Radiation Safety Course
(School of Science, the University of Tokyo)

Biological Effects of Radiation to Human Body

FY2023

Japan begins releasing treated water from Fukushima Daiichi plant

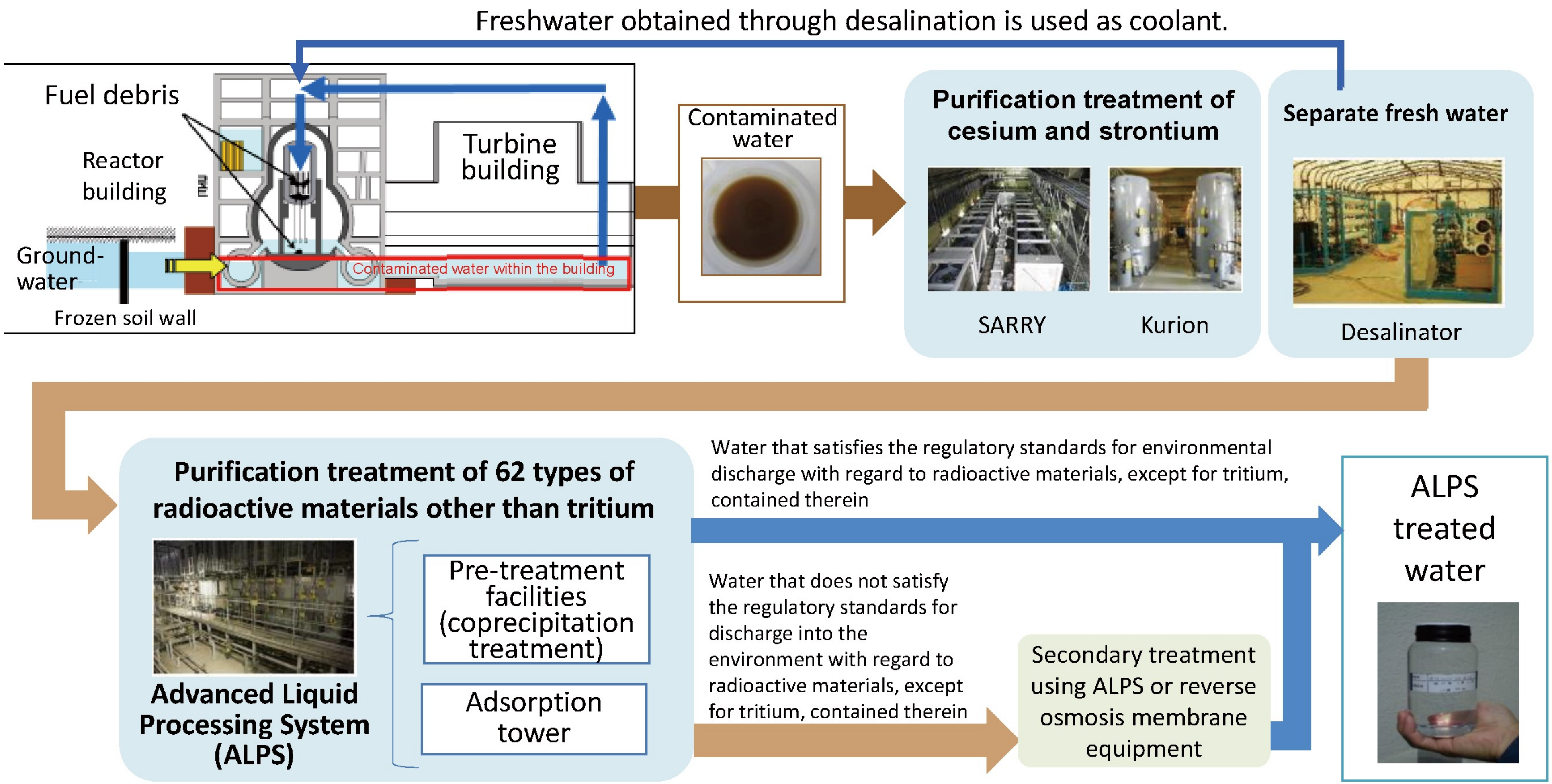
Thursday Aug. 24, 2023

Tokyo Electric Power Company said it has started discharging treated and diluted water from the Fukushima Daiichi nuclear power plant. The first round of the release will happen over 17 days. The full process could take at least 30 years to complete.

