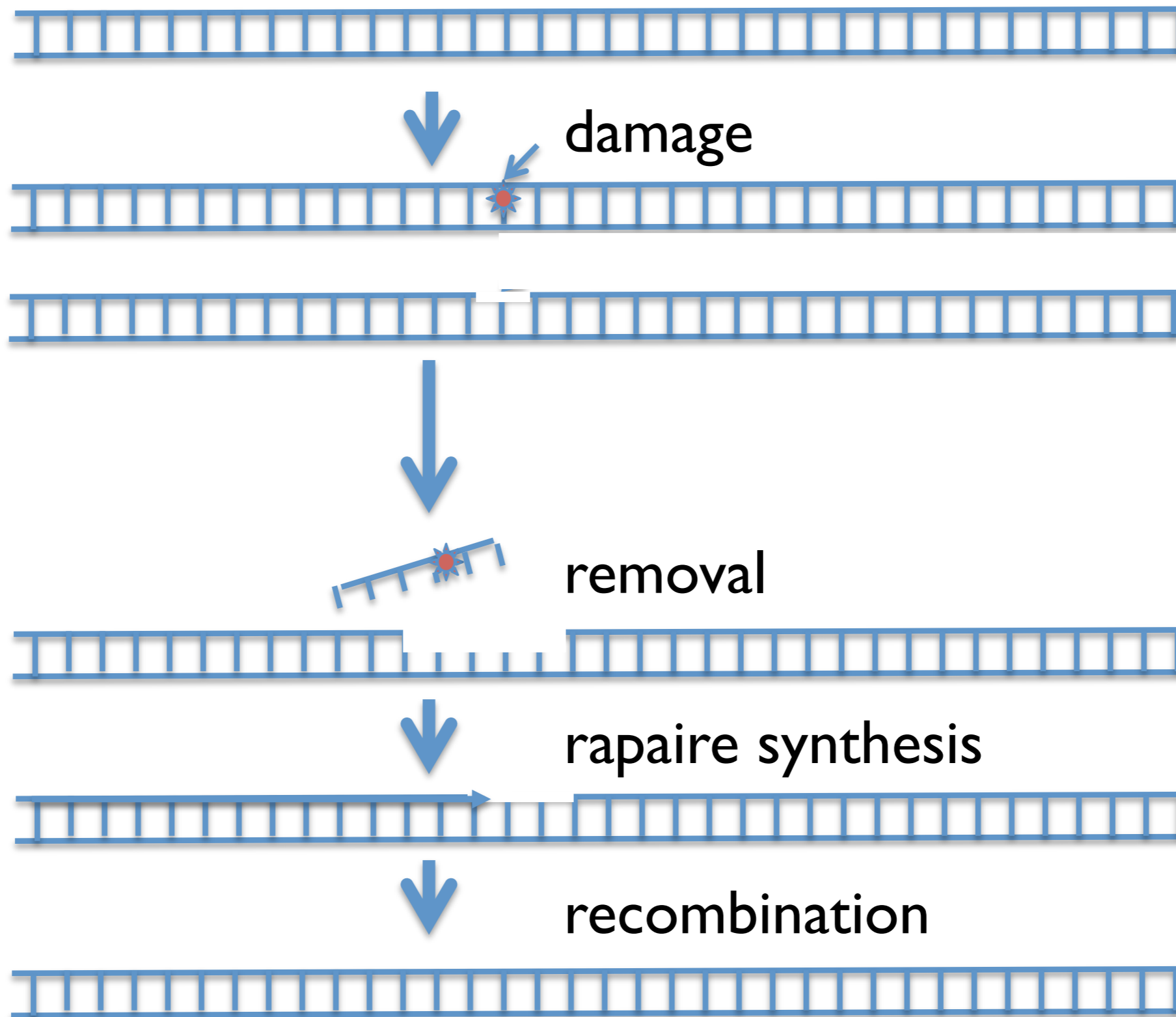


Lethal dose  
= 4 Gy

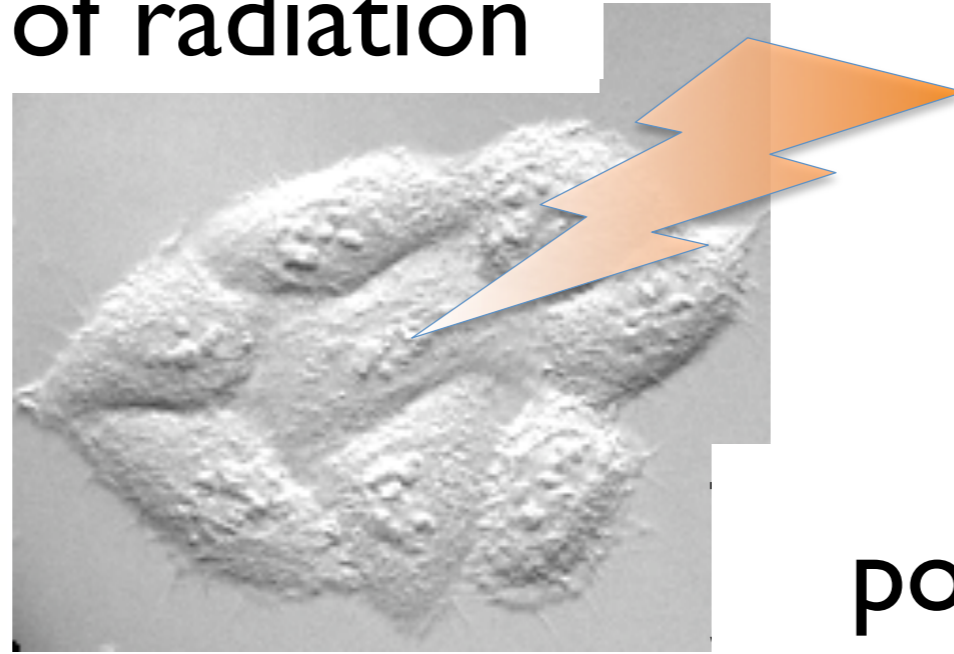
Deterministic effects  
of radiation above  
threshold dose



