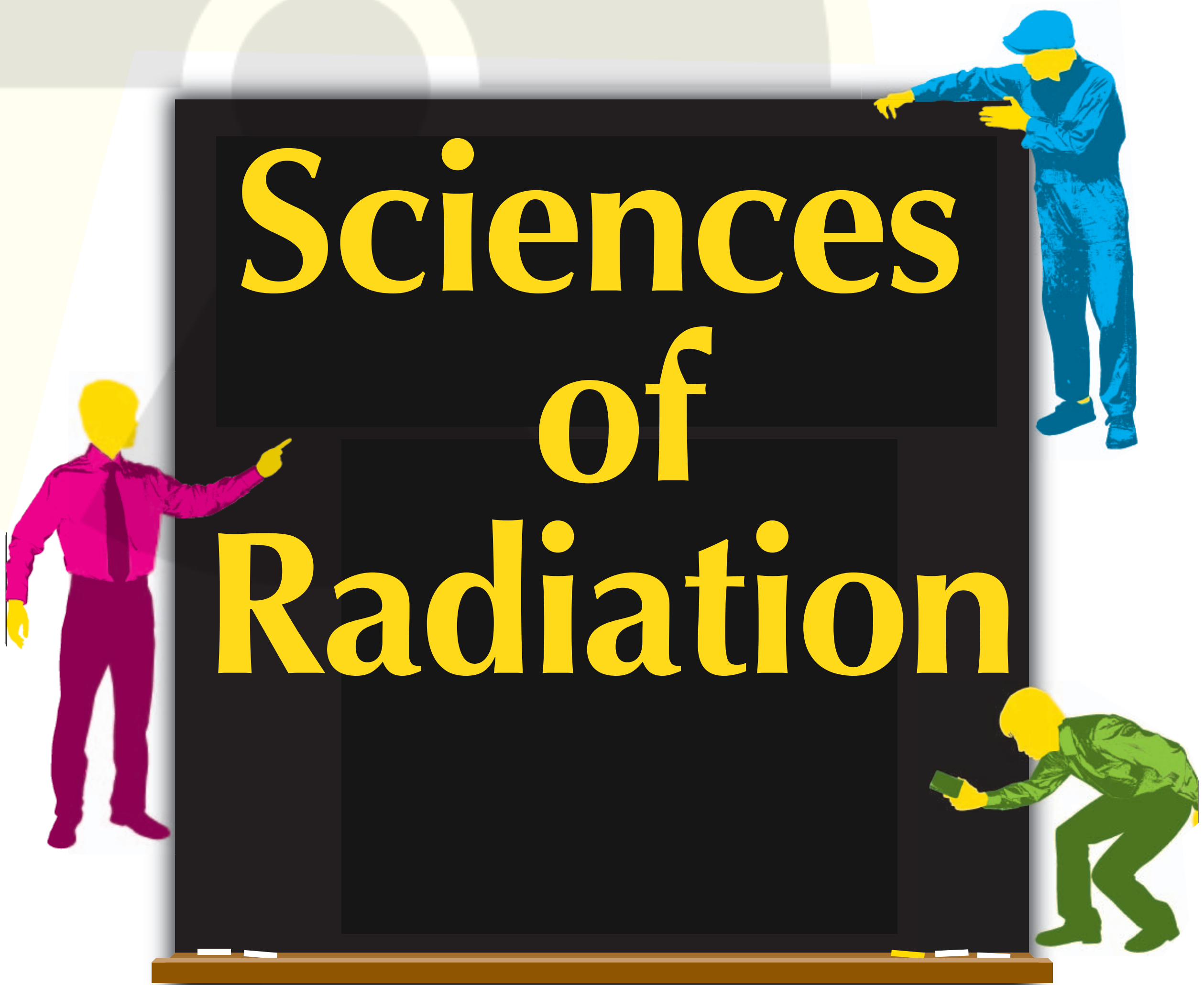
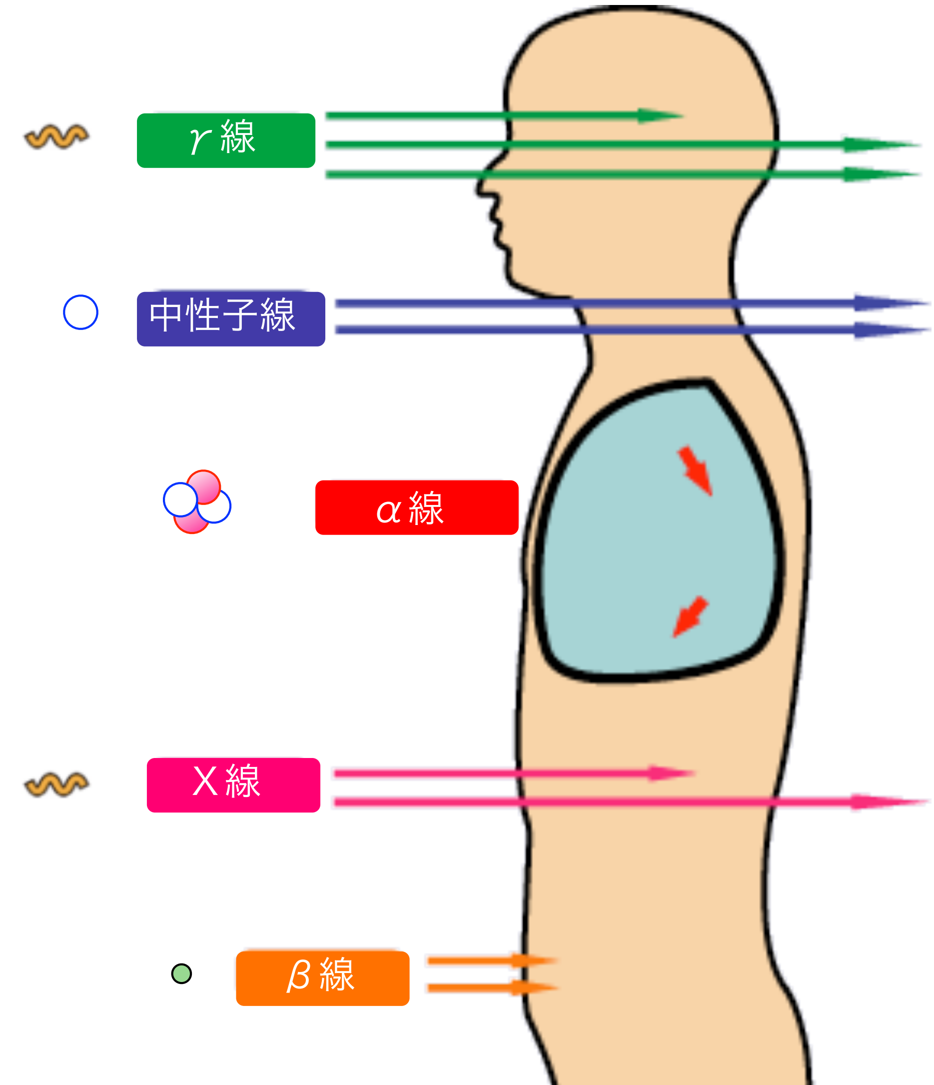
Special lecture for PEAK students, Univ. of Tokyo

Sciences of Radiation





Mon 10th June 2013

鳥居 寛之 (Hiroyuki A. TORII)

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

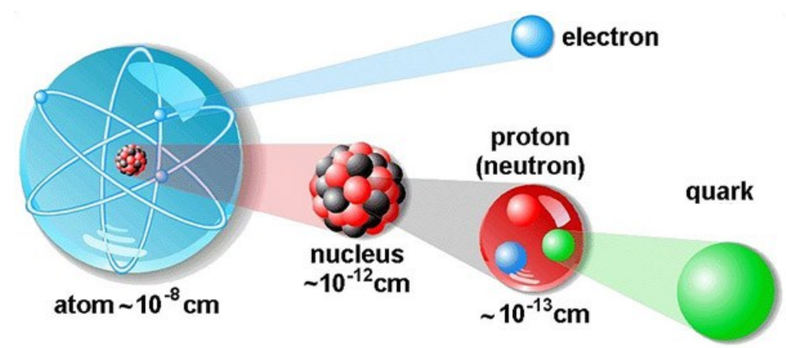
書籍「放射線を科学的に理解する — 基礎からわかる東大教養の講義 —」

とあわせて、どうぞご活用下さい。http://radphys4.c.u-tokyo.ac.jp/~torii/lecture/

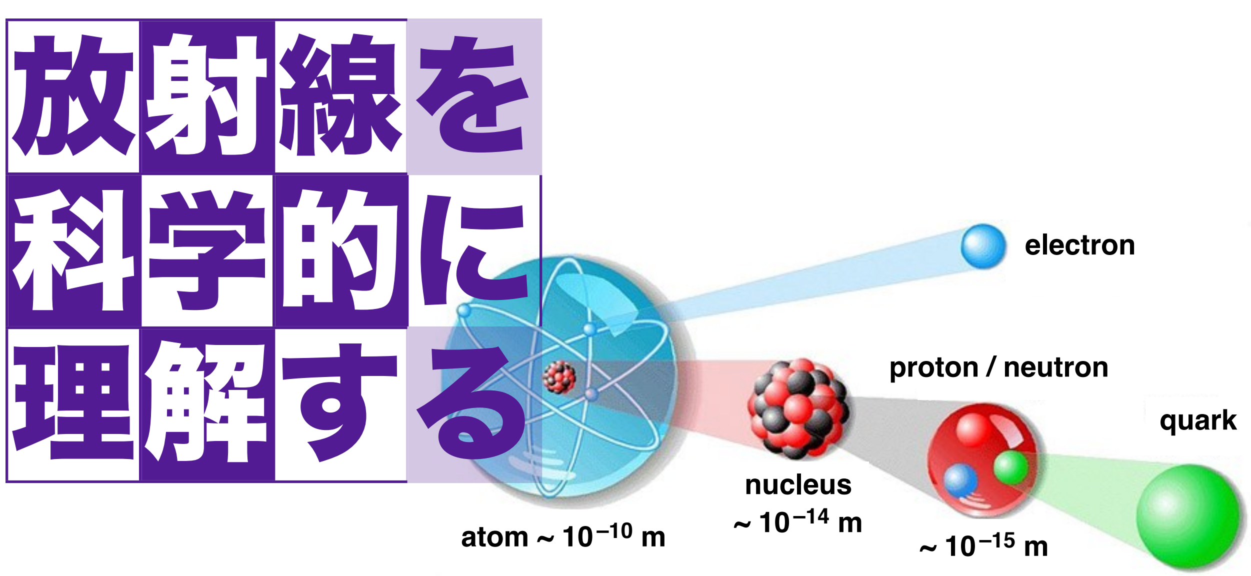
torii-radio@radphys4.c.u-tokyo.ac.jp

2011年度夏学期 自主講義

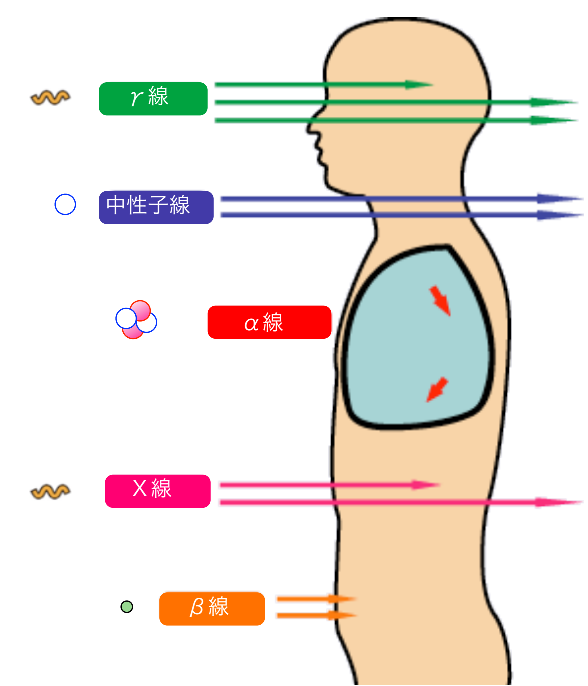
自主講義 放射線学

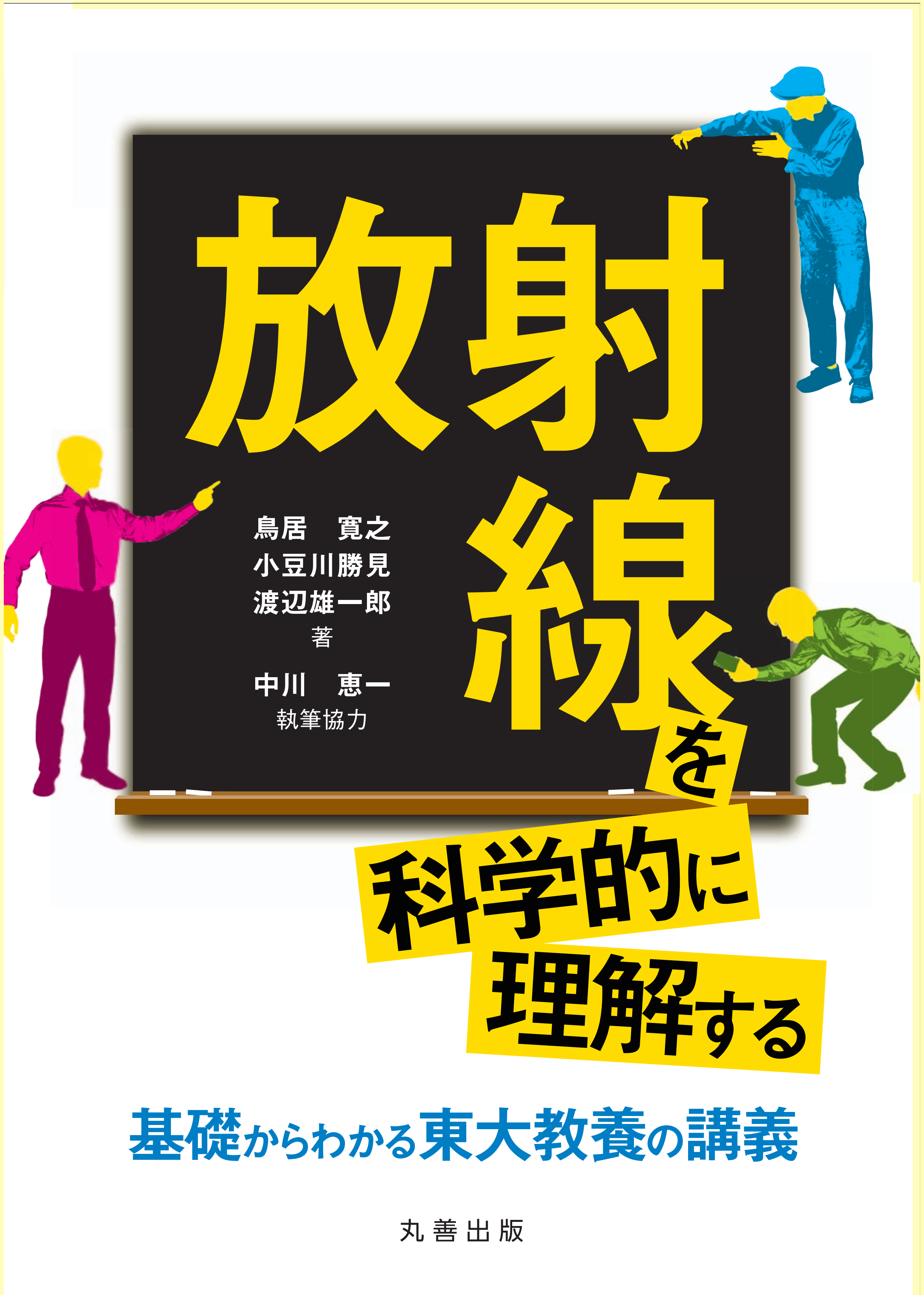


2011年度冬学期 主題科目テーマ講義



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
― 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

丸善出版　本体 2500円＋税

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

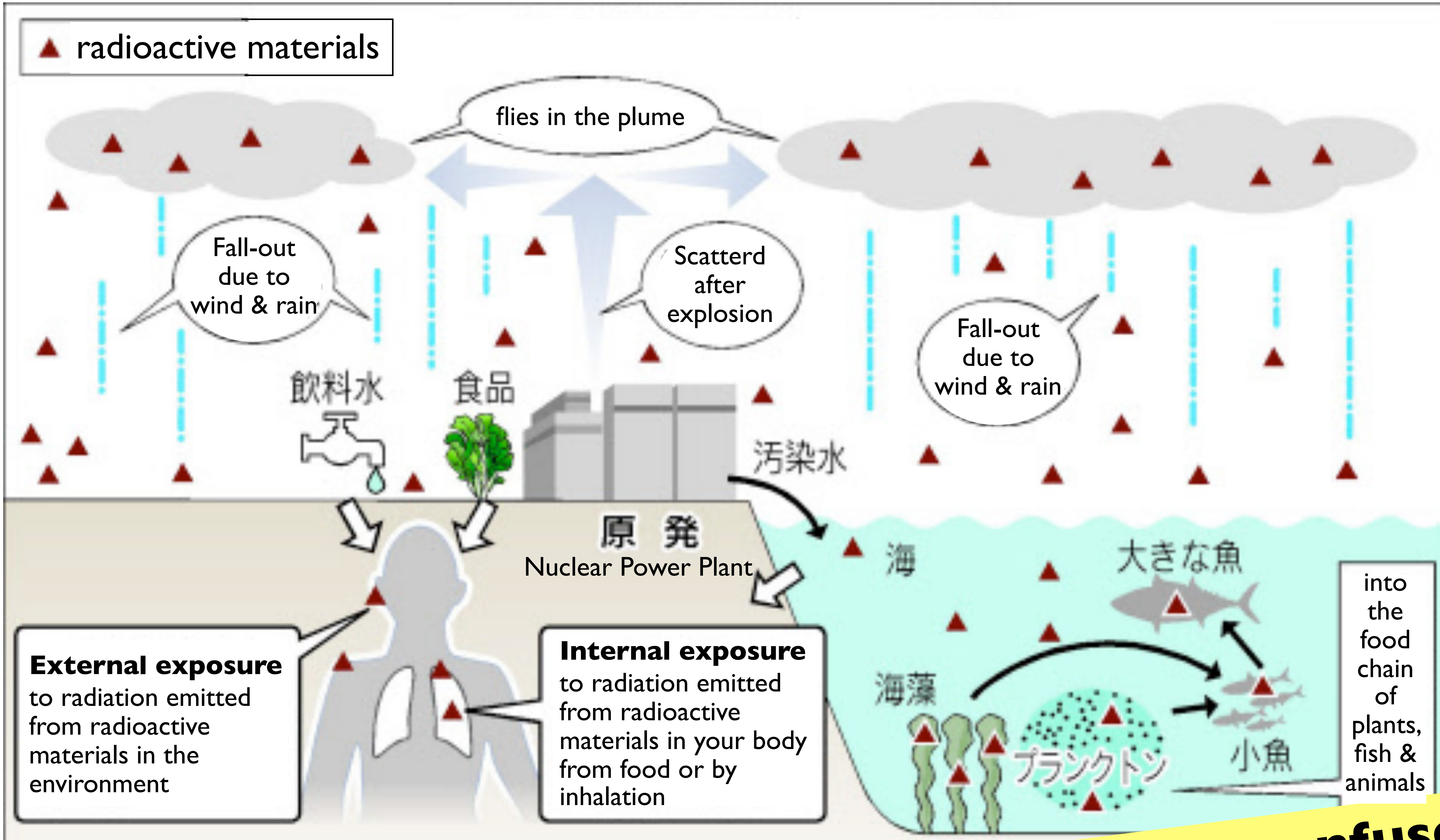
Nov. 2011

Public lecture in Fukushima, Nov. 2011

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

Univ. of Tokyo × Hakuhodo × Jiji Press

Radiation
Radioactivity
Radioactive materials



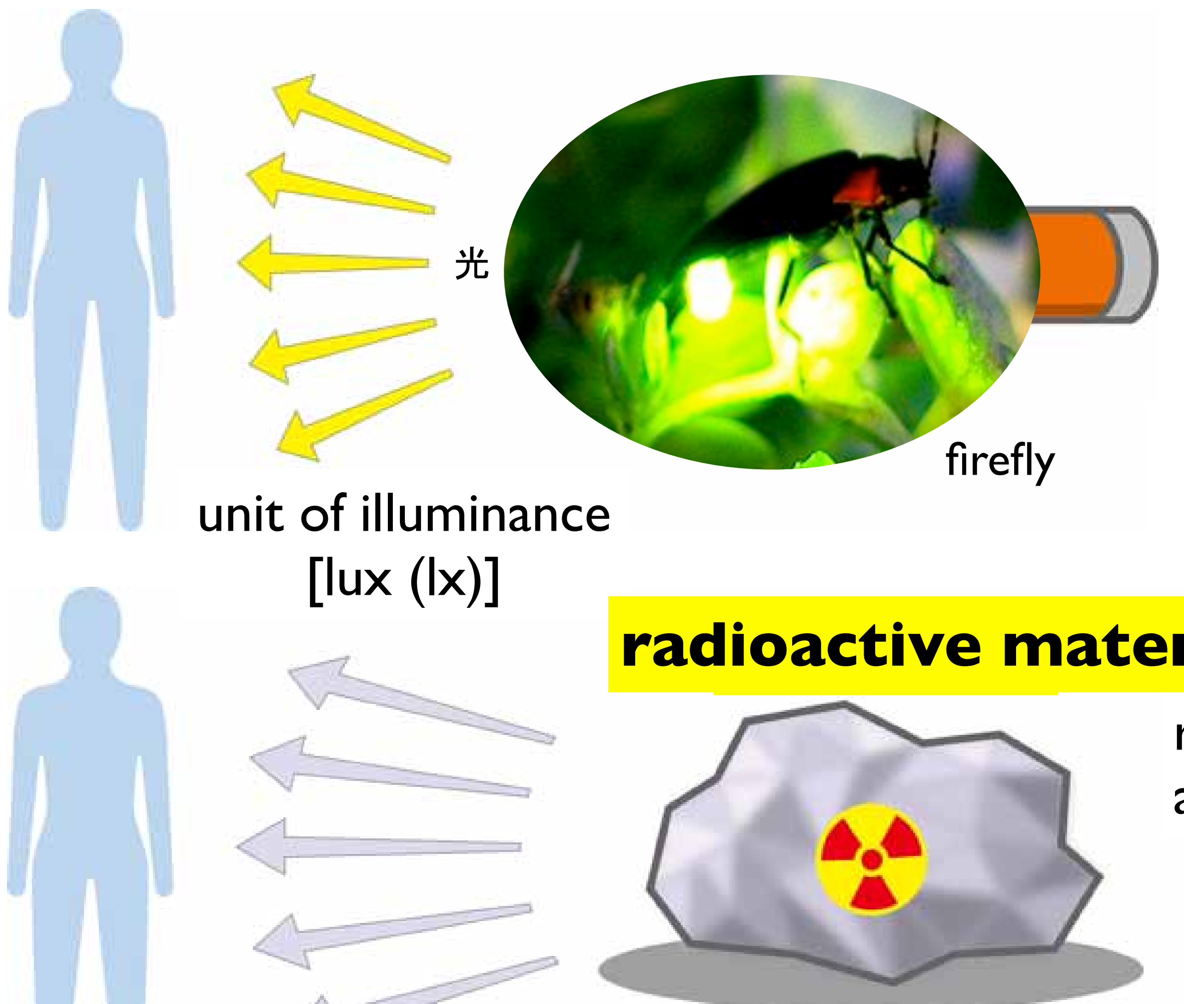
Don't confuse radioactivity with radiation.