Cited from NHK WORLD-JAPAN News (https://www3.nhk.or.jp/nhkworld/en/news/)

ALPS Treated Water – Purification of Contaminated Water –

- Contaminated water with radioactive materials is being generated after the accident at TEPCO's Fukushima Daiichi NPS. "ALPS treated water" refers to the water that has been treated by the Advanced Liquid Processing System (ALPS) and other equipment and has been purified to a level where contained radioactive materials, except for tritium, satisfy the regulatory standards for discharge into the environment.



(Source) Prepared based on "Fukushima Daiichi Nuclear Power Station: Contaminated water management: What is 'slurry'? Why is it generated? How is it stored?" by the Agency for Natural Resources and Energy (https://www.enecho.meti.go.jp/en/category/special/article/detail_157.html)

経済産業省 Ministry of Economy, Trade and Industry

Nuclides Other than Tritium

- Contaminated water generated at TEPCO's Fukushima Daiichi NPS not only contains tritium but also contains Cesium 137, Strontium 90 and other radioactive materials which are seldom detected in water discharged from ordinary nuclear power stations.
- Out of those radioactive materials, 62 types of nuclides that are likely to be contained in the contaminated water at certain levels in consideration of regulatory standards respectively set for those types of nuclides are purified by the use of the Advanced Liquid Processing System (ALPS) and other equipment to the extent that their concentrations become below those regulatory standards.

Nuclides to be purified using ALPS (62 types)

Major seven types:

- Cesium 137
- Cesium 134
- Strontium 90
- Cobalt 60
- Antimony 125
- Ruthenium 106
- Iodine 129

55 types:

- ·
- ·
- ·
- Technetium 99

Other nuclides:

- Carbon 14
- ·
- ·
- ·

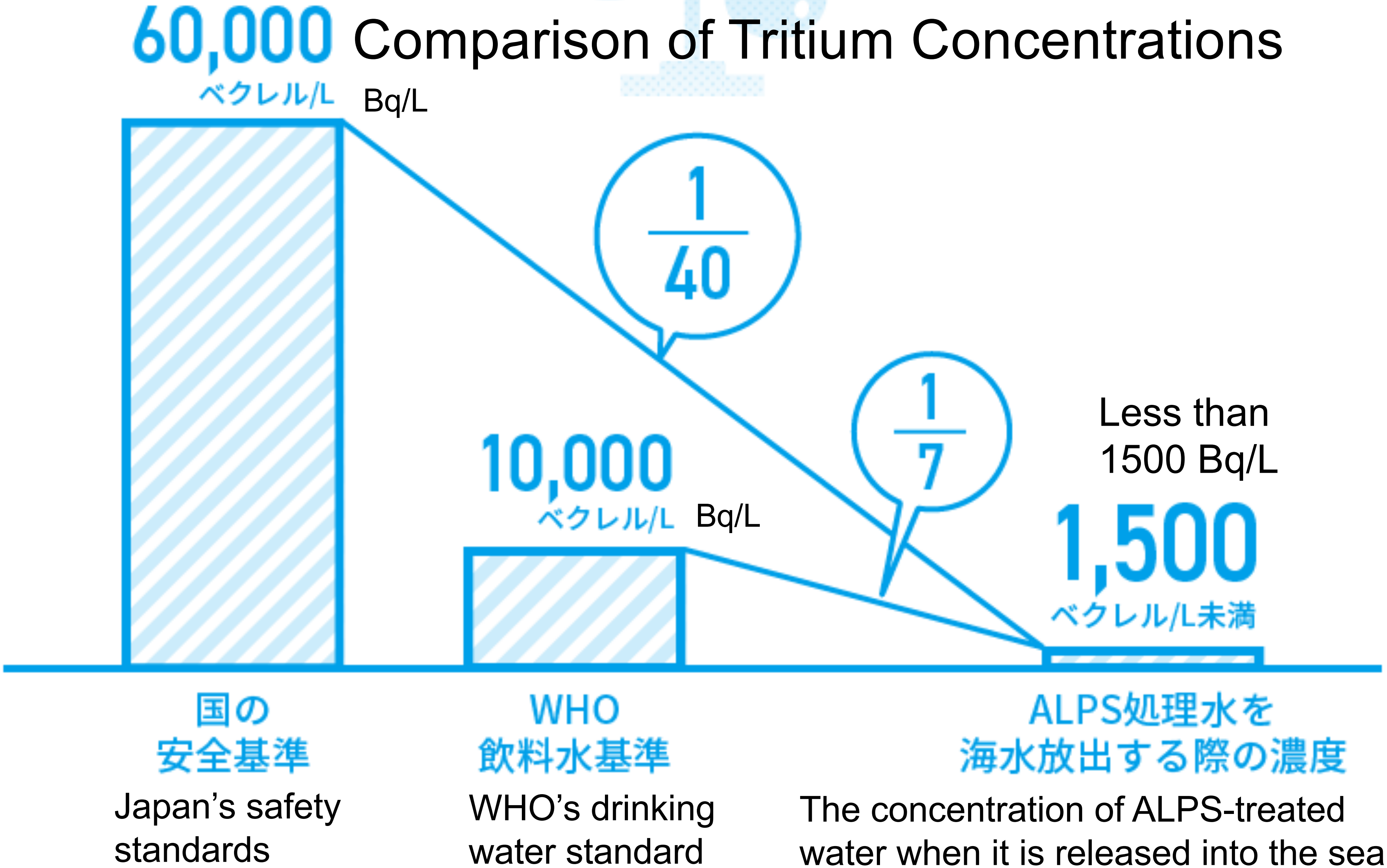
(Source) Prepared based on "Advanced Liquid Processing System (ALPS)" (https://www.tepco.co.jp/nu/fukushima-np/f1/genkyo/fp_cc/fp_alps/) (in Japanese) and "Performance test regarding secondary treatment of ALPS treated water," etc. by Tokyo Electric Power Company Holdings