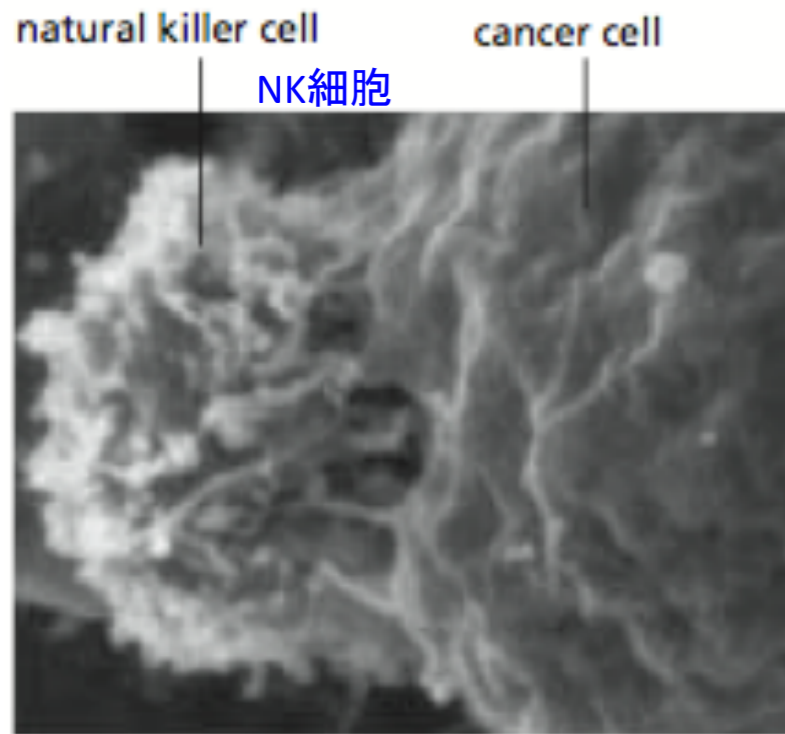
# Examples of repair of DNA damages



# Stochastic effect of radiation



possibility of cancer



**DNA repair**

In rare occasions, DNA repair fails.