Some **radioactive materials** flew to Tokyo.

Radiation cannot reach Tokyo directly from Fukushima NPP.

Radioactivity & Radiation

Sievert



ability to emit light

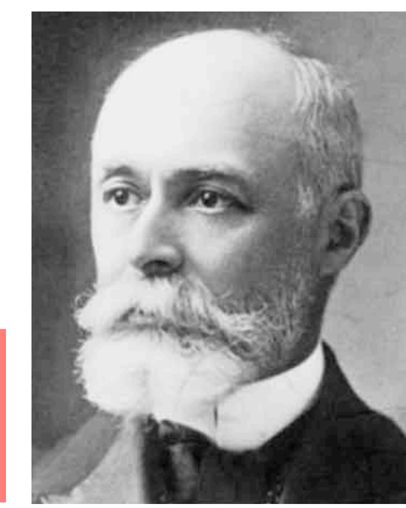
unit of luminous intensity
[candela (cd)]

unit of illuminance
[lux (lx)]

radioactive material

radioactivity =
ability to emit radiation

Becquerel



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

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

出典：資源エネルギー庁「原子力2010」

Units of **radioactivity**

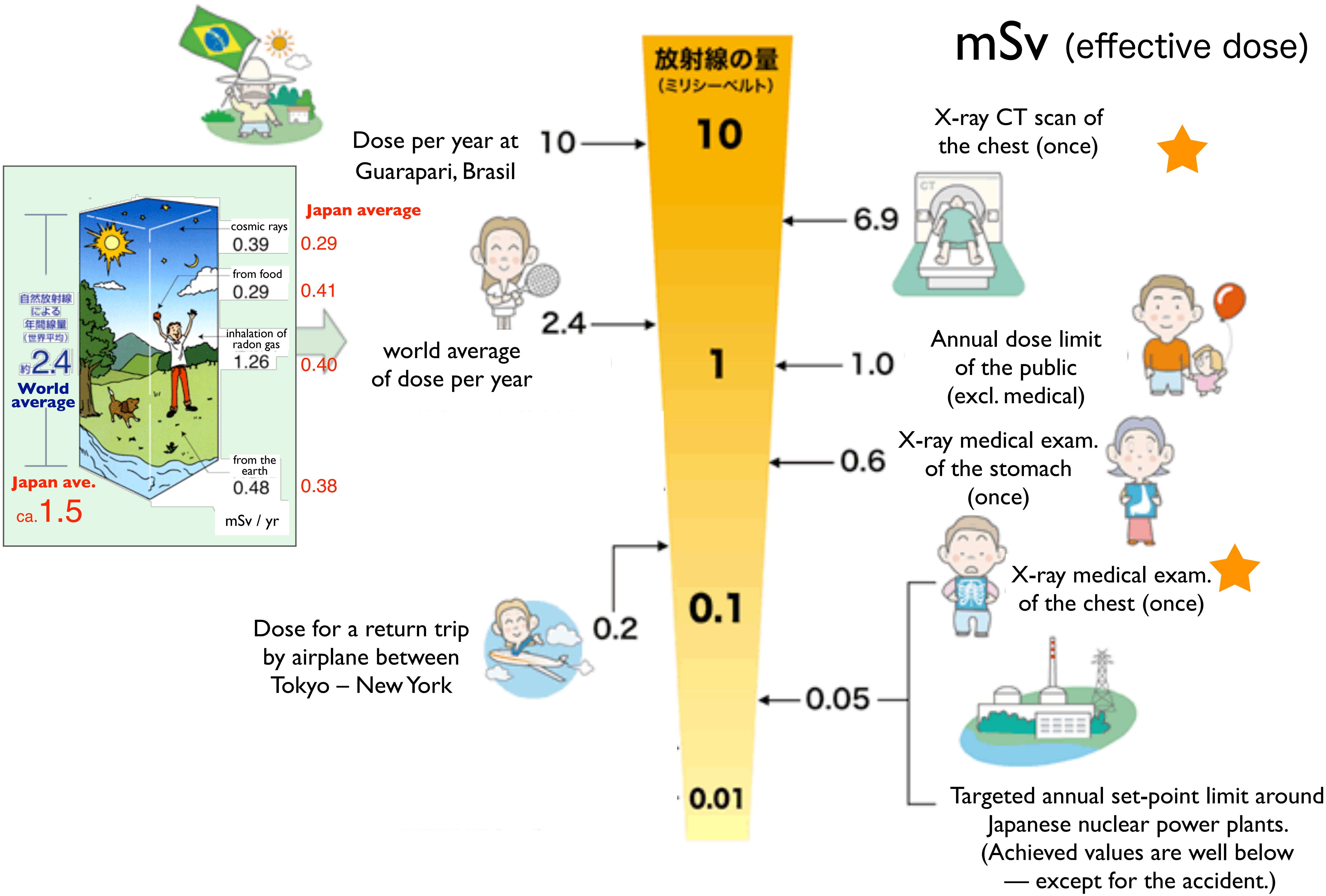
[Bq] 1 Bq = 1 dps, [Ci] 1 Ci = 37 GBq

decay/disintegration per second

Curie

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

Natural (environmental) & medical radiation

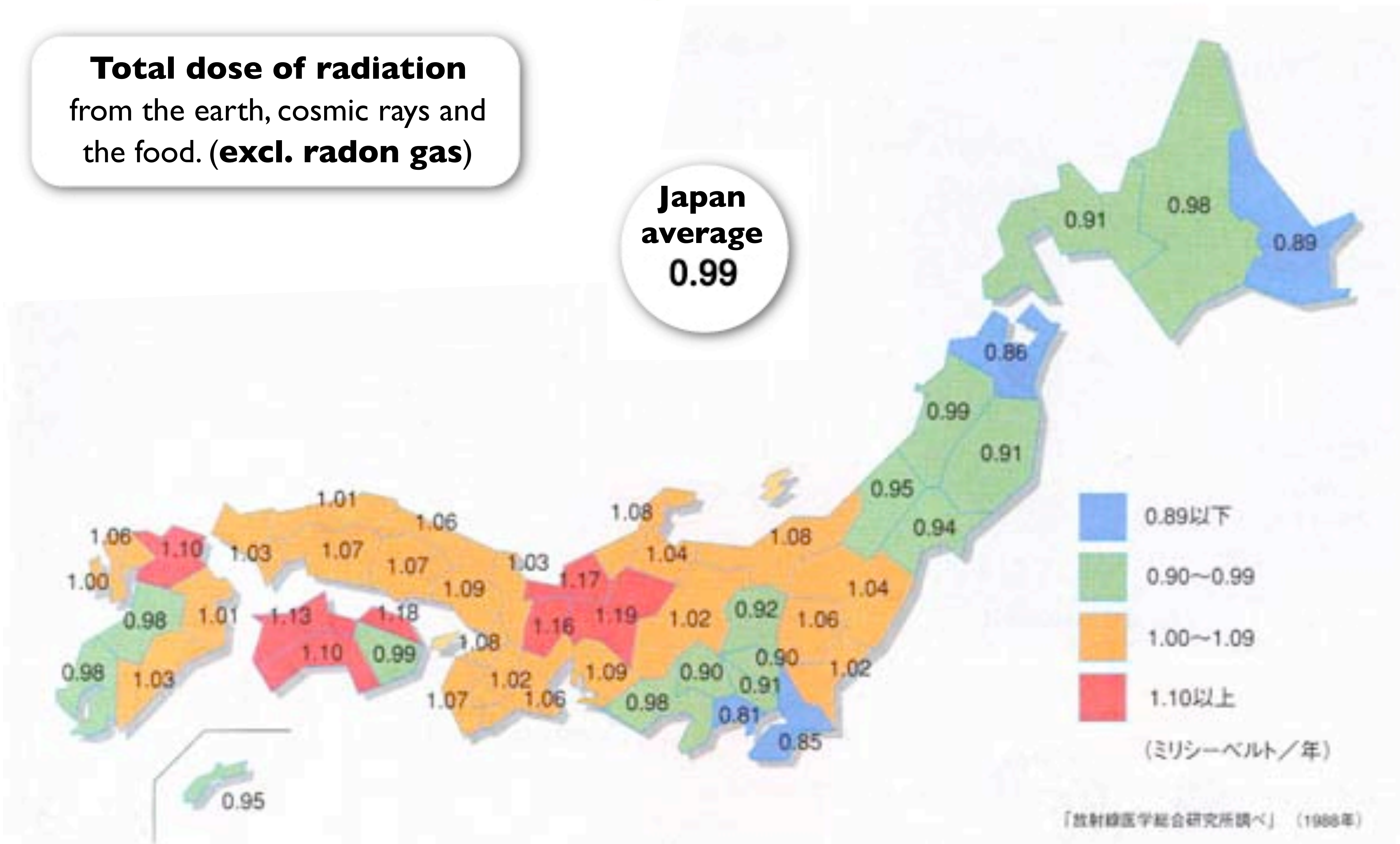


Japanese natural dose of radiation

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)

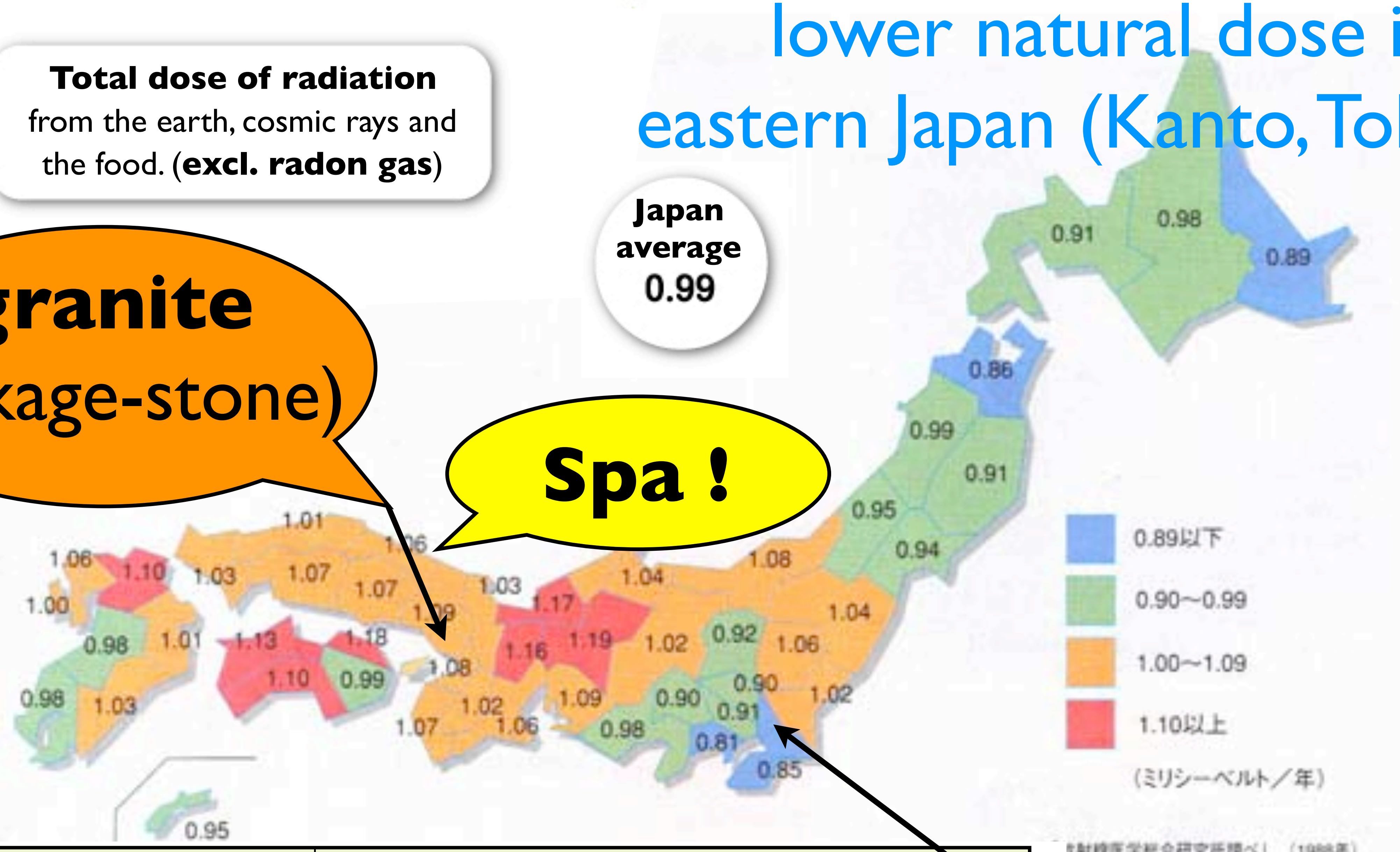
Total dose of radiation from the earth, cosmic rays and the food. (**excl. radon gas**)

Japan average 0.99

granite (Mikage-stone)

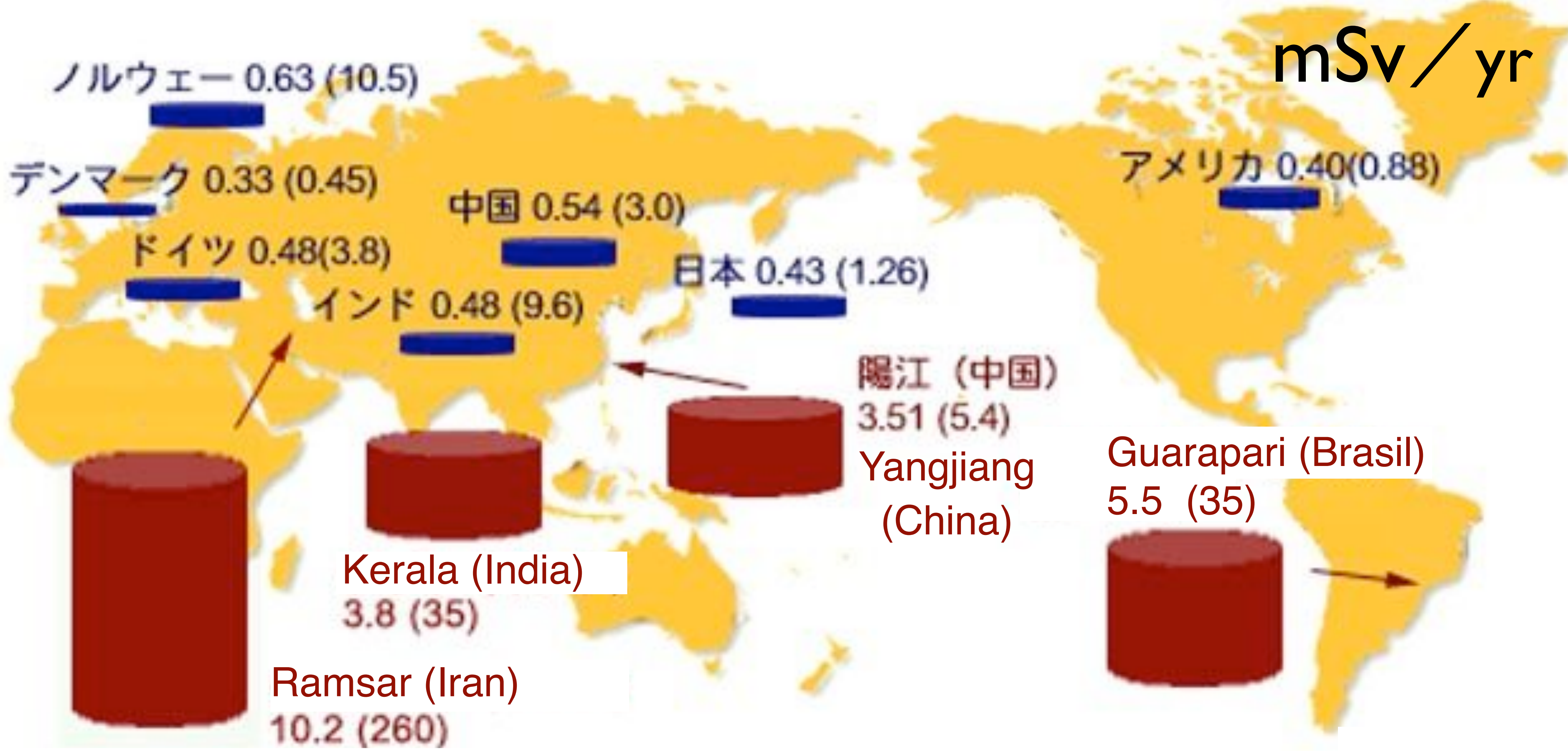
Spa !

Kanto loamy layer



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

出典：国連放射線影響科学委員会報告（1982）など

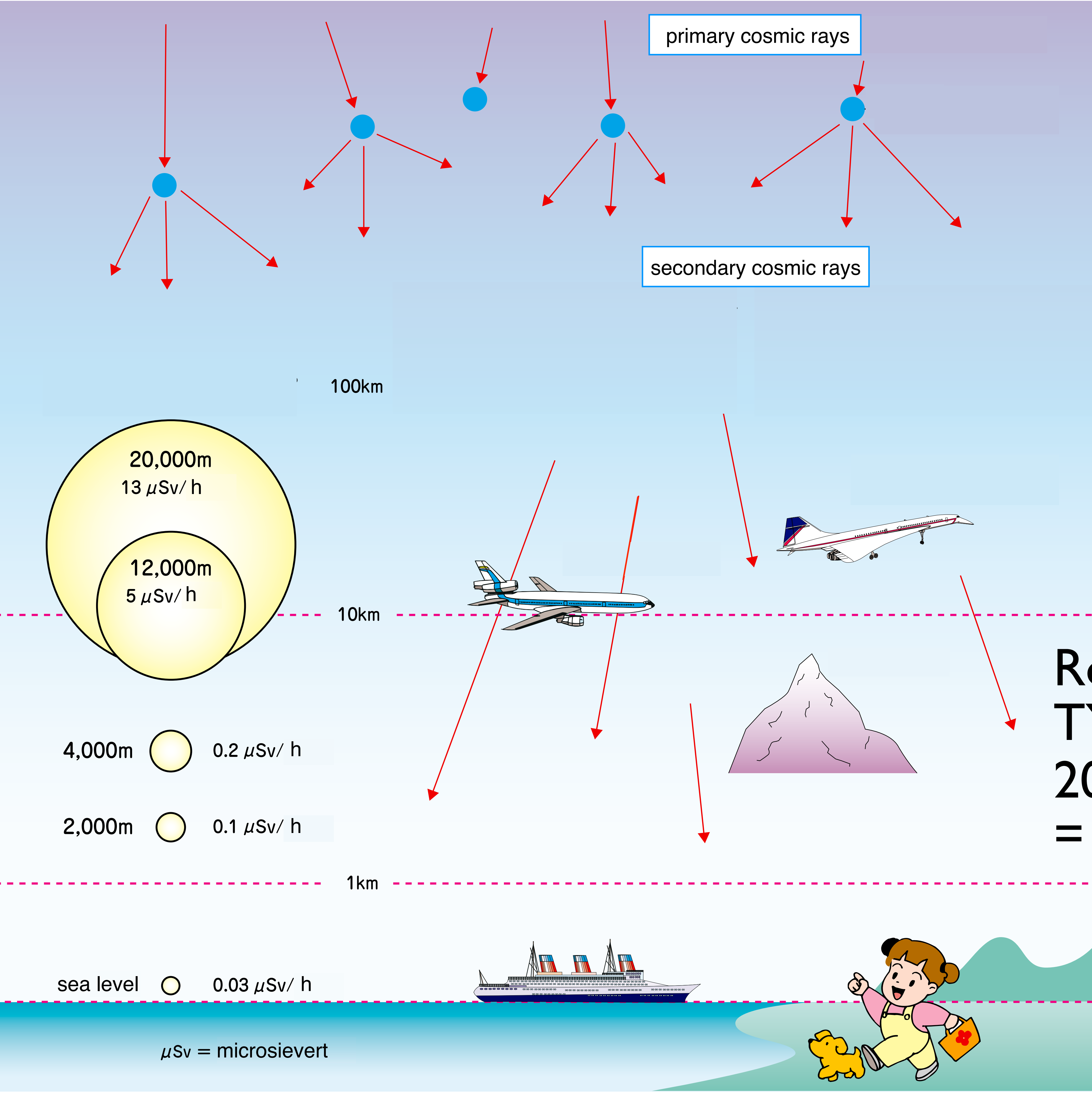


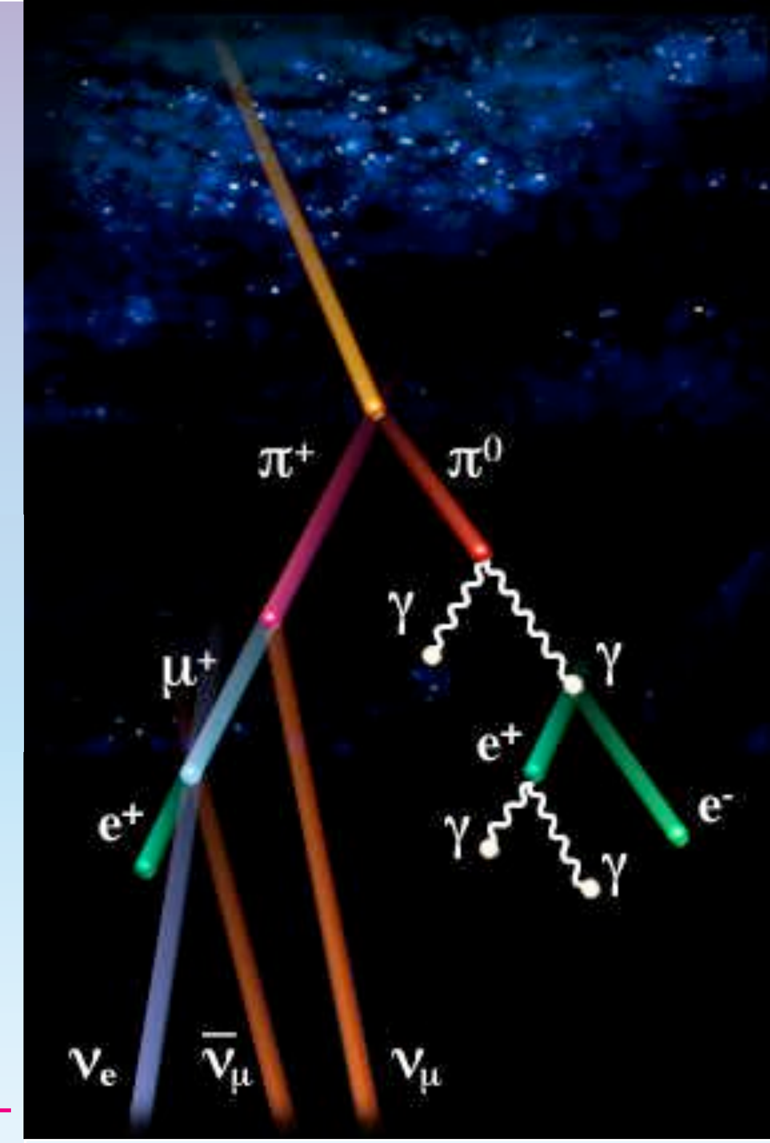
max. value in ( )