経済産業省
Ministry of Economy, Trade and Industry

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

トリチウム濃度の比較

Comparison of Tritium Concentrations

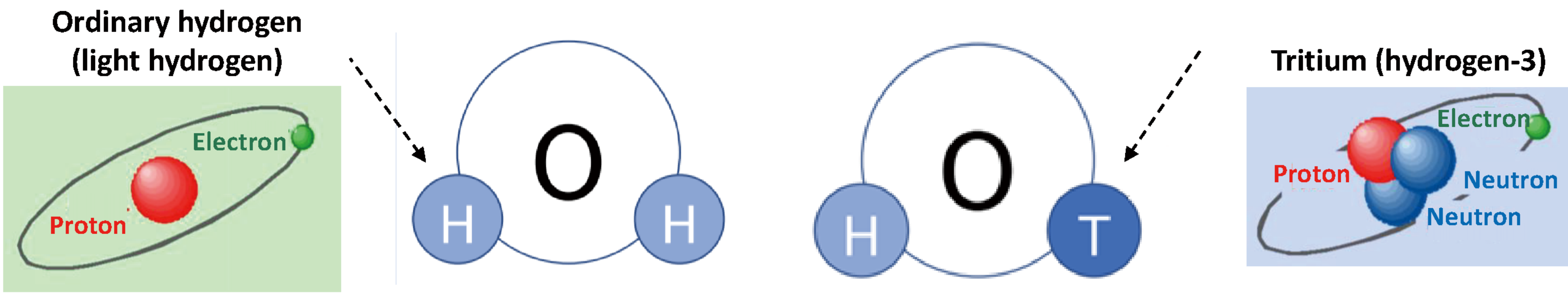


Cited from METI website（https://www.meti.go.jp/earthquake/nuclear/hairo_osensui/shirou_alps.html）

Characteristics of Tritium

Tritium is a radioisotope of hydrogen, called "hydrogen-3."