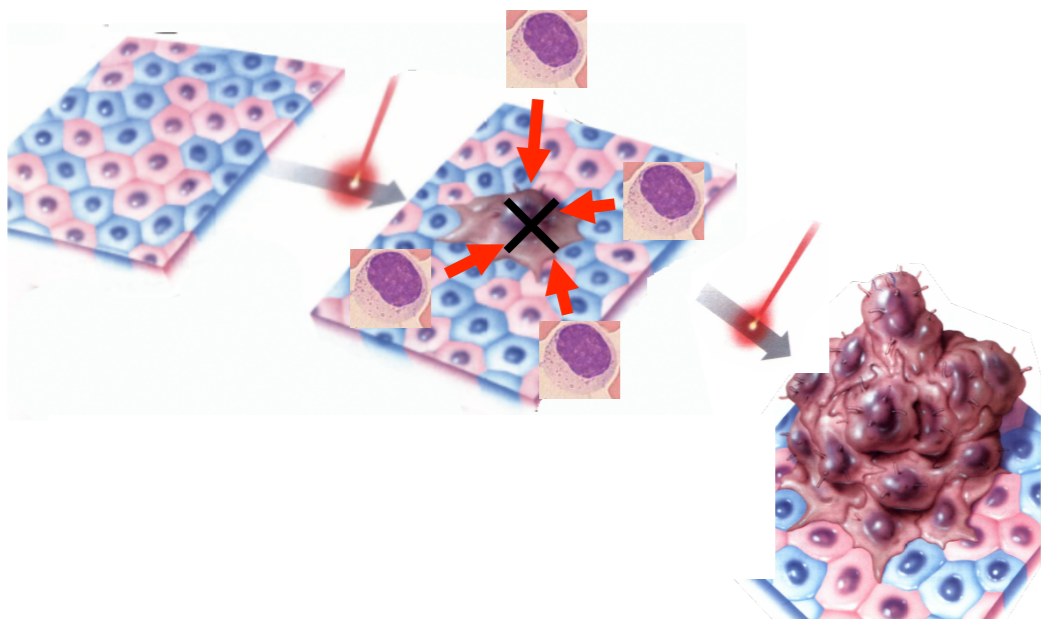
**programmed cell death  
(apoptosis)**

apoptosis mechanism fails to work.

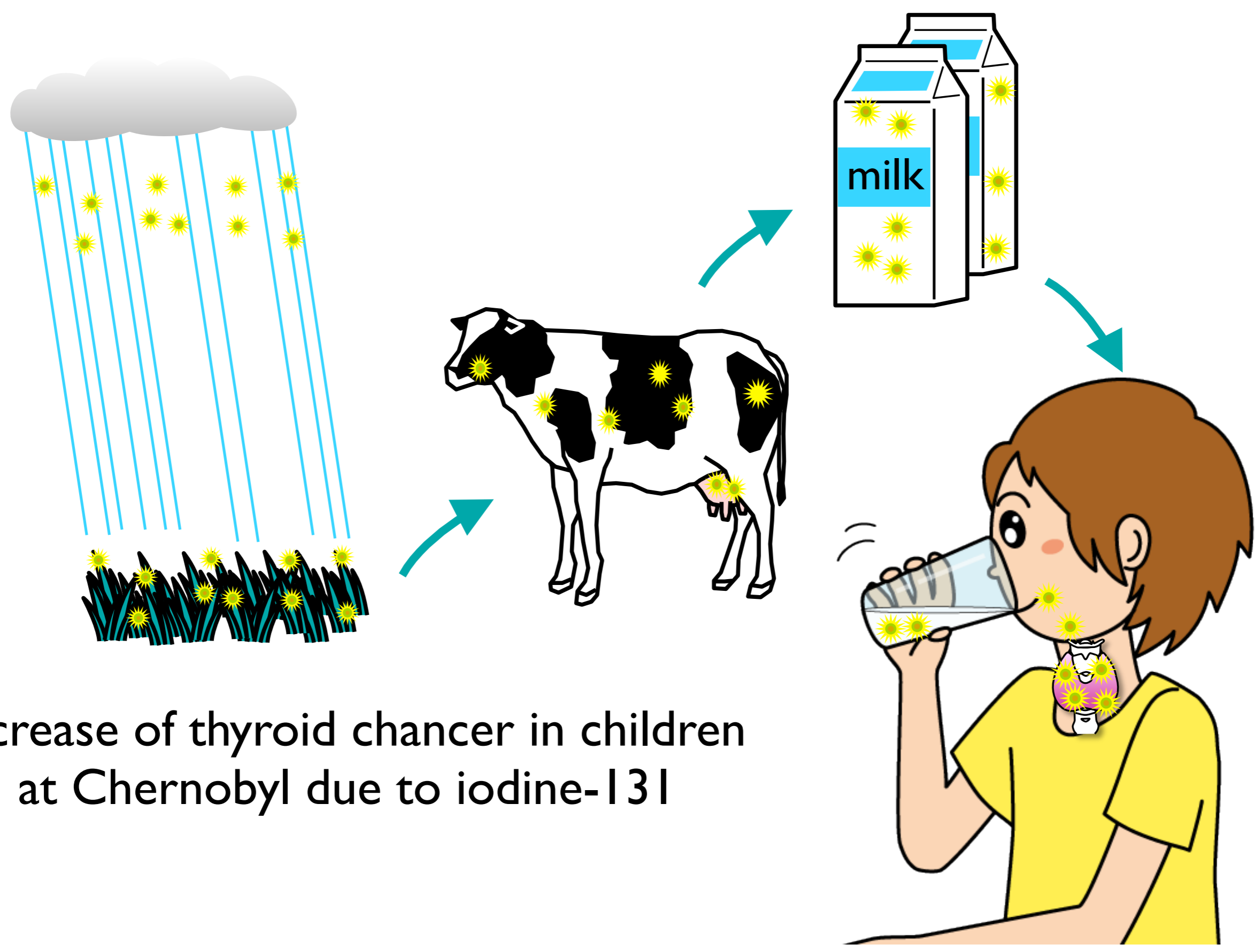
**Cancer cells are killed by  
NK cells of the immune system**

Some cancer cells avoid being caught.