図2 陽江市・恩平県放射線環境調査実施地域

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[7,8]

	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





Round-trip by flight TYO-NYC

200 μSv (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}K

isotope abundance = 0.012%

half-life 13 billion yrs

$^{40}K \rightarrow {}^{40}Ar$ (ECγ) 11%

$^{40}K \rightarrow {}^{40}Ca$ (β^-) 89%

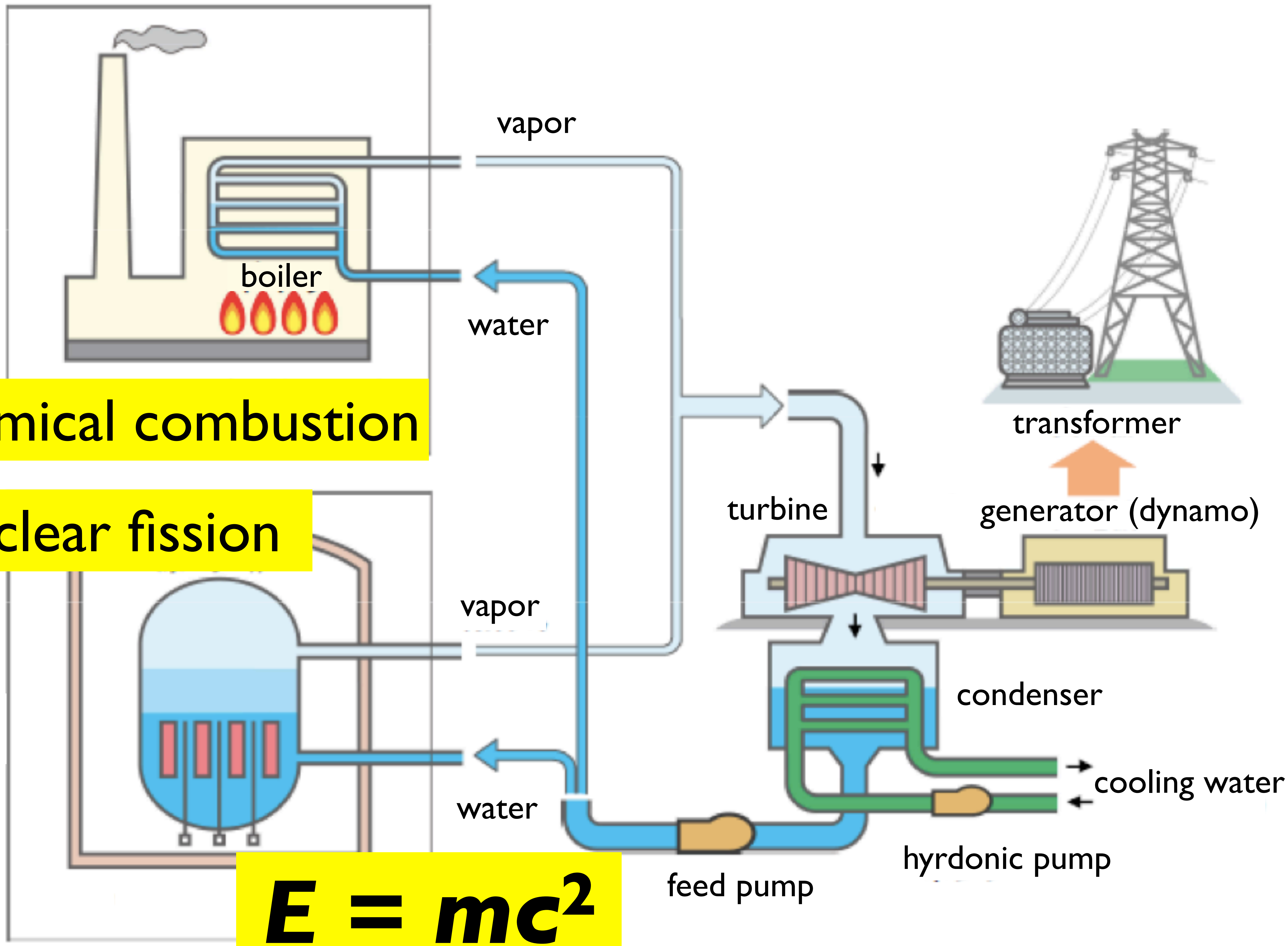
We ingest 3 g of Potassium = 80 Bq of ^{40}K every day, egesting the same amount.

Nuclear Physics

Themal vs. nuclear power generation

Themal

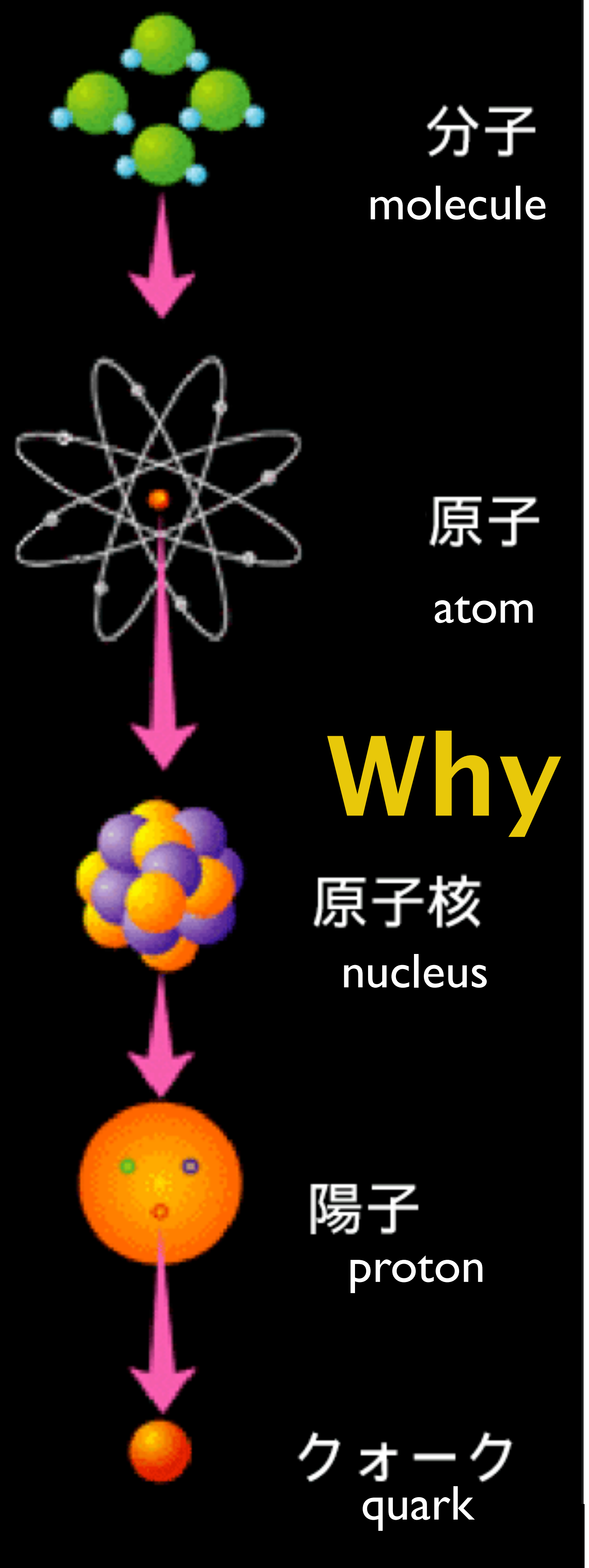
Nuclear



Chemical combustion

Nuclear fission

$$E = mc^2$$



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

Atomic
Sym
Mass

- C 固体
- Hg 液体
- H 気体
- Rf Unknown

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 / アクチノイド	遷移元素	卑金属		非金属元素	希ガス

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

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

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

Radioactive materials are

materials composed of atoms with

Radioactive nuclides
= Radioisotopes
= unstable nuclei

Radioactive materials are

materials composed of atoms with

Radioactive nuclides
= Radioisotopes
= unstable nuclei

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

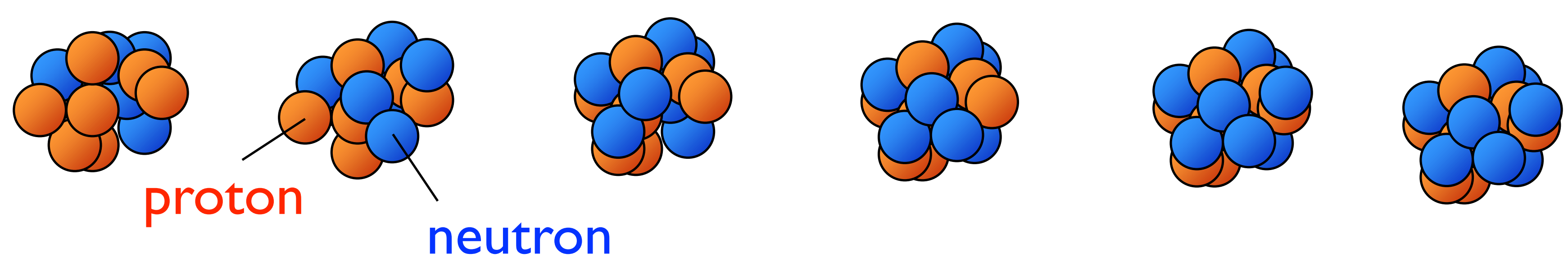
Same chemical element for the same proton number Z

Different nuclides for different neutron number N

${}^{A}_{Z}C_{N}$

element symbol

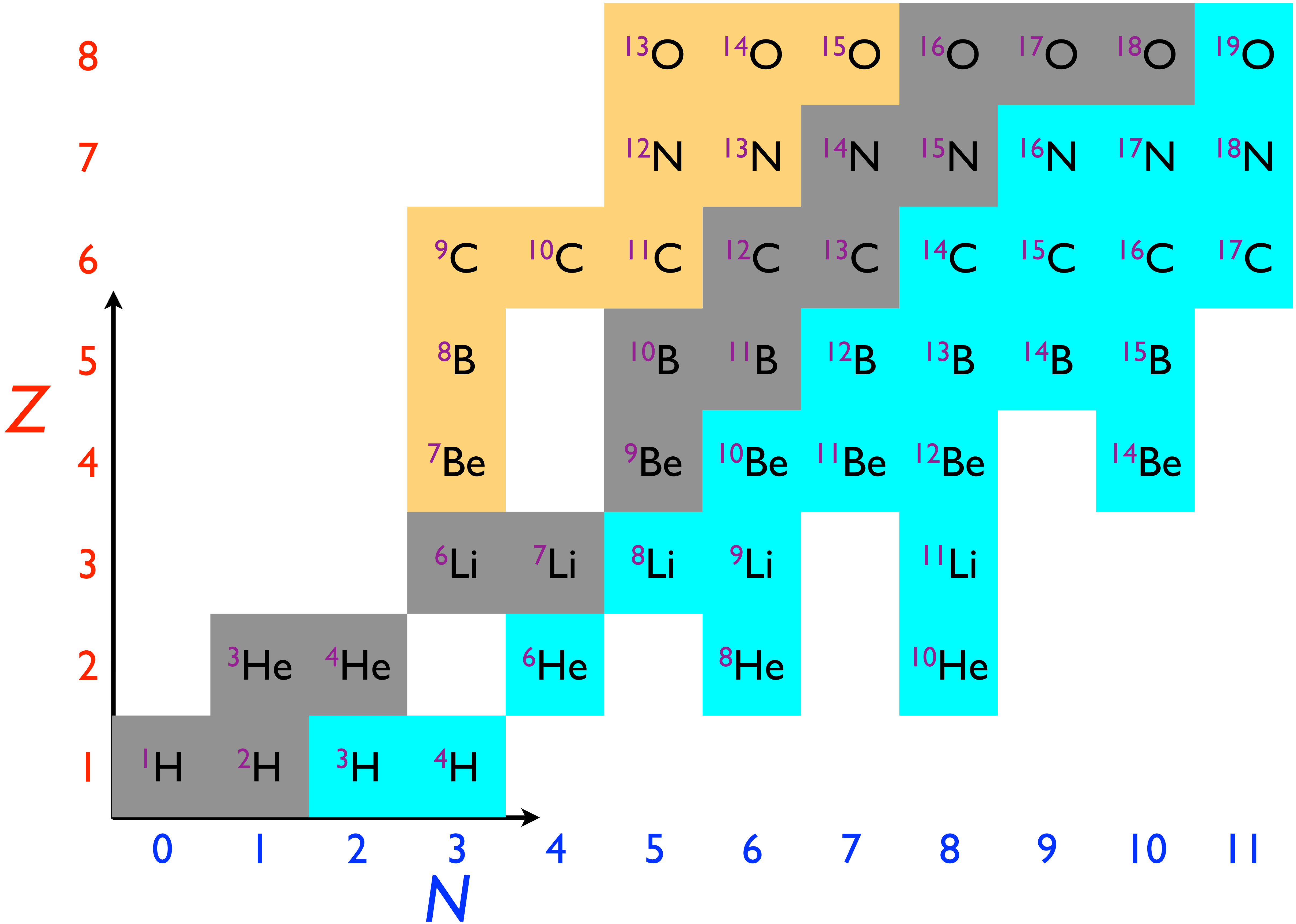
example: Carbon

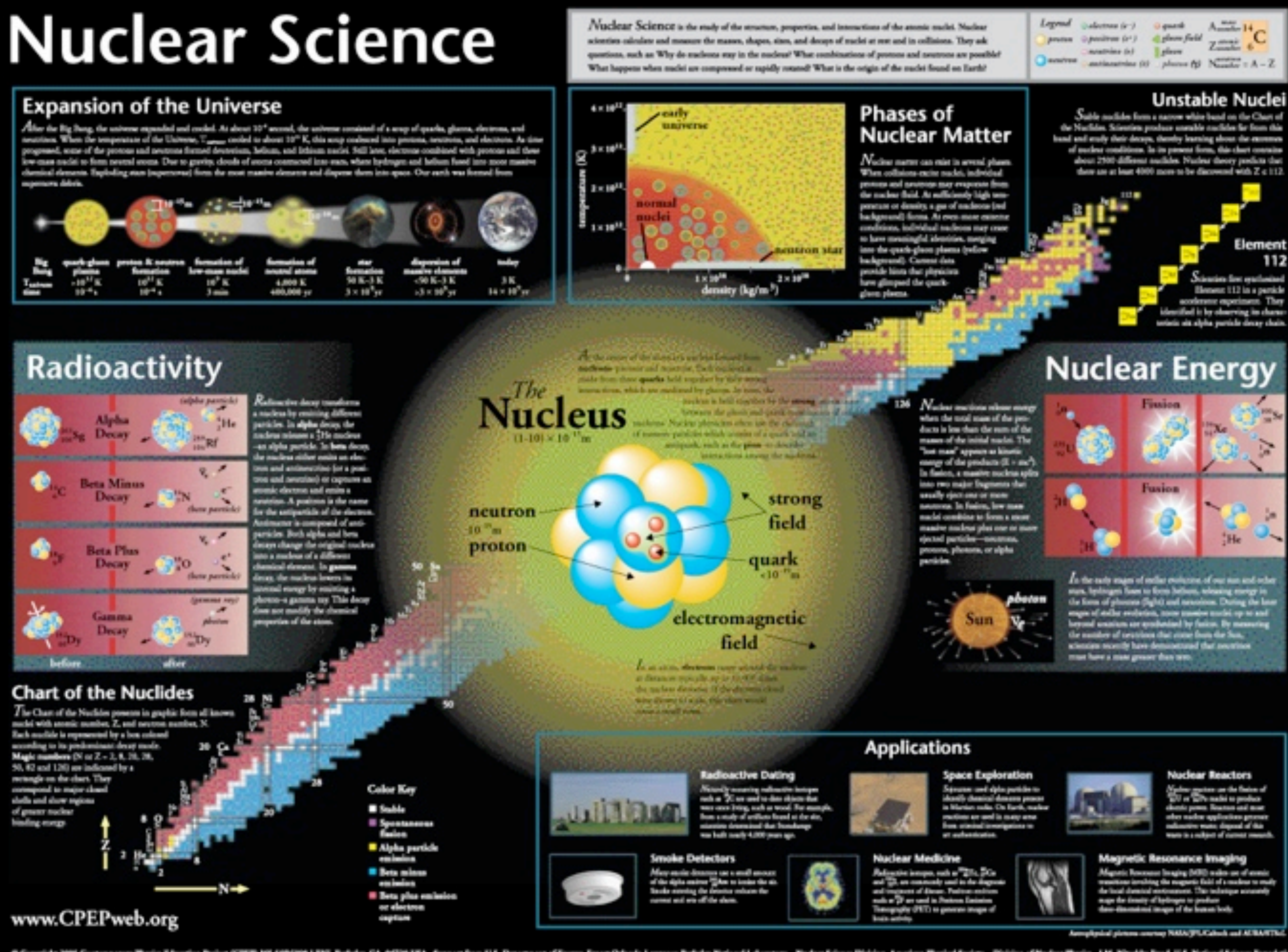


${}^{10}_{6}C_{4}$ ${}^{11}_{6}C_{5}$ ${}^{12}_{6}C_{6}$ ${}^{13}_{6}C_{7}$ ${}^{14}_{6}C_{8}$ ${}^{15}_{6}C_{9}$

radioisotopes (unstable) — stable isotopes infinate lifetimes — radioisotopes (unstable)

Nuclear chart





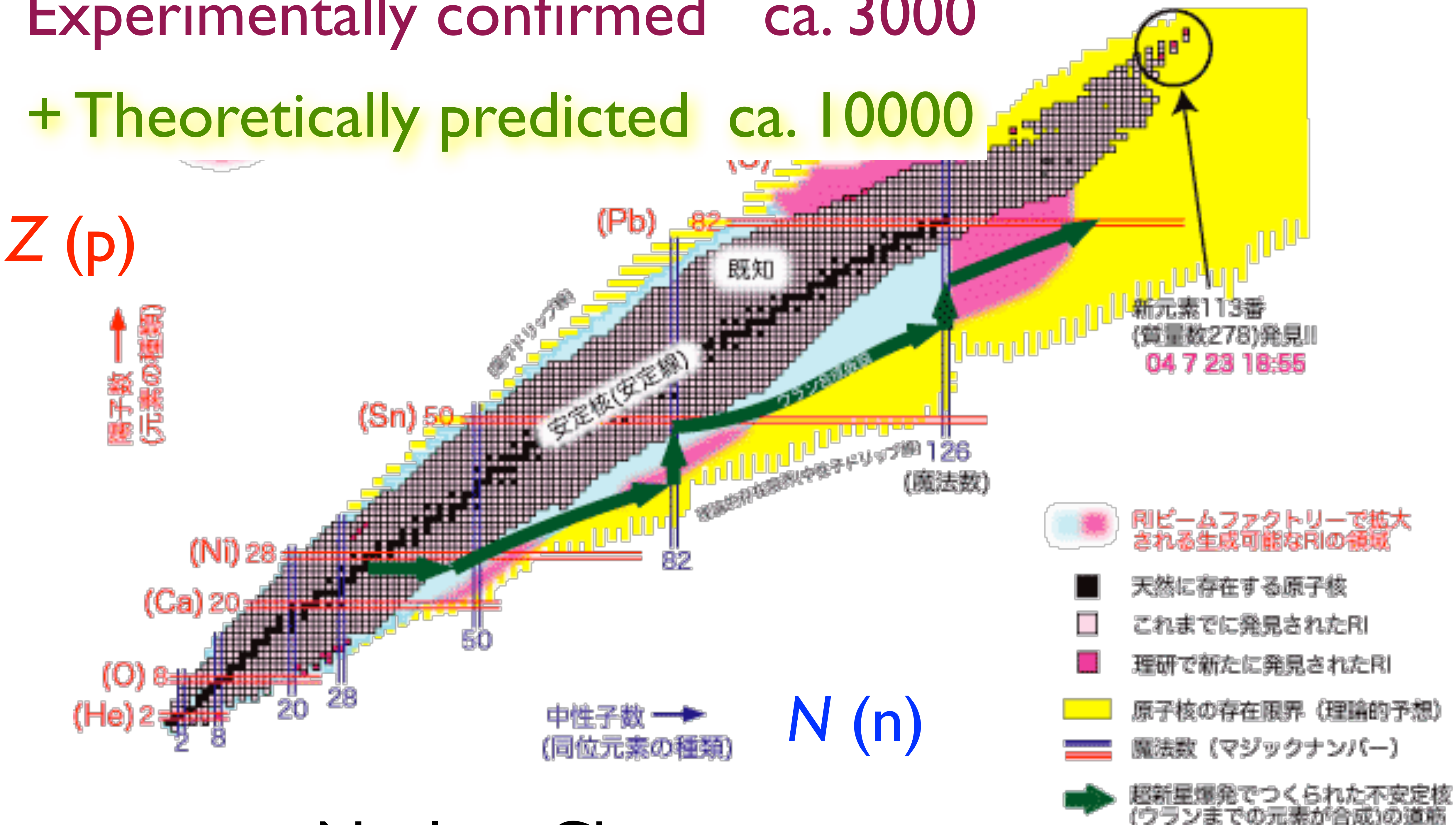
Nuclear Science
Expansion of the Universe
Phases of Nuclear Matter
early universe
normal nuclei
neutron star
density (kg/m³)
temperature (K)
Unstable Nuclei
Element 112
Radioactivity
Alpha Decay
Beta Minus Decay
Beta Plus Decay
Gamma Decay
before
after
The Nucleus
neutron
proton
strong field
quark
electromagnetic field
Nuclear Energy
Fission
Fusion
Sun
photon
Chart of the Nuclides
Color Key
Stable
Spontaneous fission
Alpha particle emission
Beta minus emission
Beta plus emission or electron capture
Applications
Radioactive Dating
Space Exploration
Nuclear Reactors
Smoke Detectors
Nuclear Medicine
Magnetic Resonance Imaging
www.CPEPweb.org