**Cancer cells remains and proliferates  
benign / malignant / infiltrative**





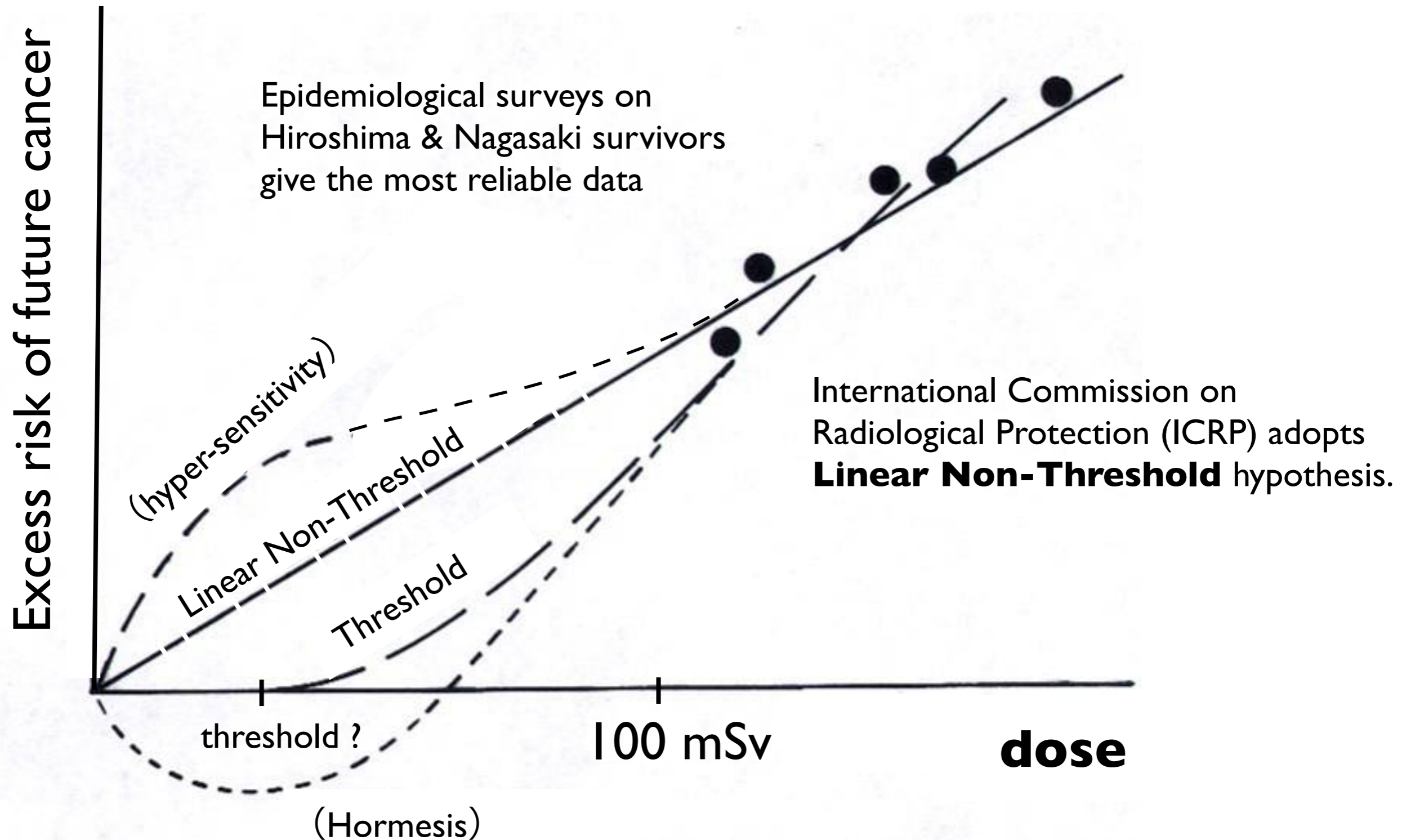