Number of nuclides

Stable nuclides ca. 300 species

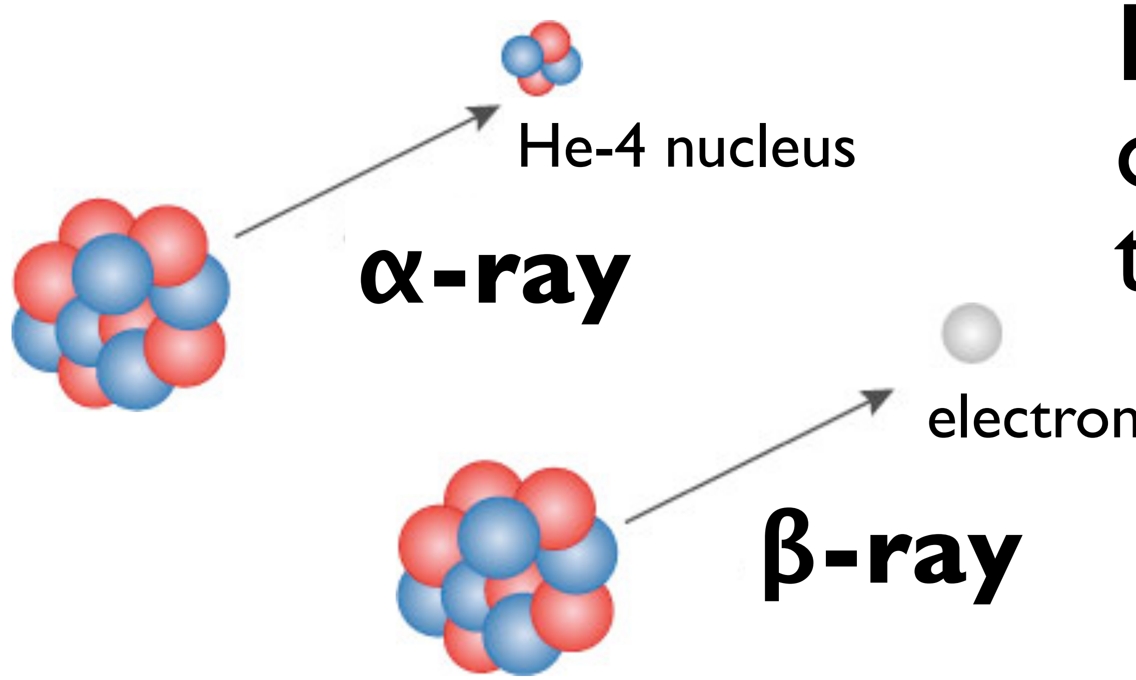
Experimentally confirmed ca. 3000

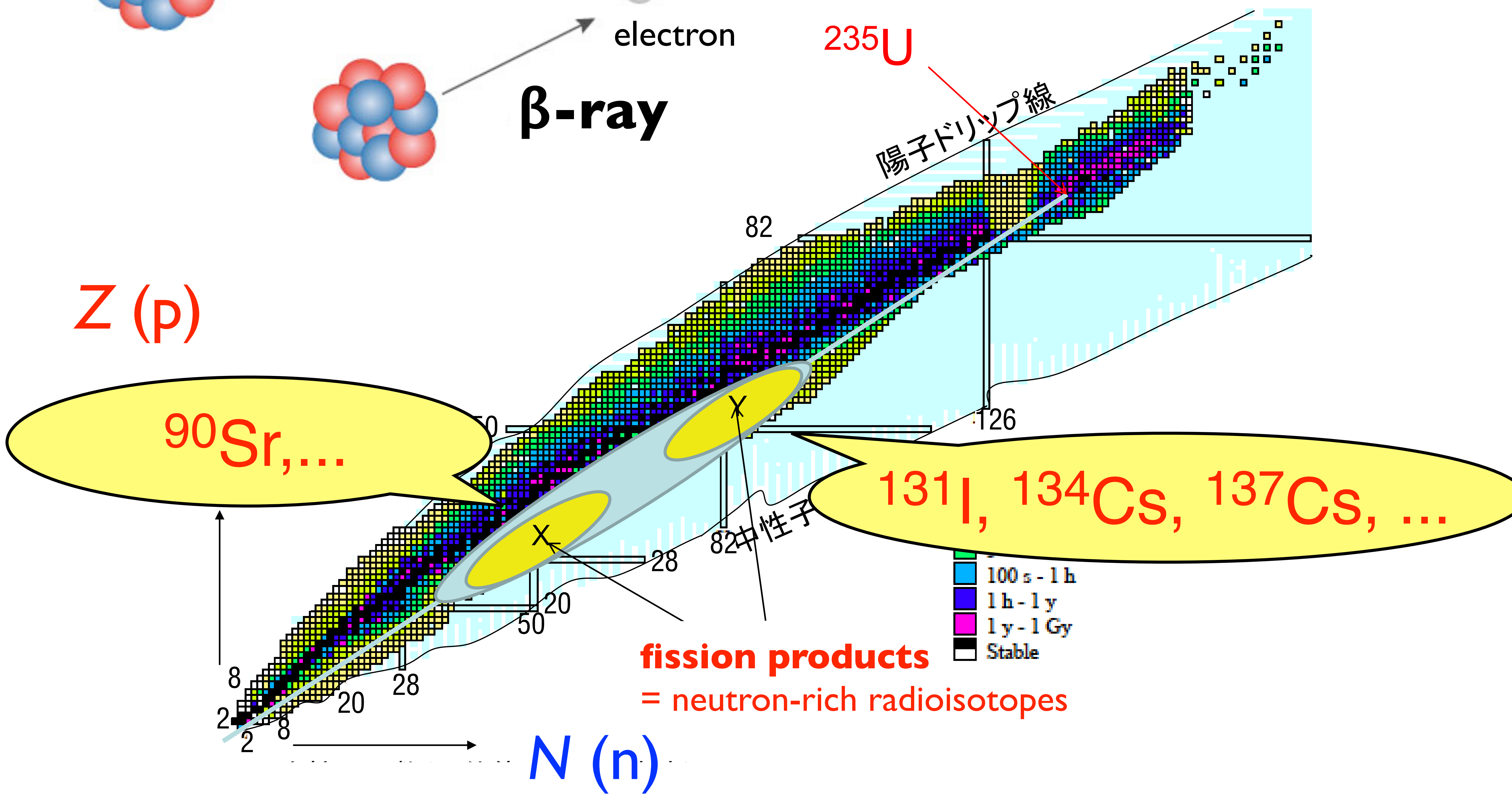
+ Theoretically predicted ca. 10000



Nuclear Chart

Radioactivity is the ability of radioactive materials to emit radiation

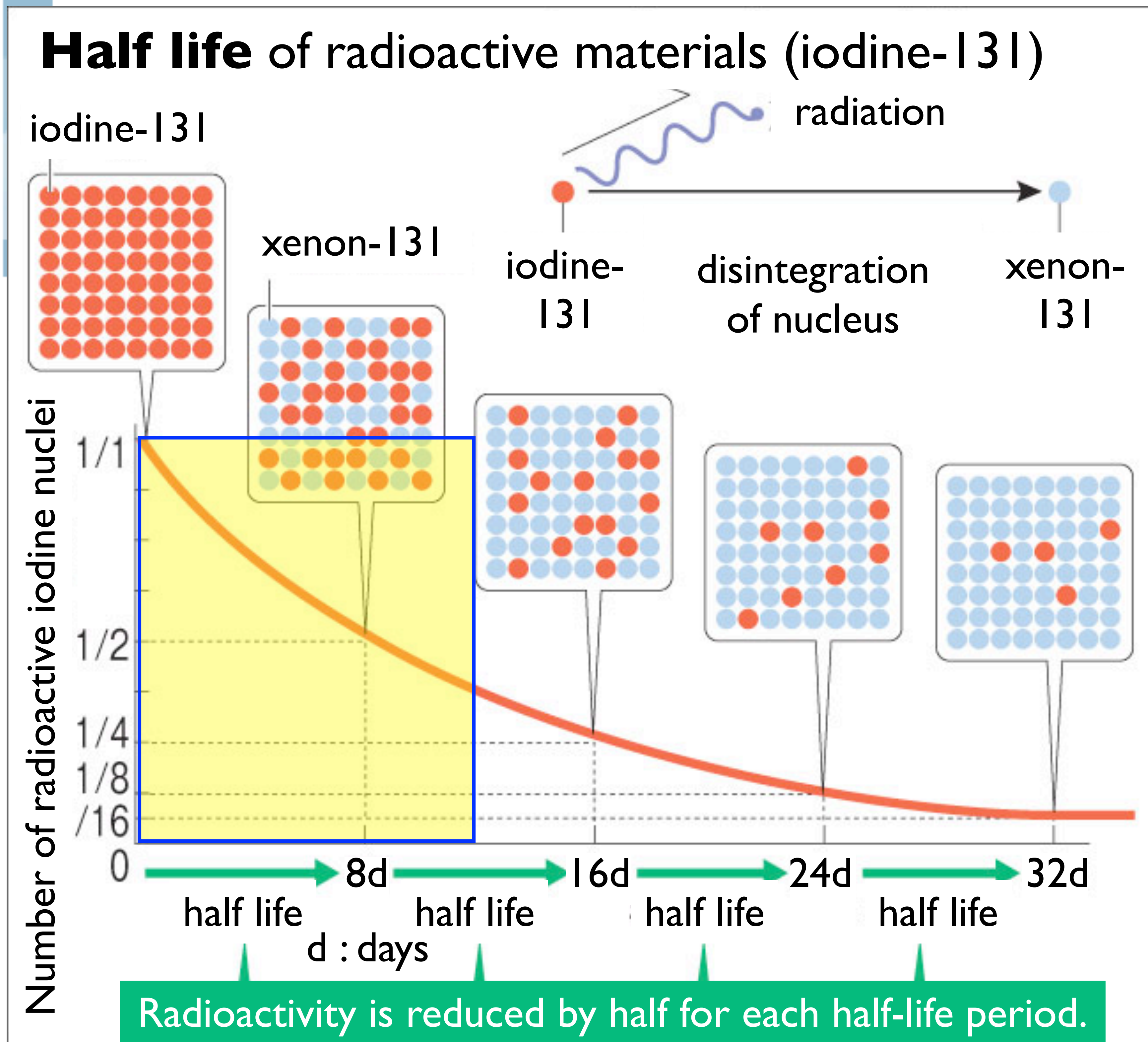




Nuclear Chart

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 ??



Various types of radiation

Billet de 500 Francs Français
en circulation: 1993–1999

α-ray **helium nucleus**
β-ray **electron**
γ-ray **photon** (EM wave)
X-ray **photon** (EM wave)

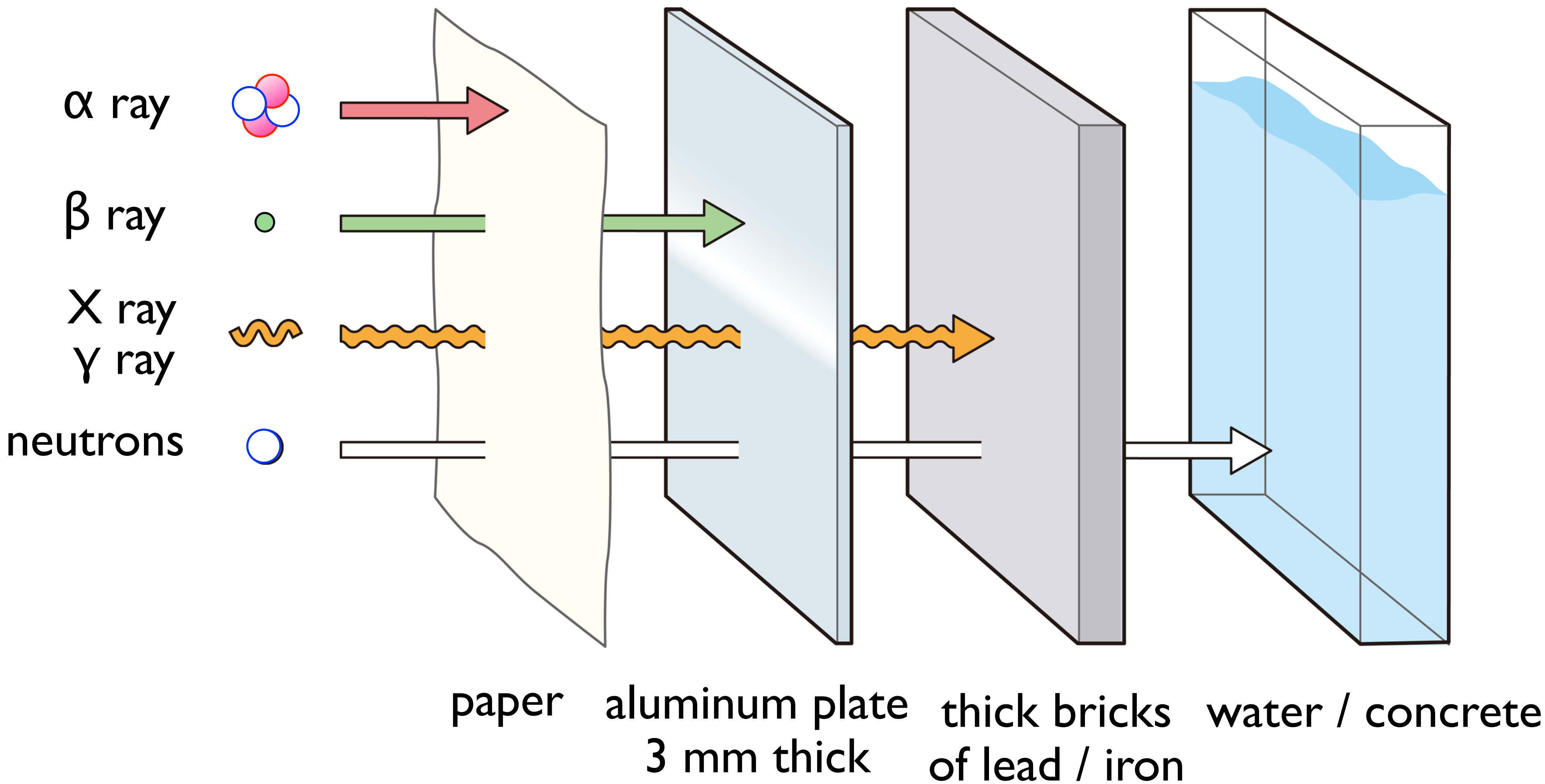
VIDEO

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



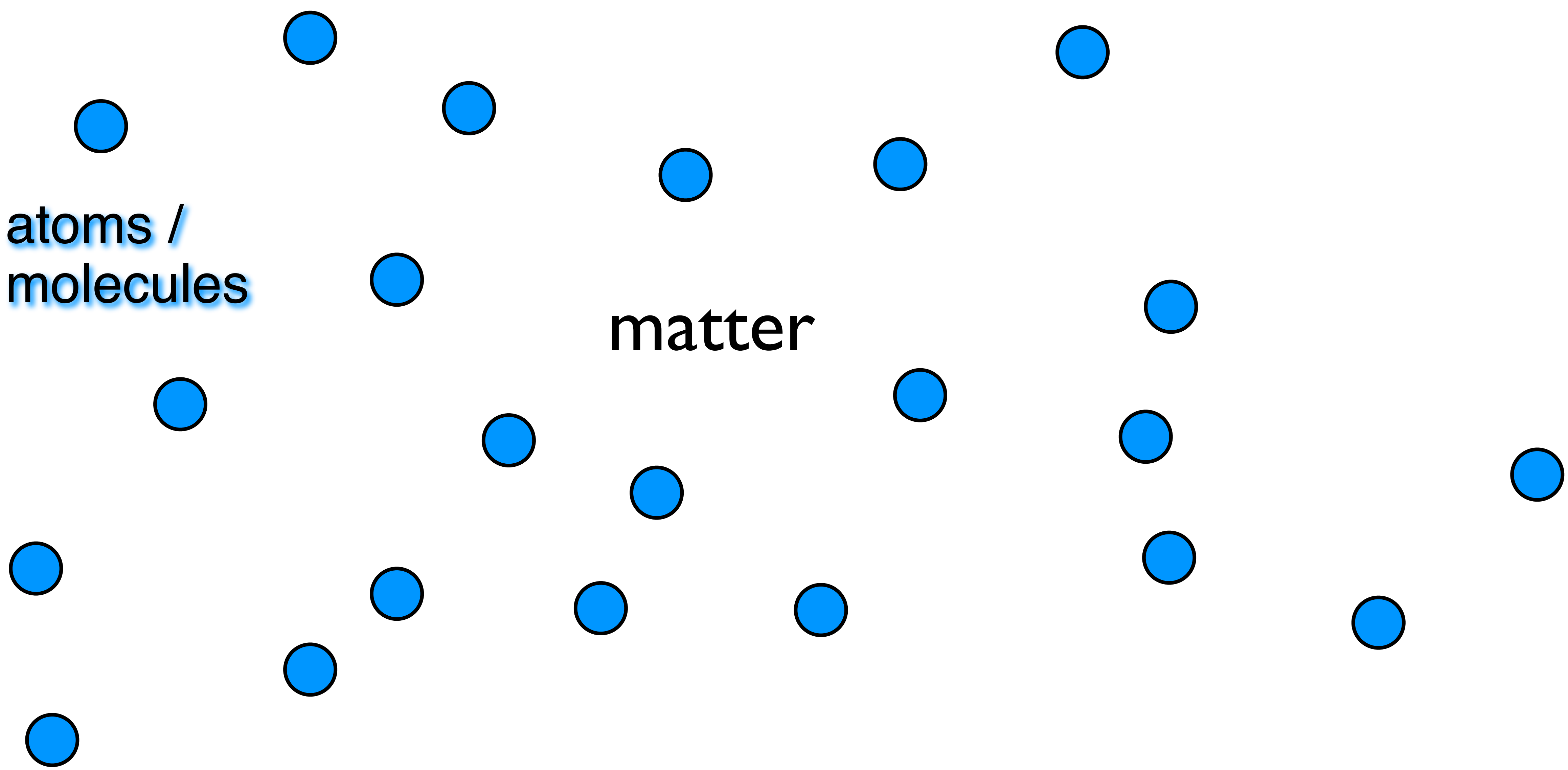
Interaction between Radiation and matter

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 = – d*E* / d*x*



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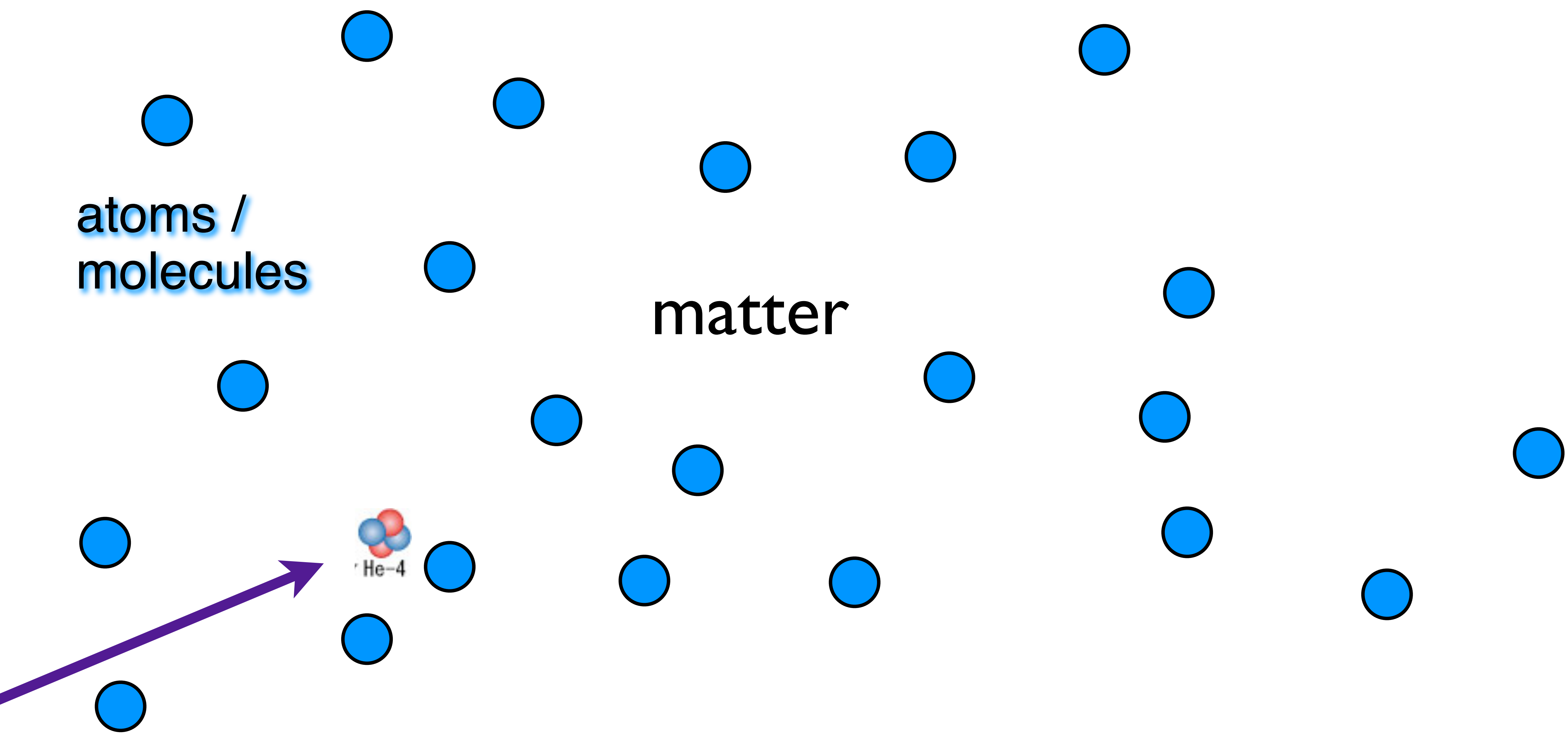

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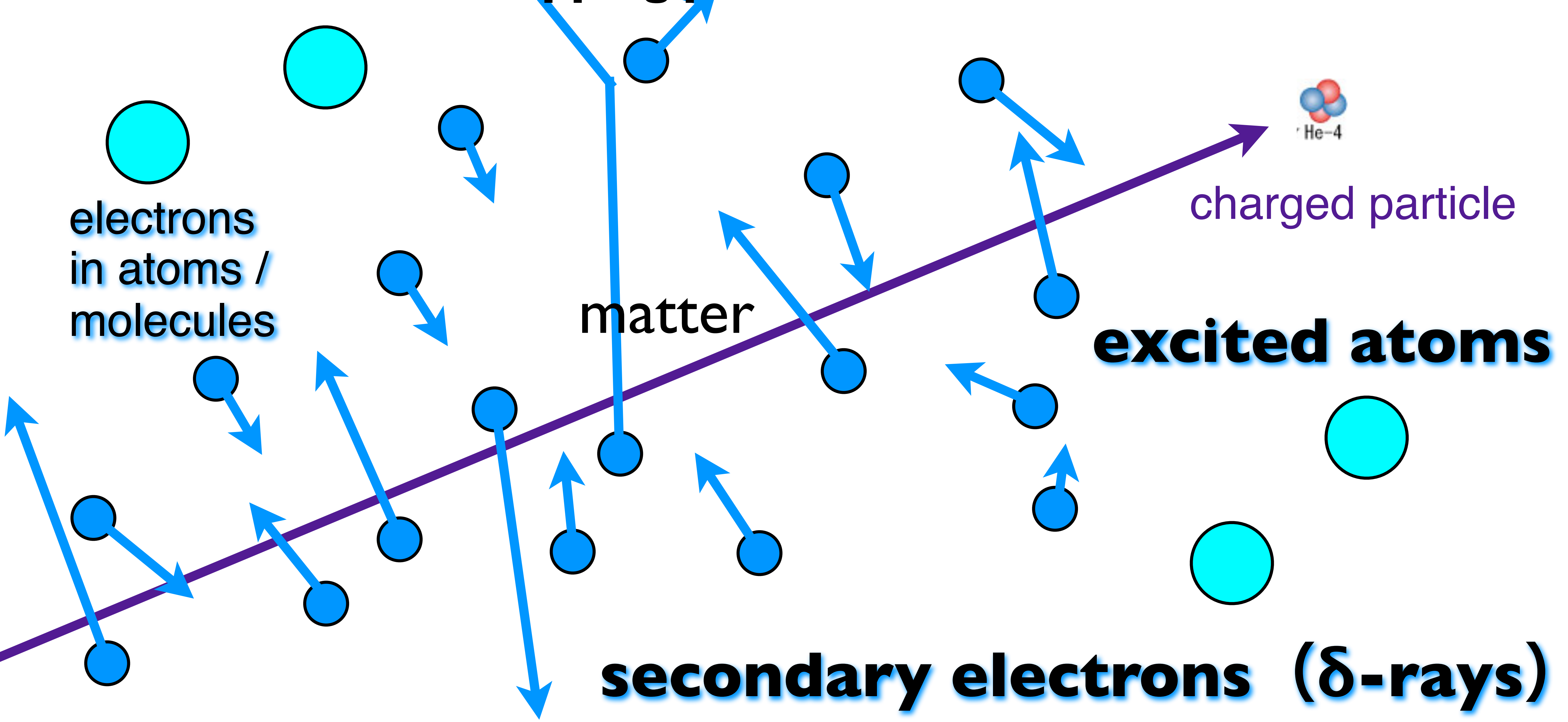
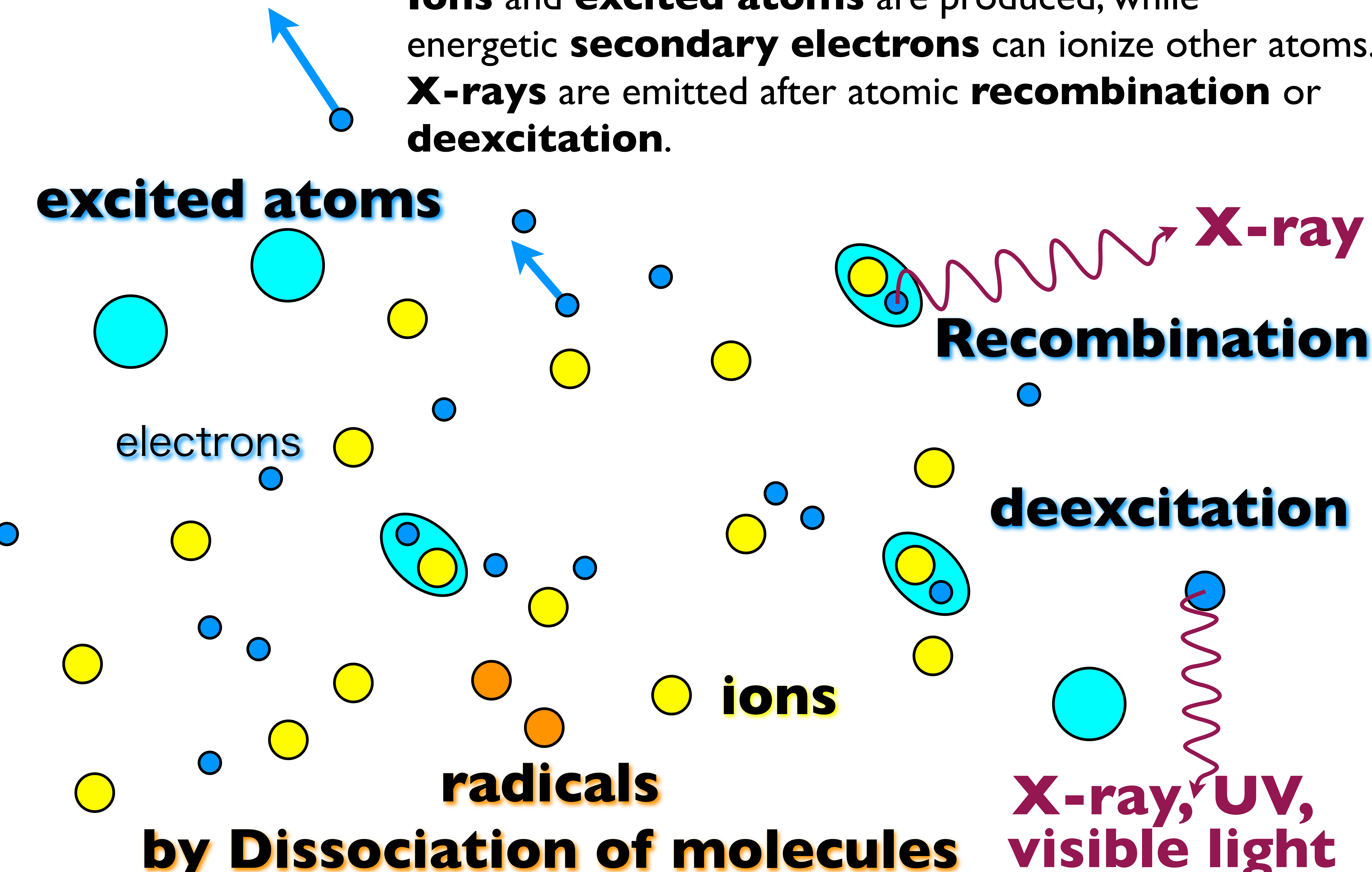


Along the track after passage of charged particles

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



Interaction between Radiation and matter

Attenuation of photons

Slowing-down and energy loss of charged particles (α ray, β ray etc.)

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

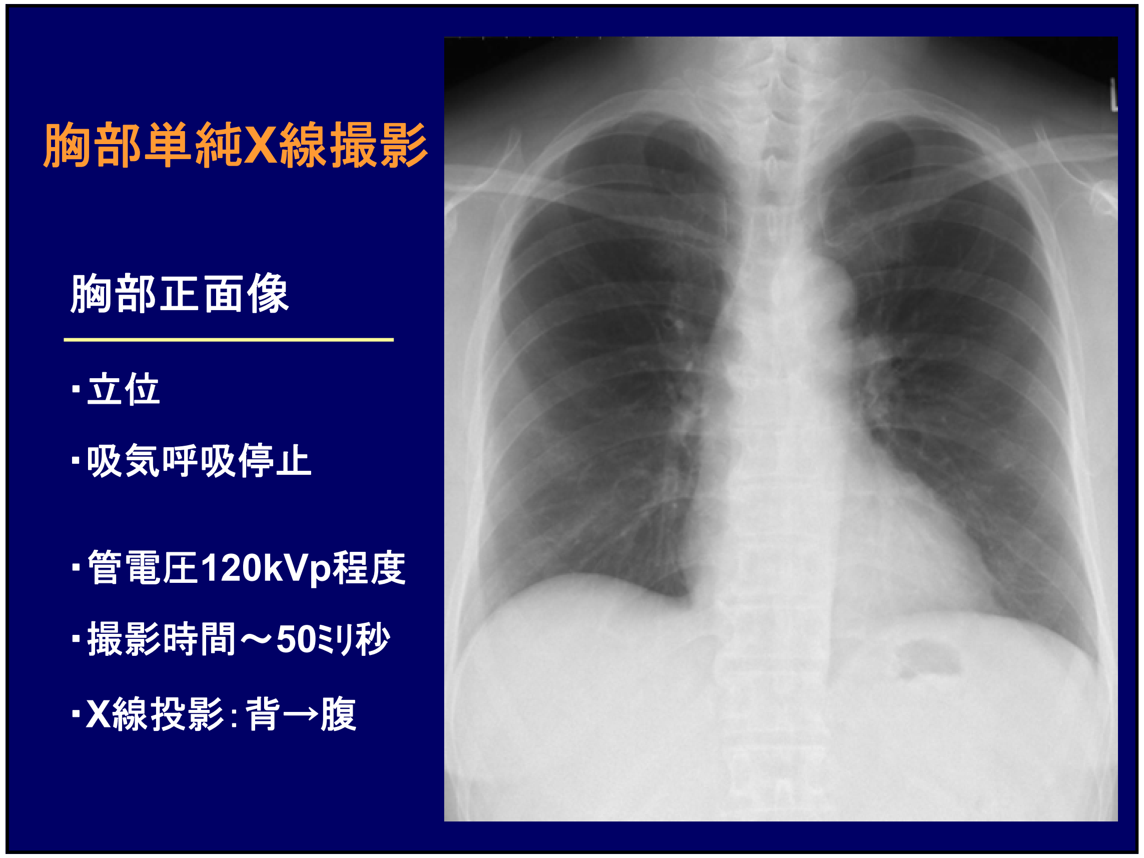
Stopping power = energy loss per unit length = $-\left\langle \frac{dE}{dx} \right\rangle$

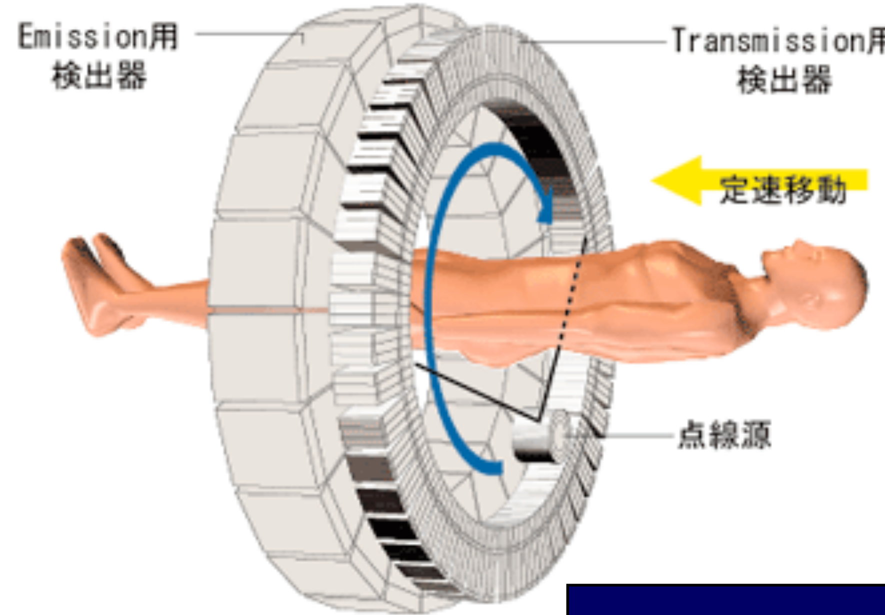
Attenuation of photons (X ray, γ ray)

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

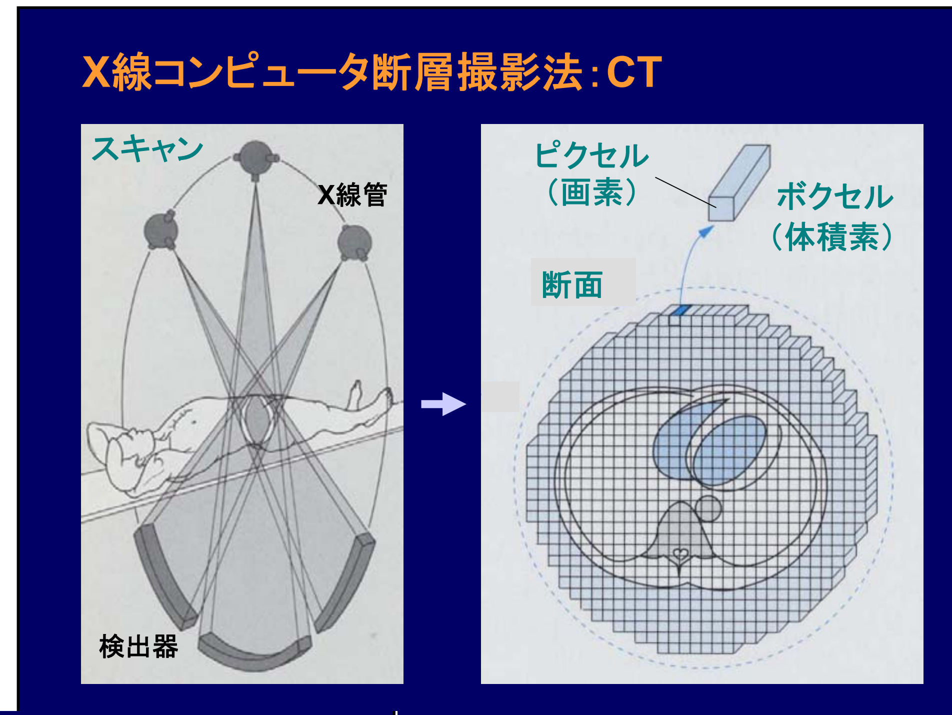
☞ Exponential decrease of photon number

reaction cross section σ gives the reaction probability per unit length.