Increase of thyroid cancer in children at Chernobyl due to iodine-131

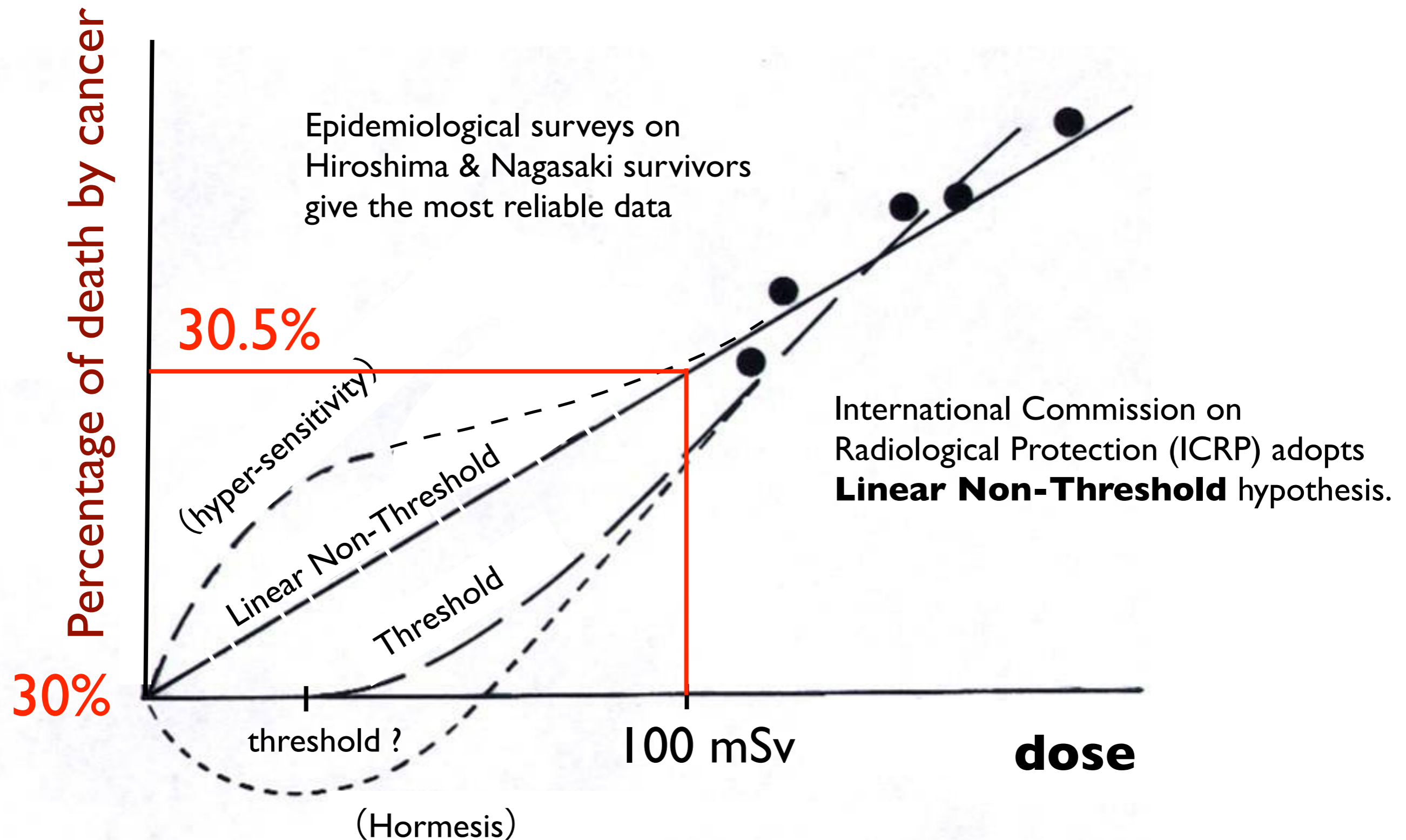
# **Radiation protection & risk evaluation**



# Risk evaluation at low dose



# Risk evaluation at low dose







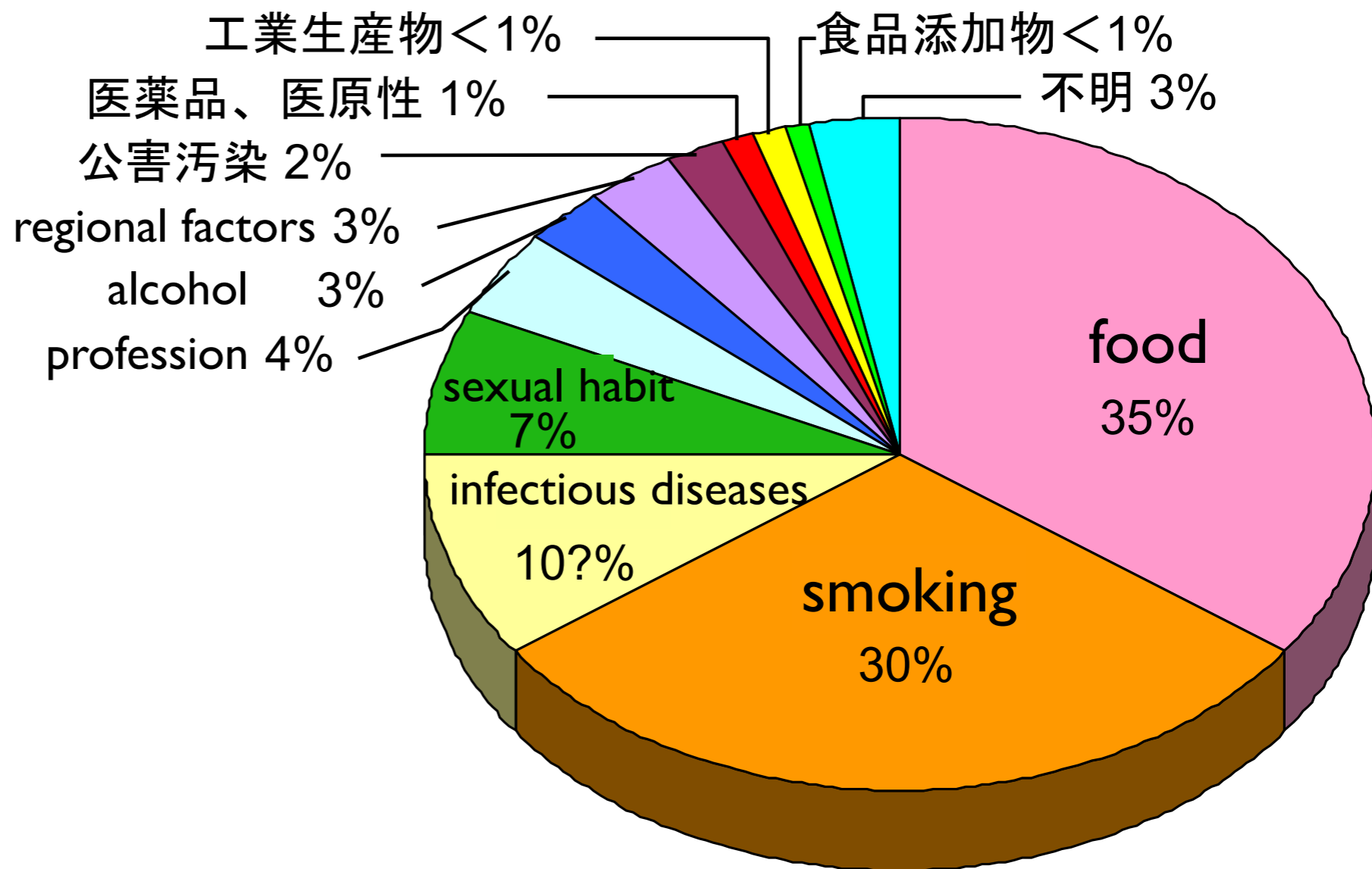
## Relative risk of cancer

passive smoking (Female)	1.02~ 1.03 x
not enough vegetables	1.06 x
Exposure to radiation dose of 100~200 mSv	1.08 x
too much salt	1.11~ 1.15 x
not enough exercise	1.15~ 1.19 x
Exposure to radiation dose of 200~500 mSv	1.19 x
fatness	1.22 x
Exposure to radiation dose of 500~1000 mSv	1.4 x
Drinking > 360 mL of sake	1.6 x
smoking	
Drinking > 540 mL of sake	1.8 x
Exposure to radiation dose of 1000~2000 mSv	

※網かけは放射線

(注)相対リスクは、例えば喫煙者と非喫煙者のがんの頻度を比較した数字

## Factors related with the cause of human cancers



(R.Dool and R.Peto, 1981)

Risks for exposure in a short time.

Percentage of each factor for cancer death (%)

(Smaller risks for long-term exposure by a factor DDREF.

There is no fixed consensus on the value, and ICRP uses the factor 2 as the DDREF.)