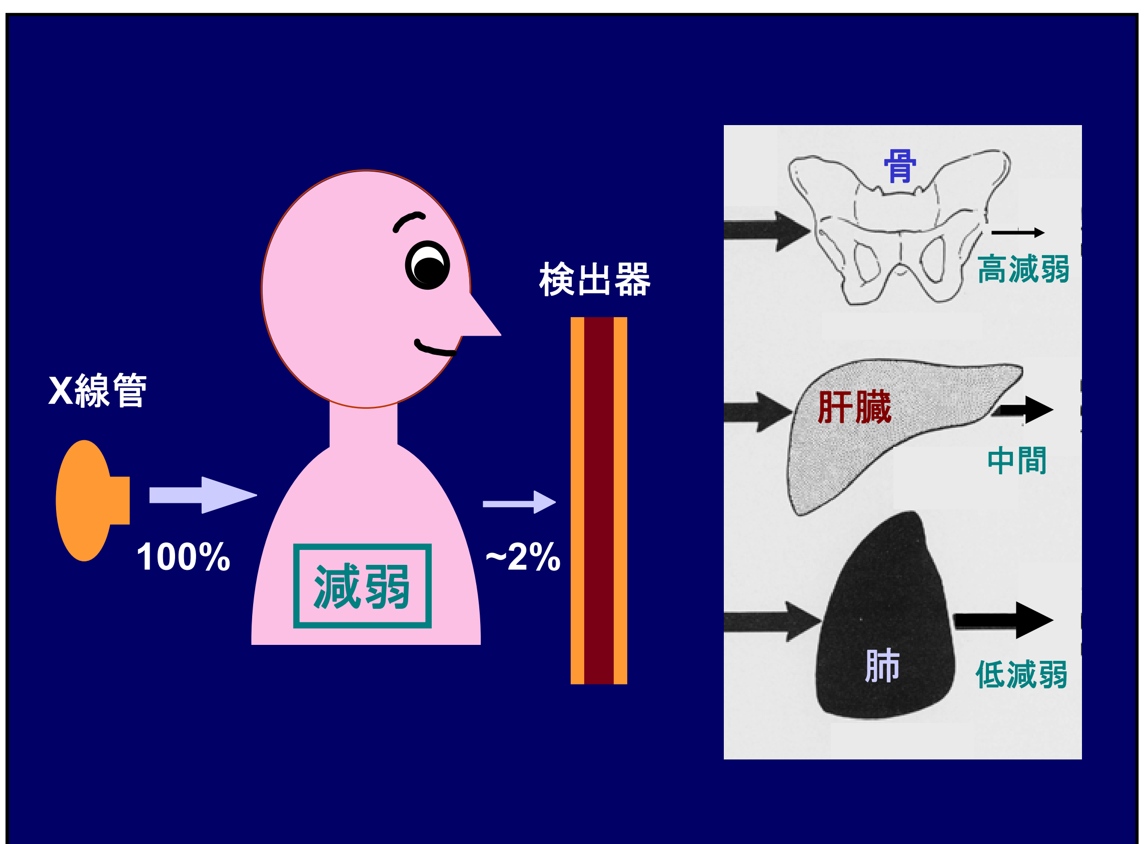


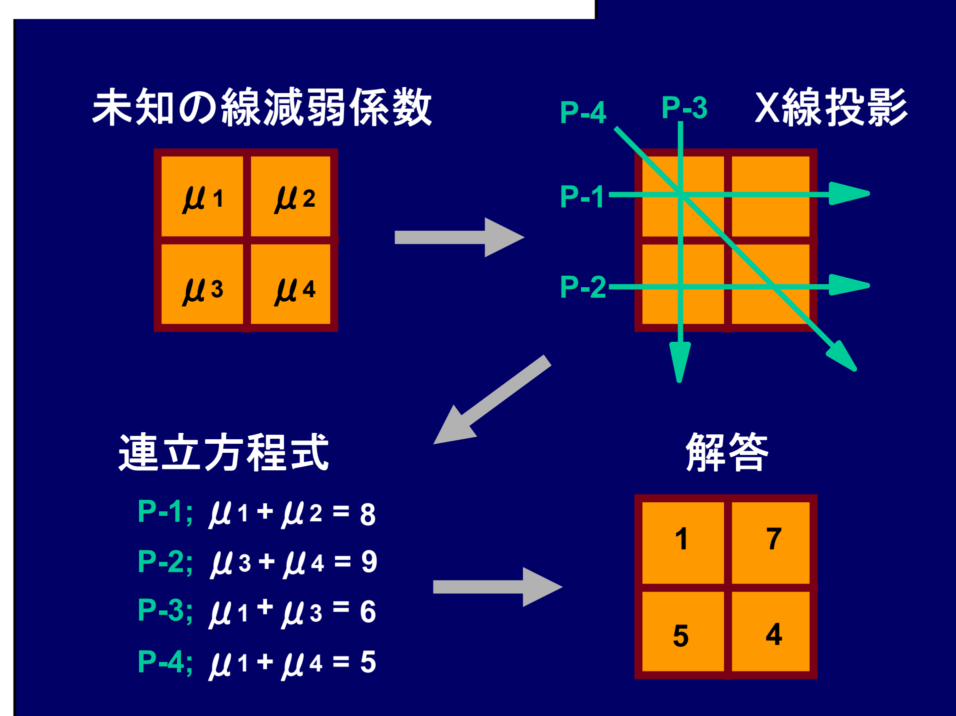
X-ray CT



Röntgen radiography

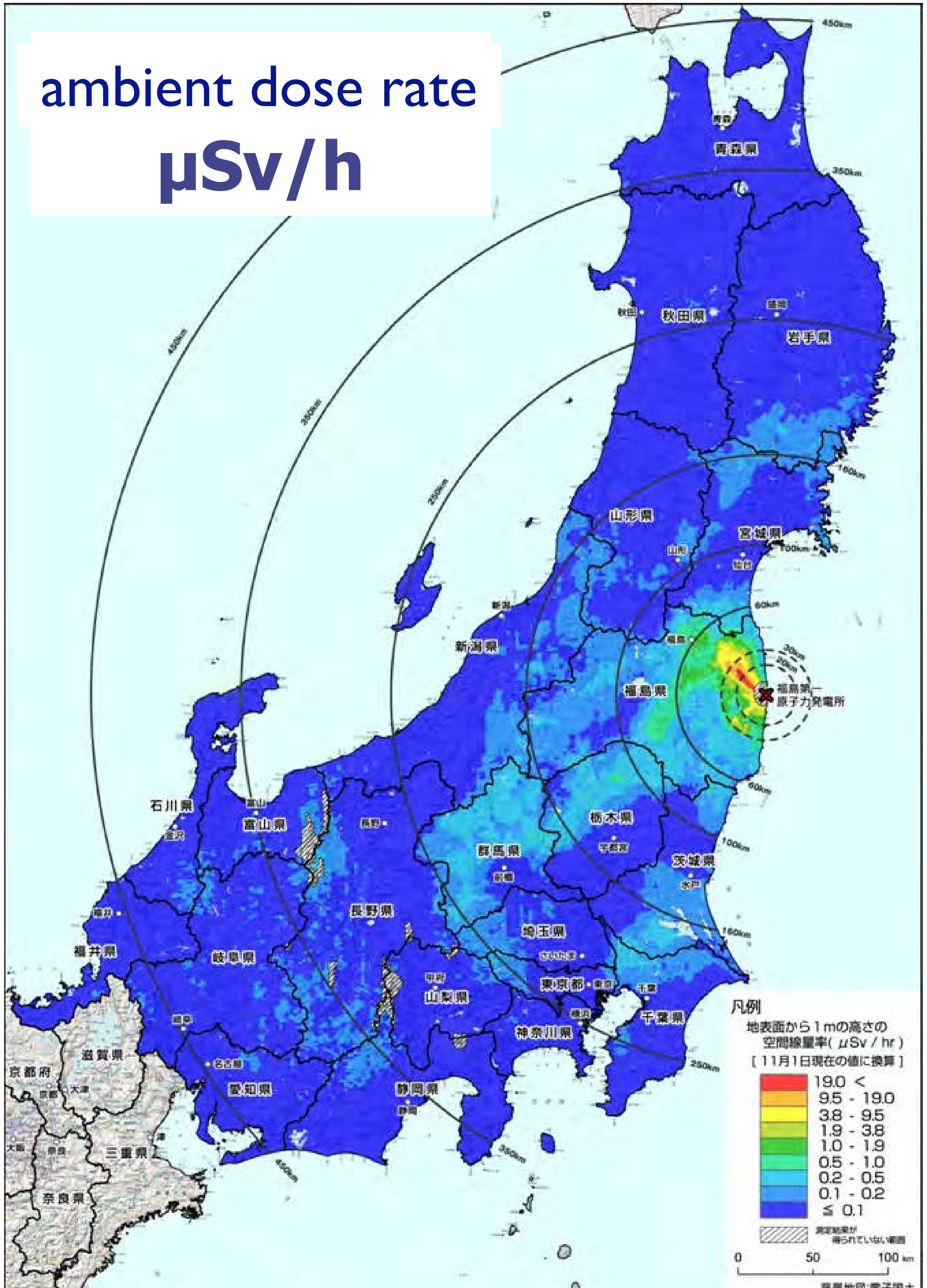
国立循環器病センター 内藤博昭先生のスライドより借用

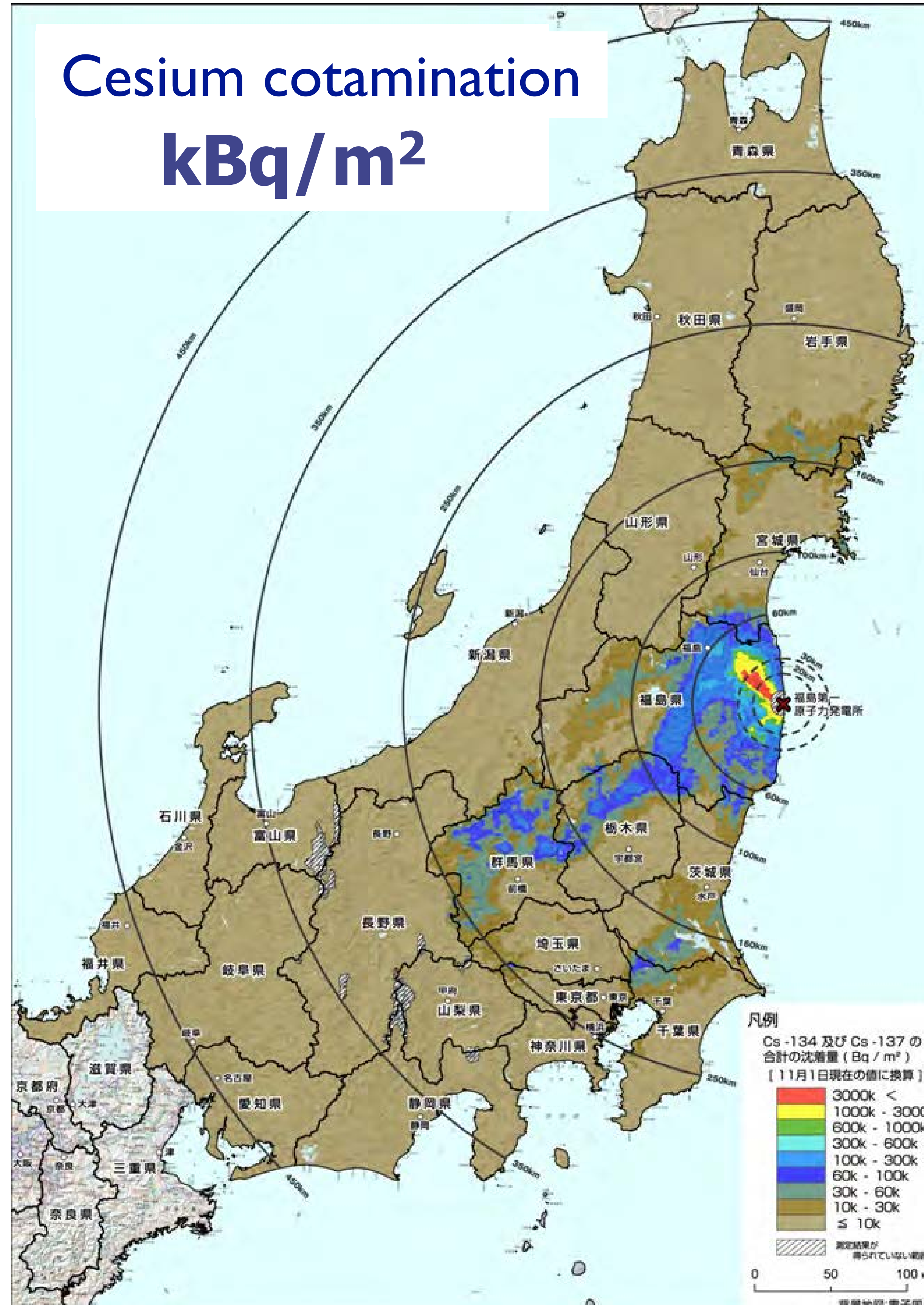




Environmental Radiochemistry

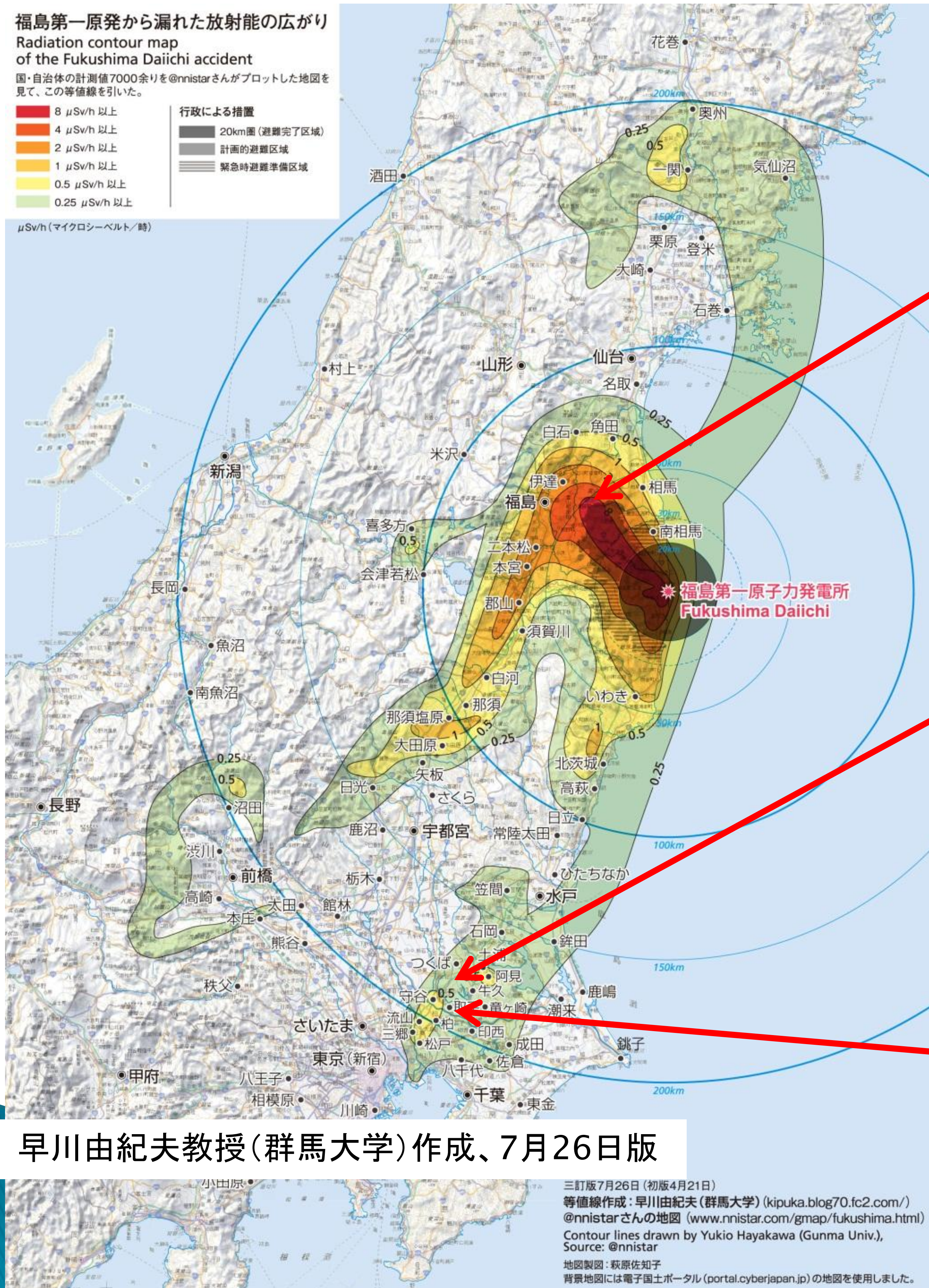
Radioactive contamination map : aerial monitoring by MEXT





http://radioactivity.mext.go.jp/ja/1910/2011/11/1910_1125_2.pdf

Radioactive contamination map



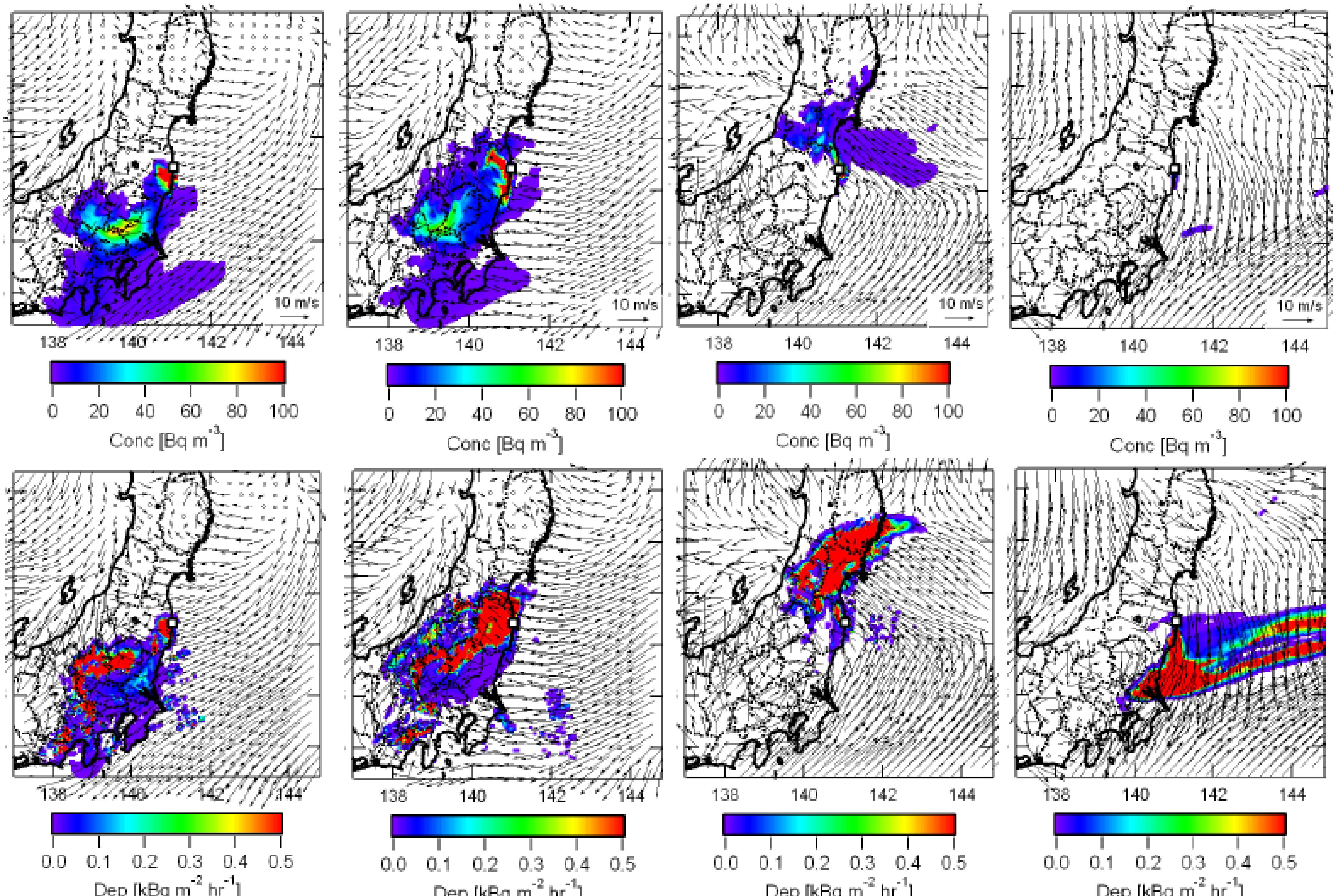
早川由紀夫教授(群馬大学)作成、7月26日版

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

福島の深刻な汚染、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

大原利眞ら, 放射性物質の大気輸送・沈着 シミュレーションの現状と課題
公開ワークショップ「福島第一原子力発電所事故による 環境放出と拡散プロセスの再構築」

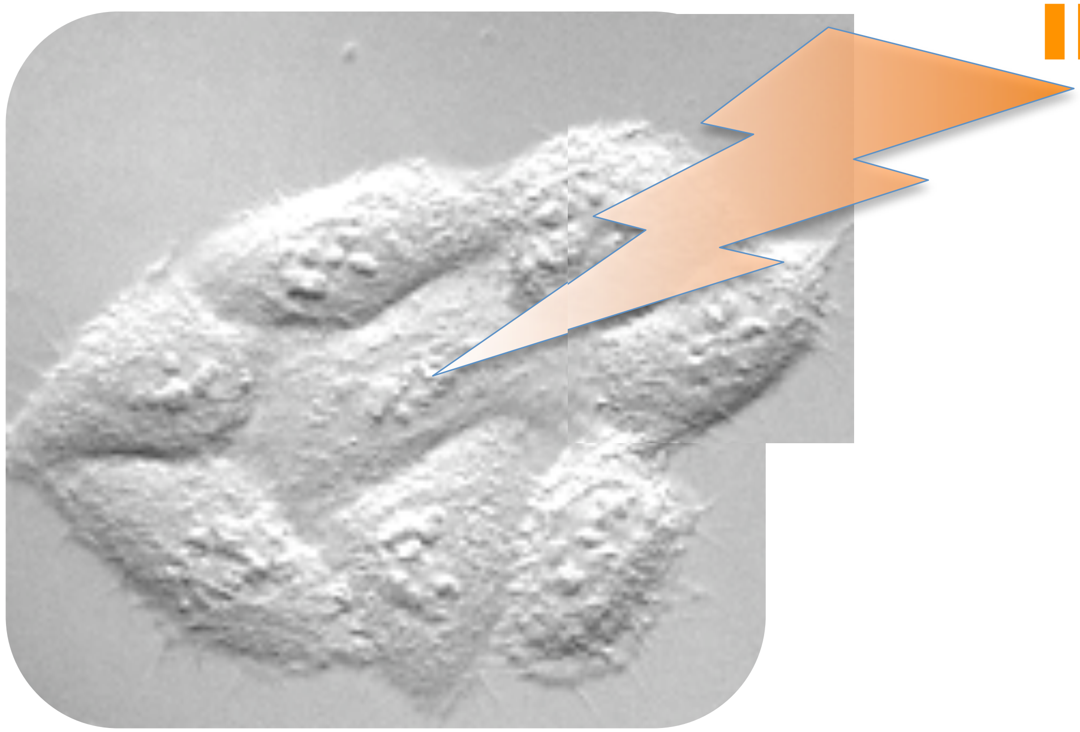
Radiation detectors

早川由紀夫教授（群馬大学）作成、7月26日版

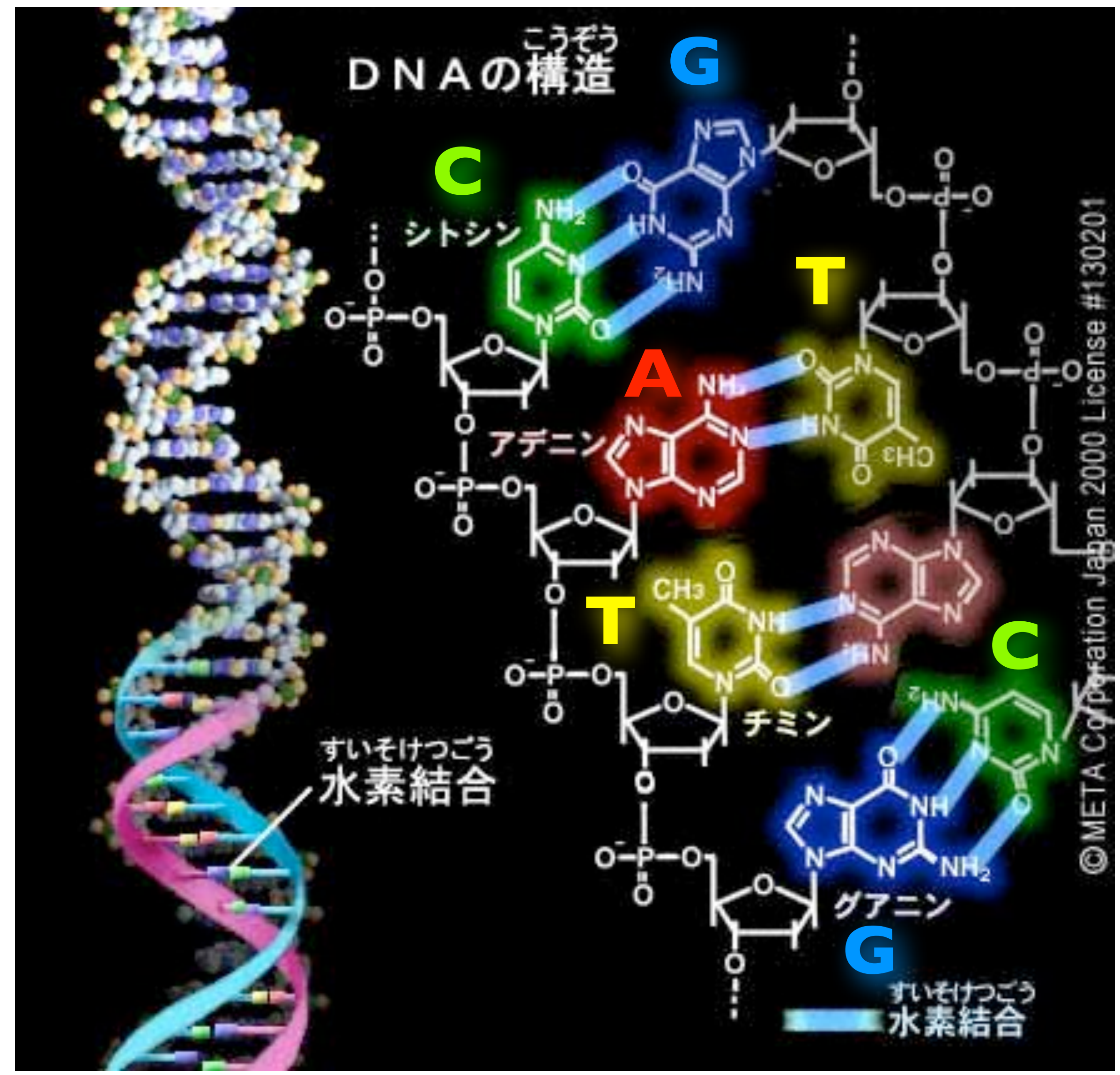
What does protective clothing protect ?