# Radiometry



# Radiometry

**counting** (cps = counts per second)



## Survey meters (ambient dose rate)

$\beta$  ( $\gamma$ ) /  $\gamma$



GM counter

$\beta$  ( $\gamma$ ) /  $\gamma$



ioniz. chamber

$\gamma$



NaI (Tl)

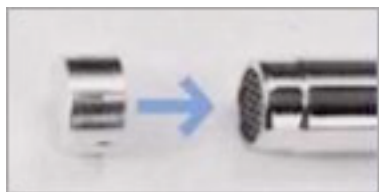


CsI (Tl)



$\beta$  ( $\gamma$ )

## 【Surface contamination check】



$\gamma$

$\beta$  ( $\gamma$ )



GM counter

$\alpha$



ZnS (Ag)



# Radiometry

## measurement of radioactivity★ in the sample

Y

Germanium (Ge) detector

Semiconductor detectors

例：Si(Li) detector (for X-rays)

Ge detector (high resolution)  
(for  $\gamma$  / X-rays)

radiation  $\Rightarrow$  ionization

$\Rightarrow$  electron-hole pair  $\Rightarrow$  charge measured

**Energy analysis**

= identification of nuclides



Ge detector for check of food samples

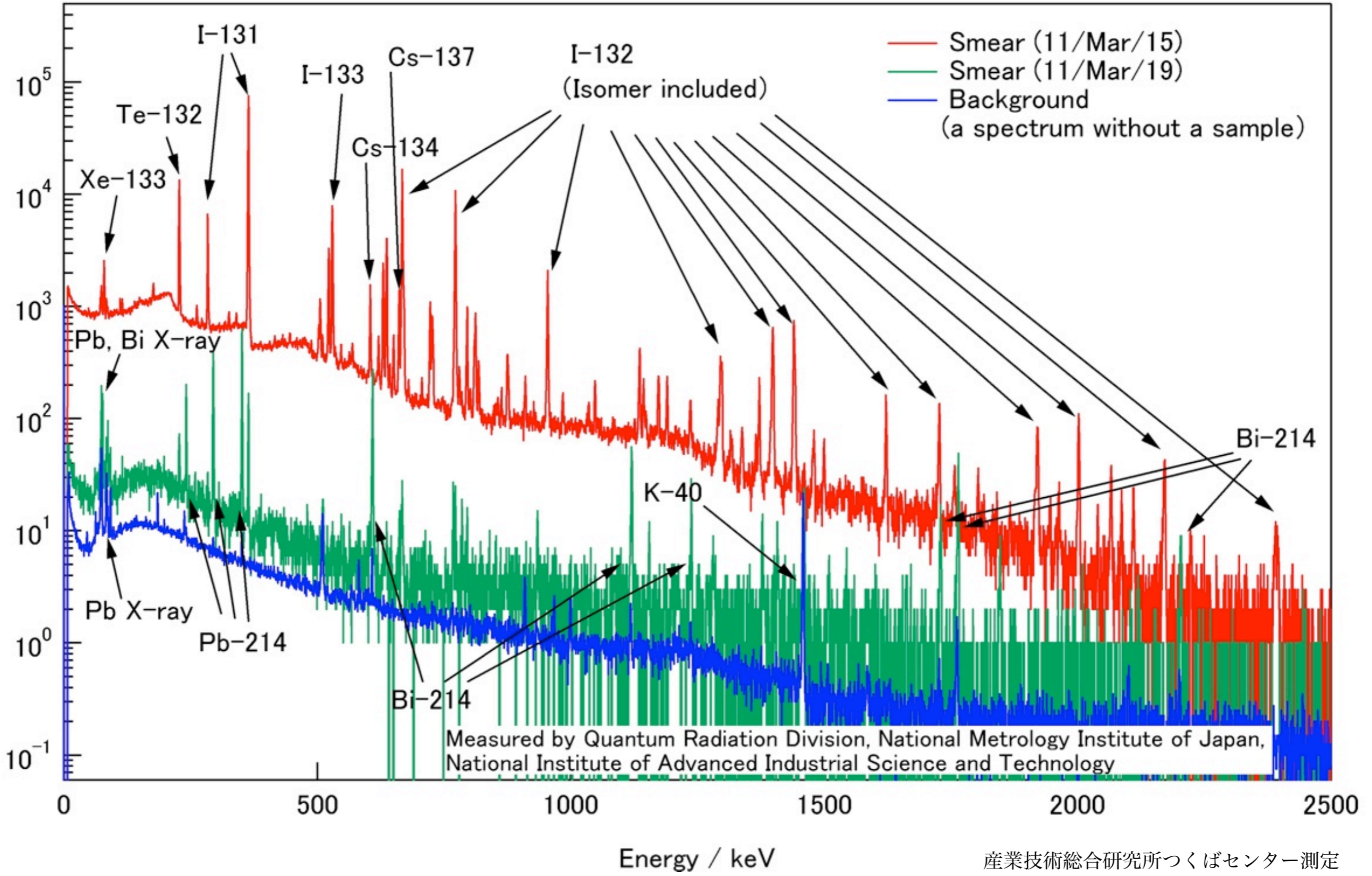






# Energy analysis = identification of nuclides

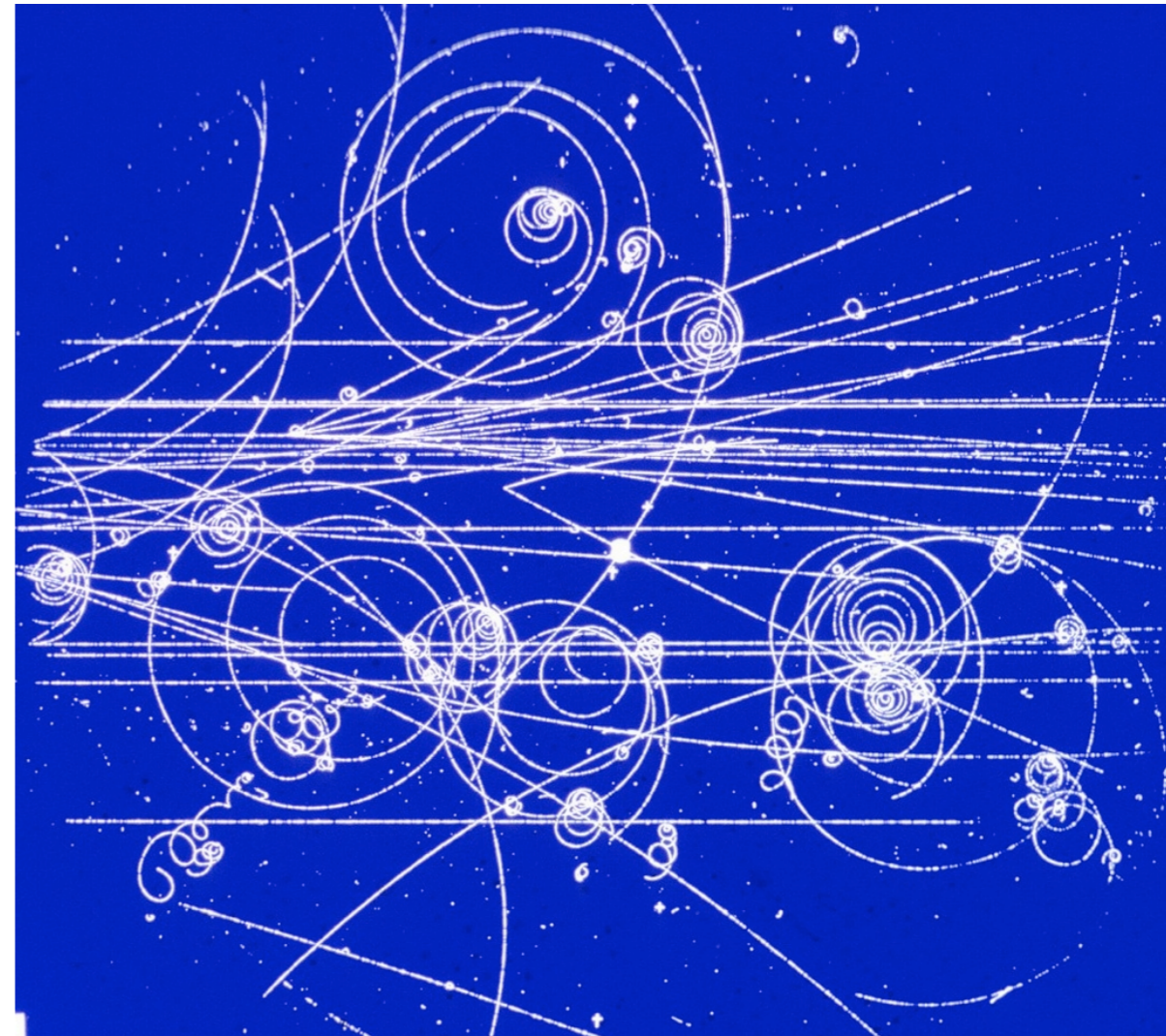
## γ-ray energy spectrum by the Ge detector





# 泡箱

Bubble chamber





Fine.

Grazie per vostra attenzione.

Merci de votre attention.

Thank you for your attention.

Спасибо за внимание.

경청해 주셔서 감사합니다.

ご清聴ありがとうございました。

鳥居 寛之

Hiroyuki A.TORII