Radiation biology

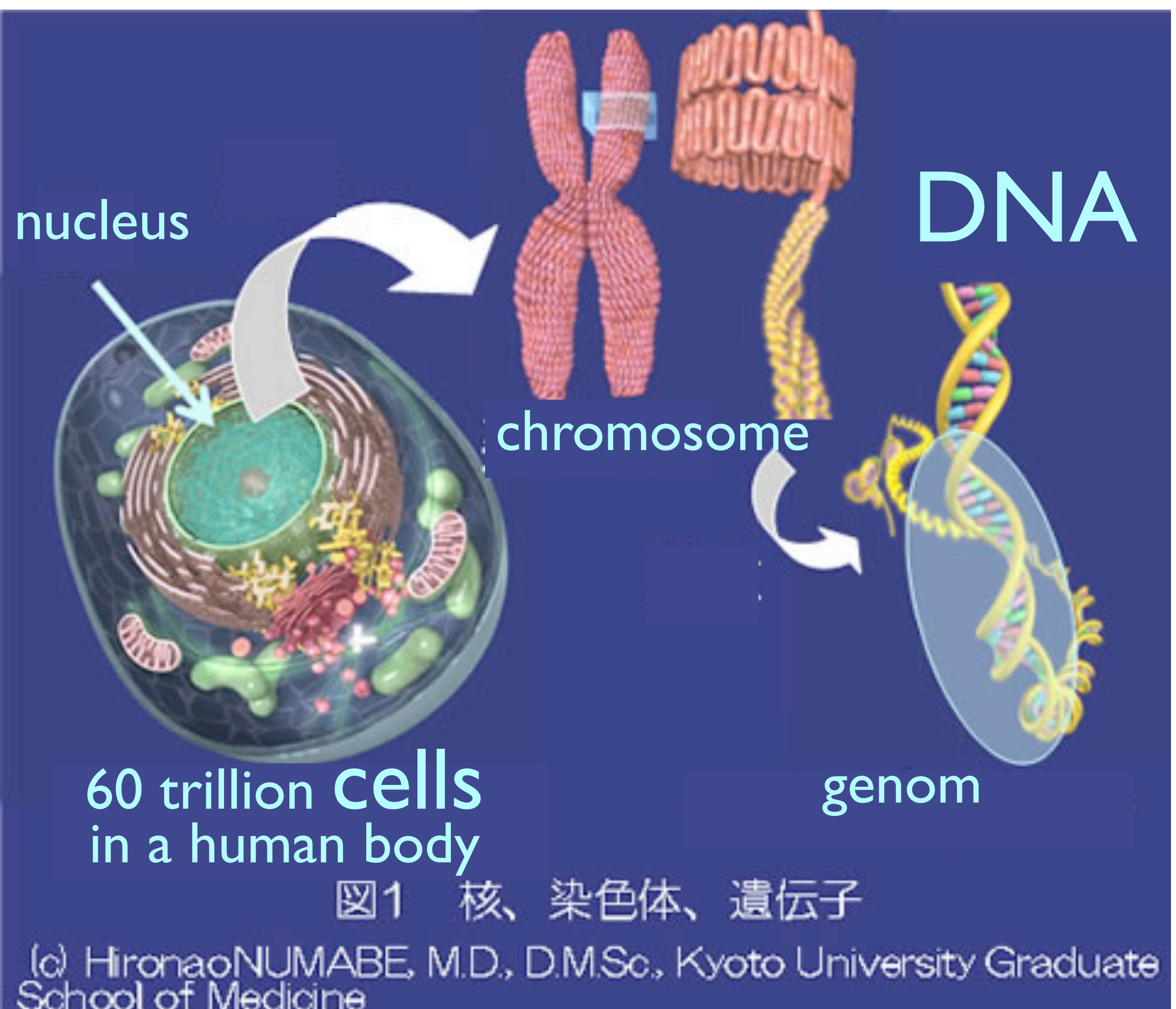
irratiation to cell nuclei



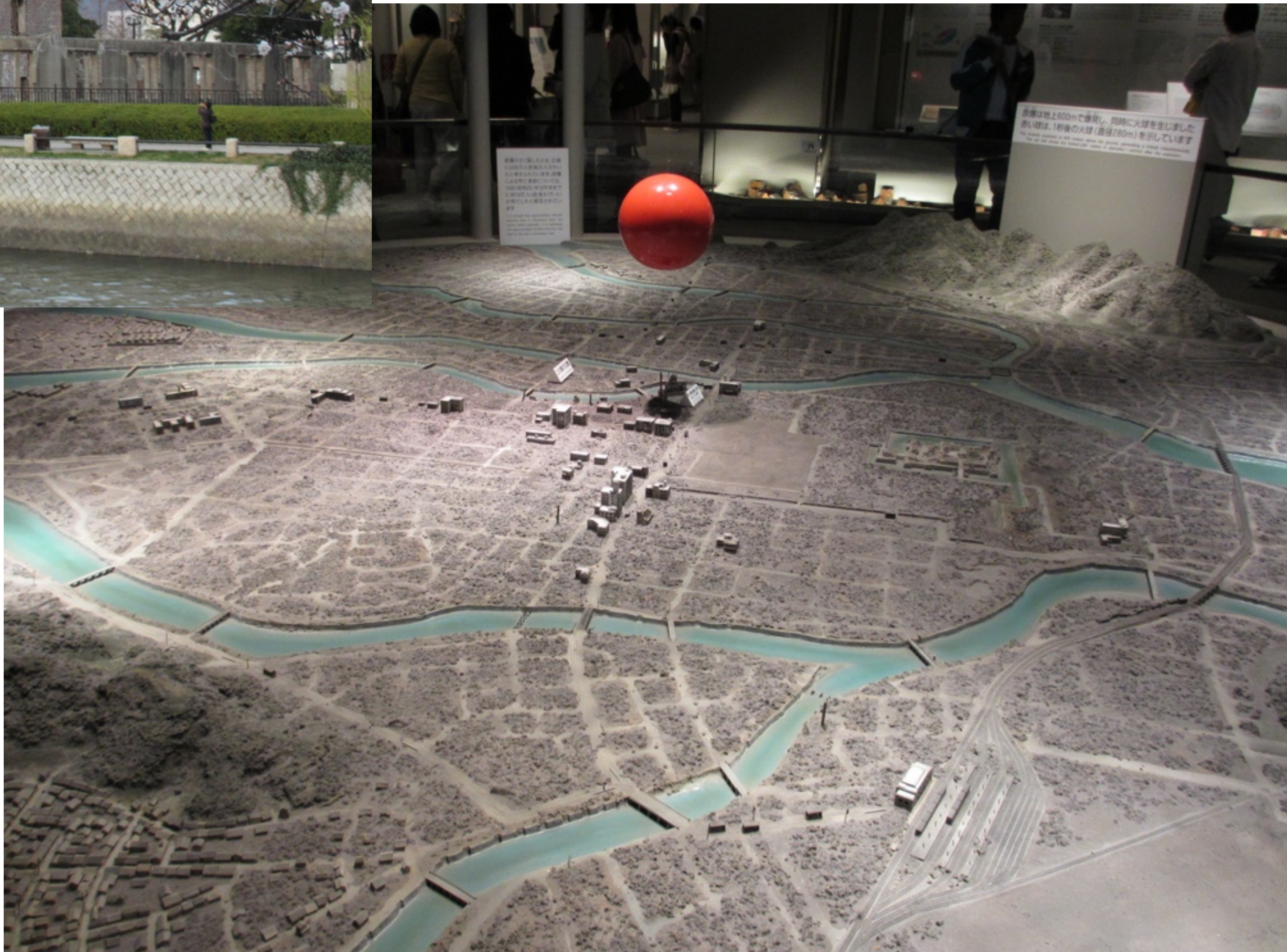
DNA



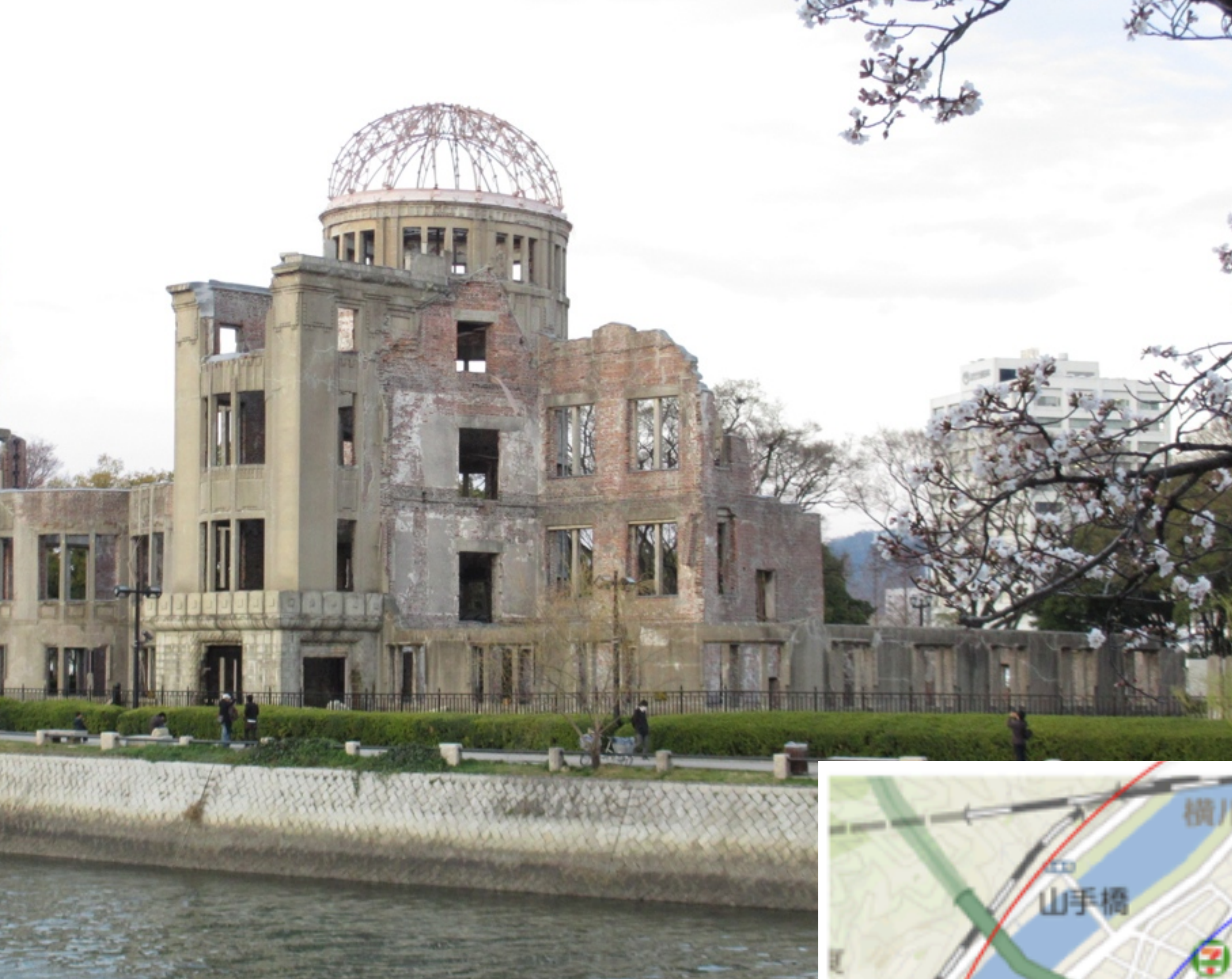
出典：IPA「教育用画像素材集サイト」 http://www2.edu.ipa.go.jp/gz/



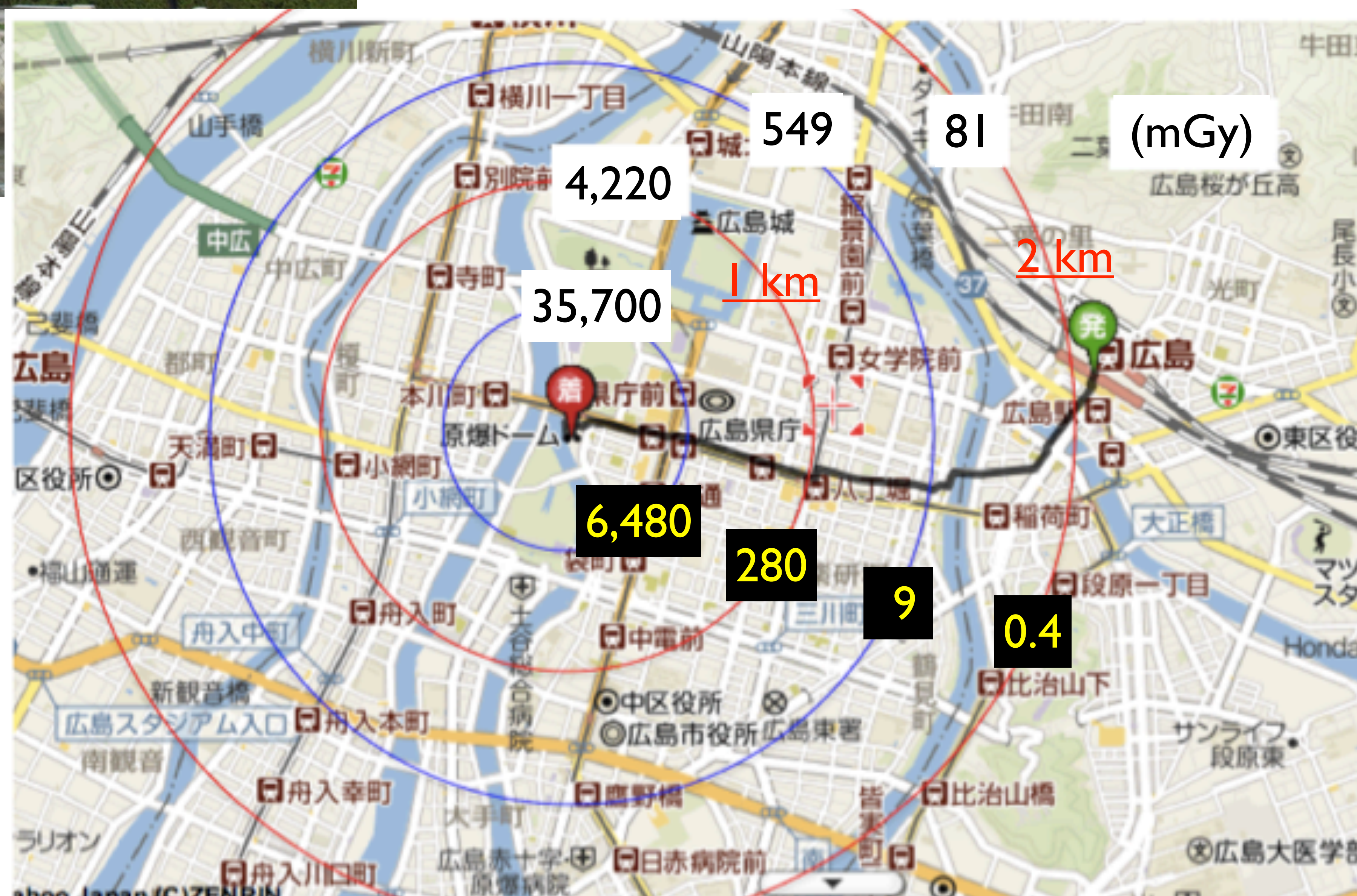
Atomic Bomb Dome in Hiroshima



Atomic Bomb Dome in Hiroshima



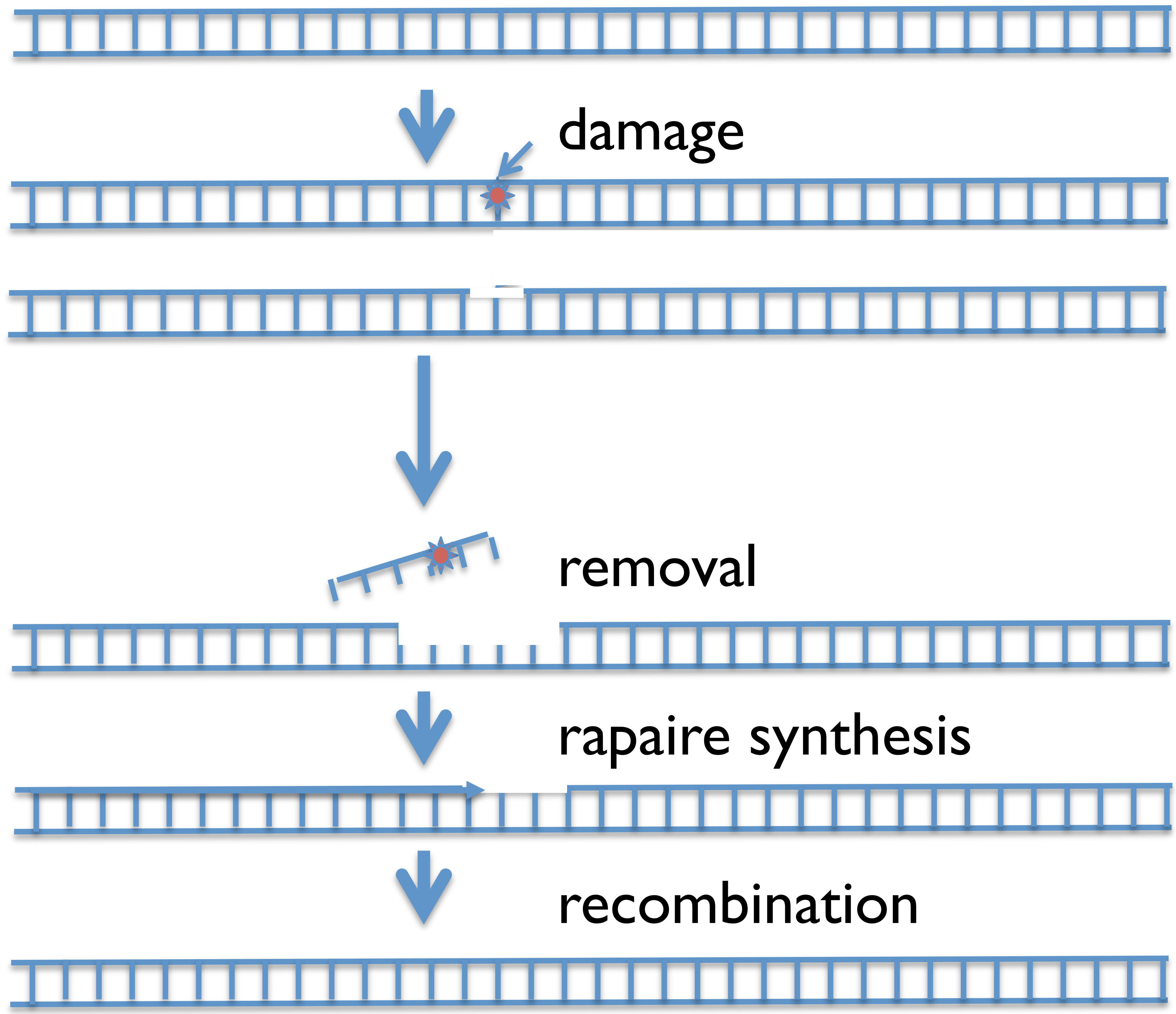
Estimated dose due to γ rays (mGy) due to neutrons



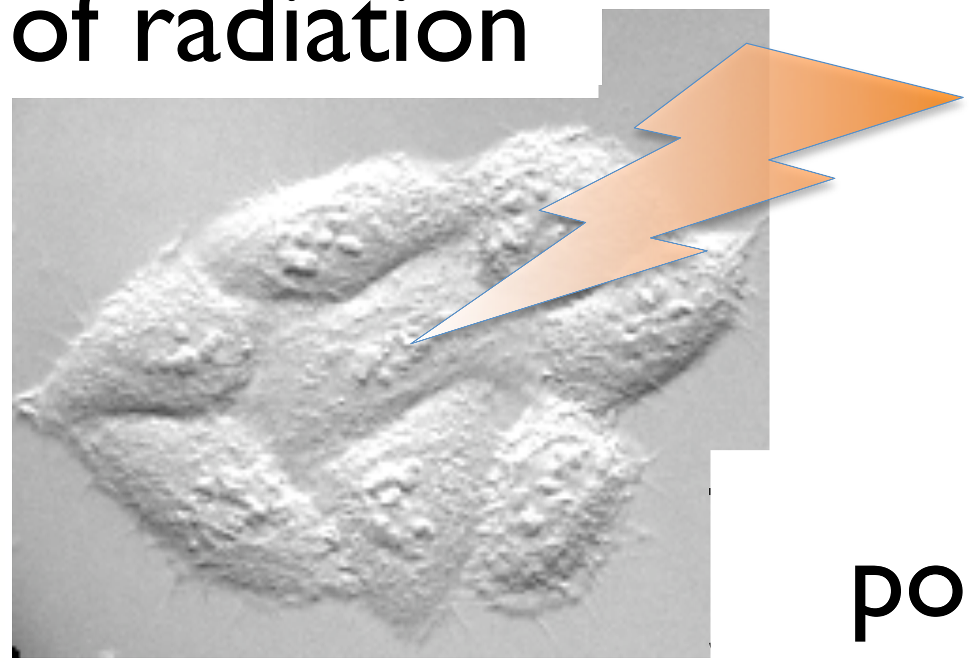
Lethal dose = 4 Gy

Deterministic effects of radiation above threshold dose

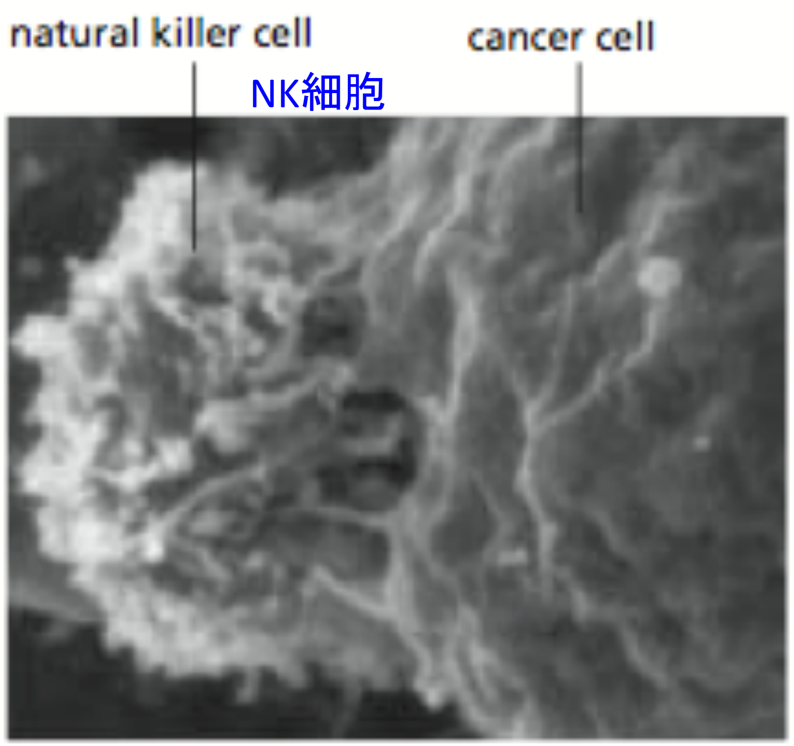
Examples of repair of DNA damages



Stochastic effect of radiation



possibility of cancer



DNA rapair

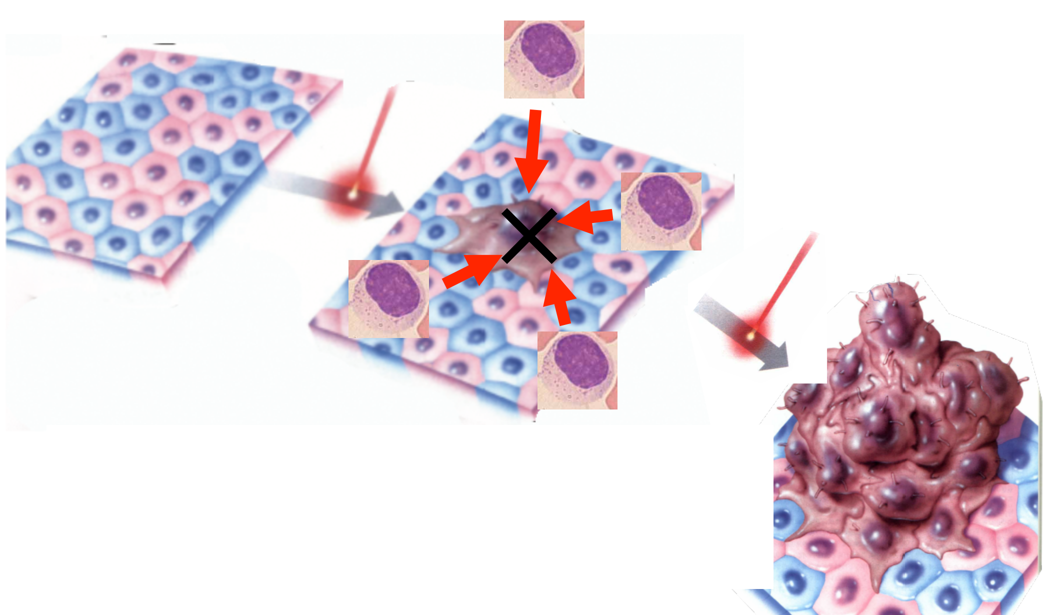
In rare occasions, DNA repair fails.

programmed cell death
(apoptosis)

apotosis mechanism fails to work.

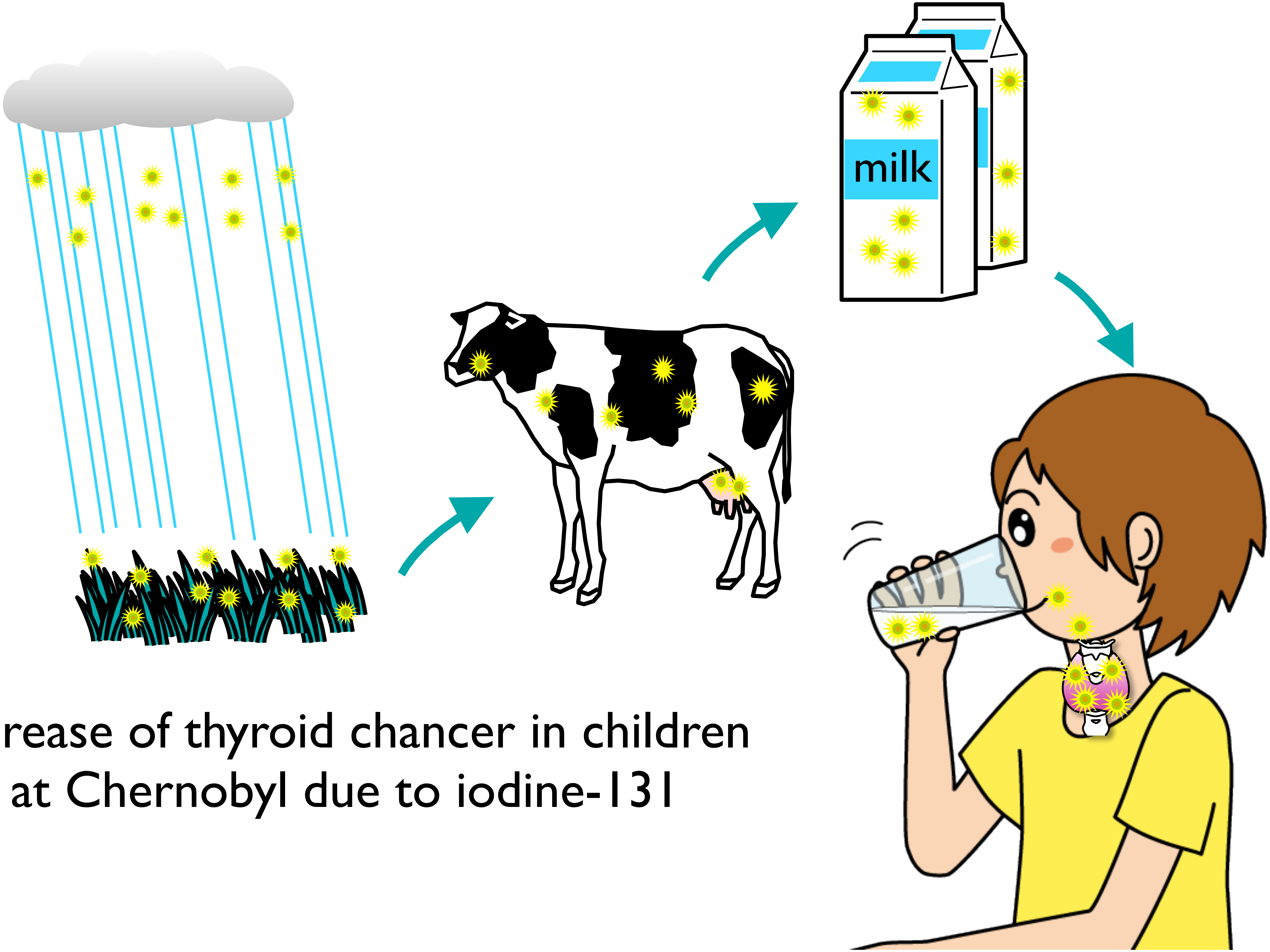
Cancer cells are killed by
NK cells of the immune system

Some cancer cells avoid being caught.



Cancer cells remains and proliferates

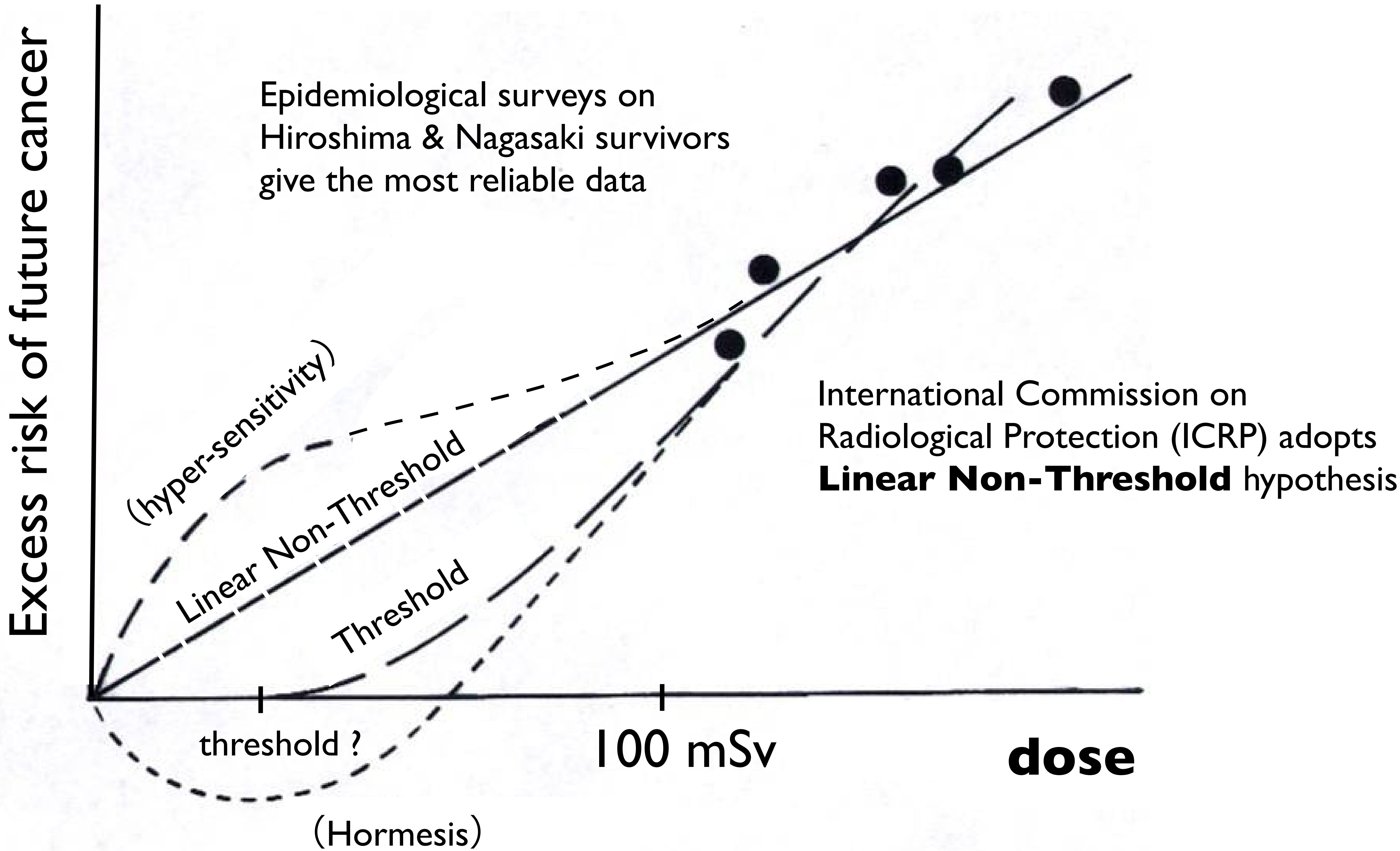
benign / malignant / infiltrative



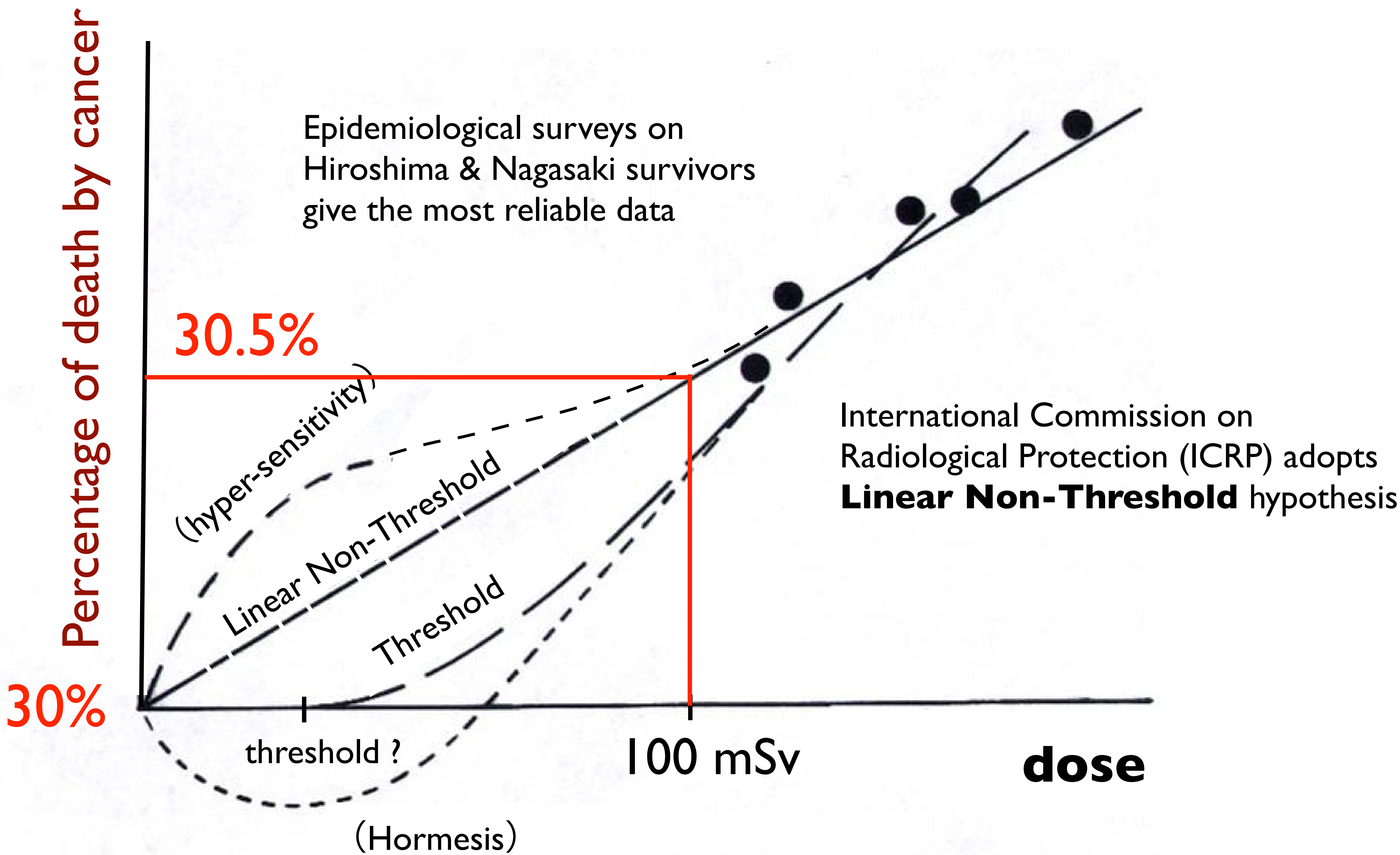
Increase of thyroid chancer in children
at Chernobyl due to iodine-131

Radiation protection & risk evaluation

Risk evaluation at low dose



Risk evaluation at low dose

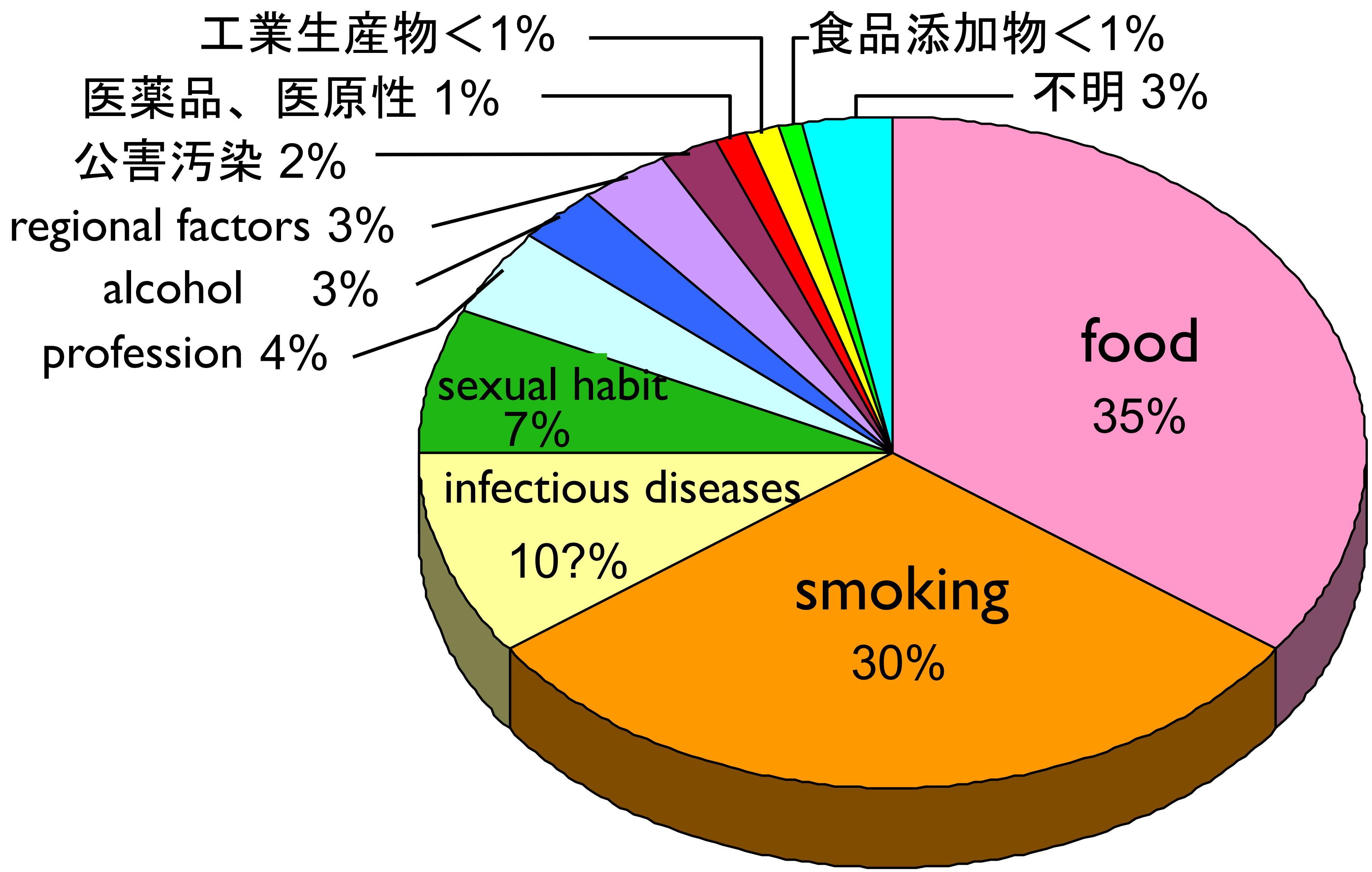


Relative risk of cancer

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 excercise	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	
smoking	1.6 x
Drinking > 540 mL of sake	
Exposure to radiation dose of 1000～2000 mSv	1.8 x

※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】

β (γ) / γ

GM counter

β (γ) / γ

ioniz. chamber

NaI (Tl)

γ

CsI (Tl)

β (γ)

γ

【Surface contamination check】

β (γ)

GM counter

α

ZnS (Ag)

Radiometry

measurement of radioactivity★ in the sample

γ

Germanium (Ge) detector

Semiconductor detectors

例：Si(Li) detector (for X-rays)

Ge detector (high resolution) (for γ/X-rays)

radiation ⇒ ionization

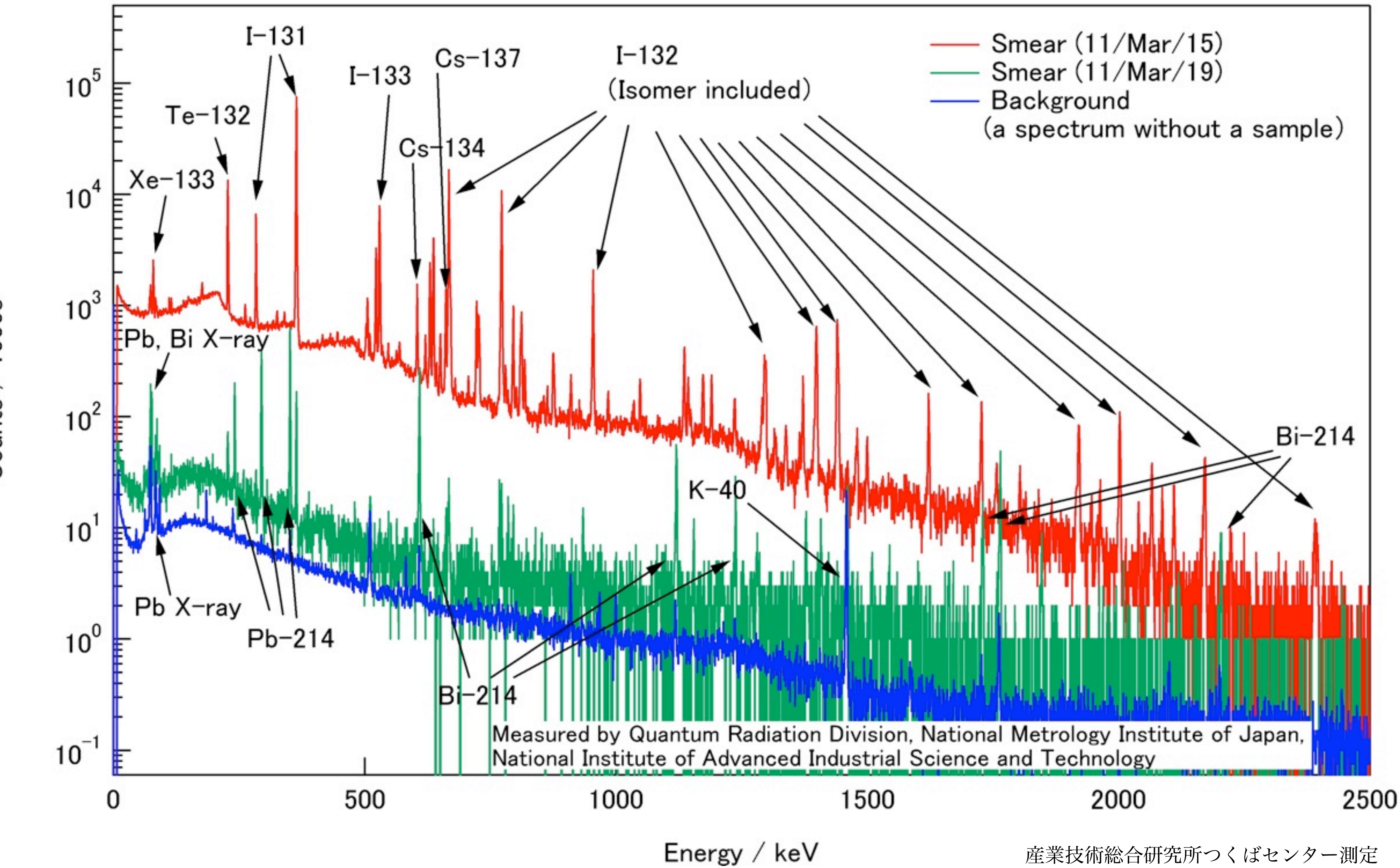
⇒ electron-hole pair ⇒ charge measured

Ge detector for check of food samples

Energy analysis
= identification of nuclides

Energy analysis = identification of nuclides

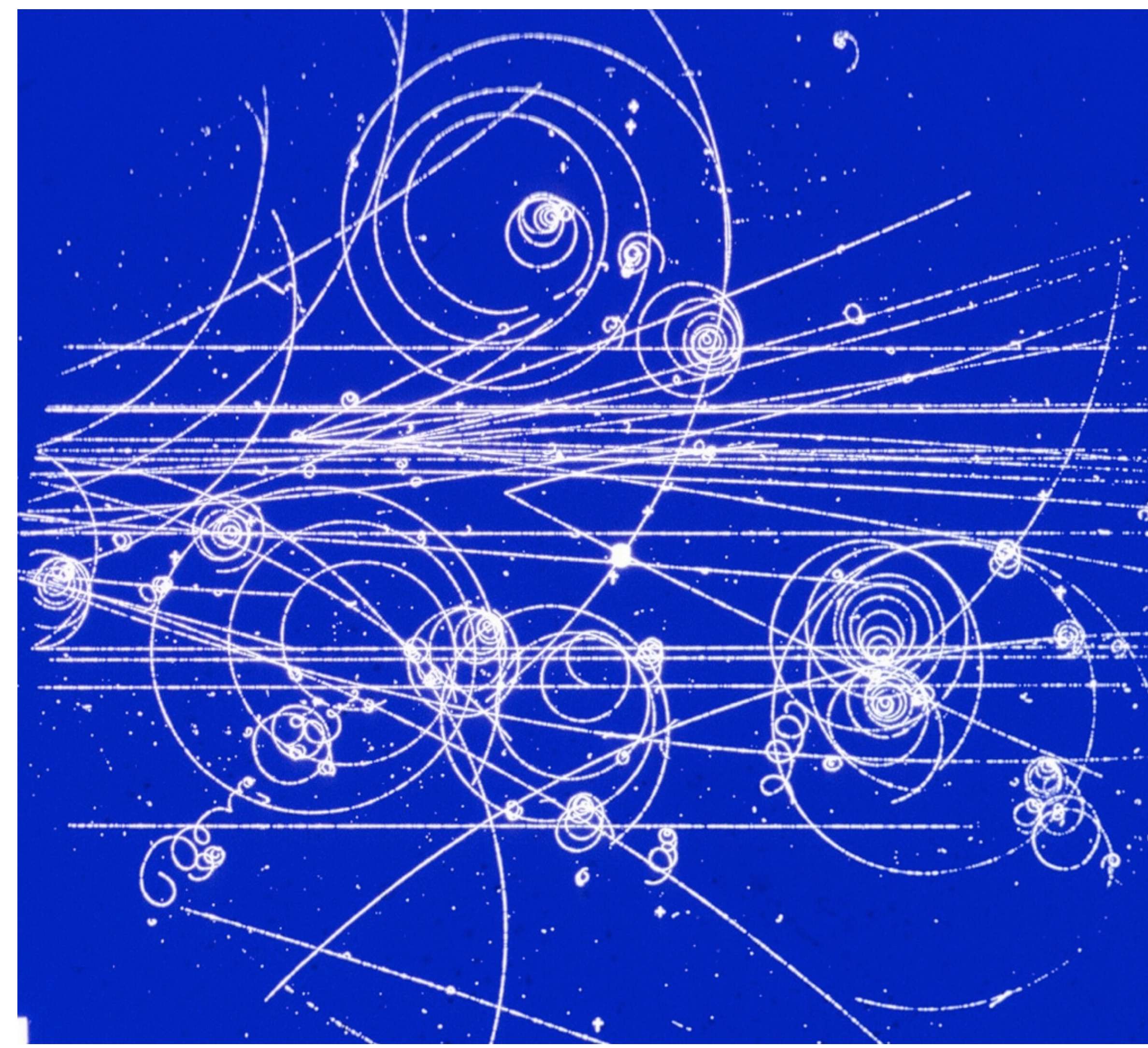
γ-ray energy spectrum by the Ge detector



産業技術総合研究所つくばセンター測定

泡箱

Bubble chamber



Fine.

Grazie per vostro 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