【Structure of water molecules】



Water molecule solely consisting of ordinary hydrogen

H_2O

Water molecule consisting of ordinary hydrogen and tritium

HTO

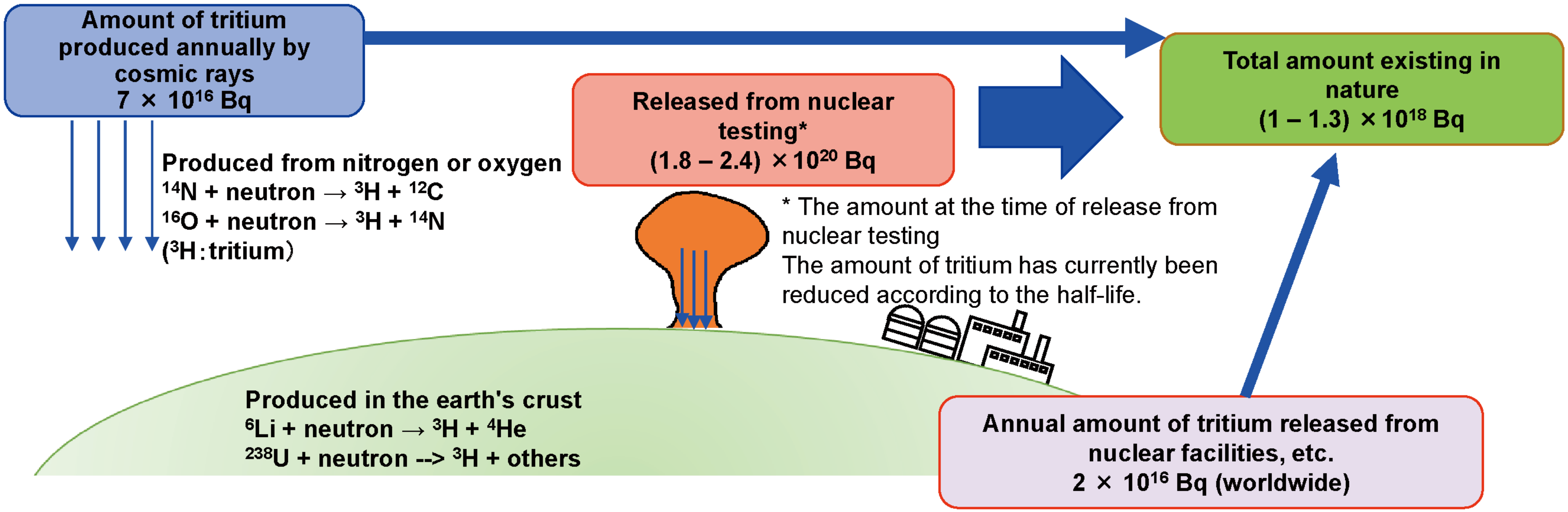
Physical half-life：12.3 year

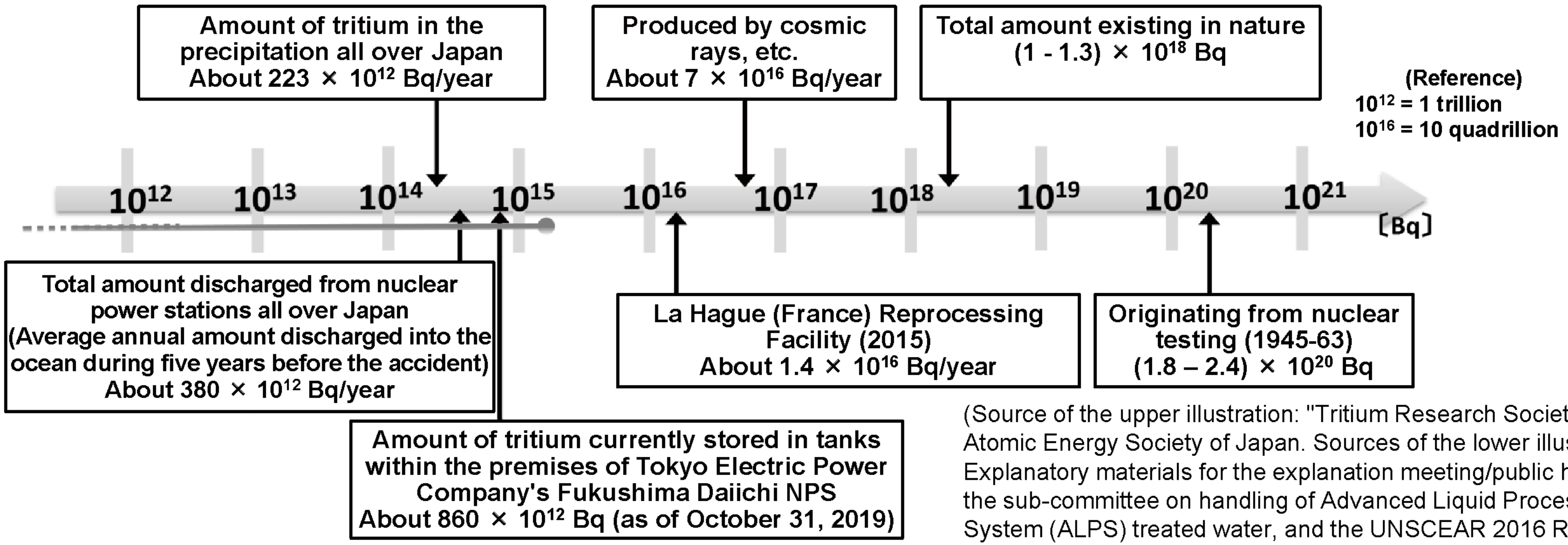
E_{mean} ： 5.7 keV

E_{max} ： 18.6 keV

Source: Prepared based on the "Important Stories on Decommissioning 2018" by the Agency for Natural Resources and Energy, METI, the "Tritiated Water Task Force Report" by the Tritiated Water Task Force (2016), and the "Scientific Characteristics of Tritium (draft)" by the Subcommittee on Handling of the ALPS Treated Water

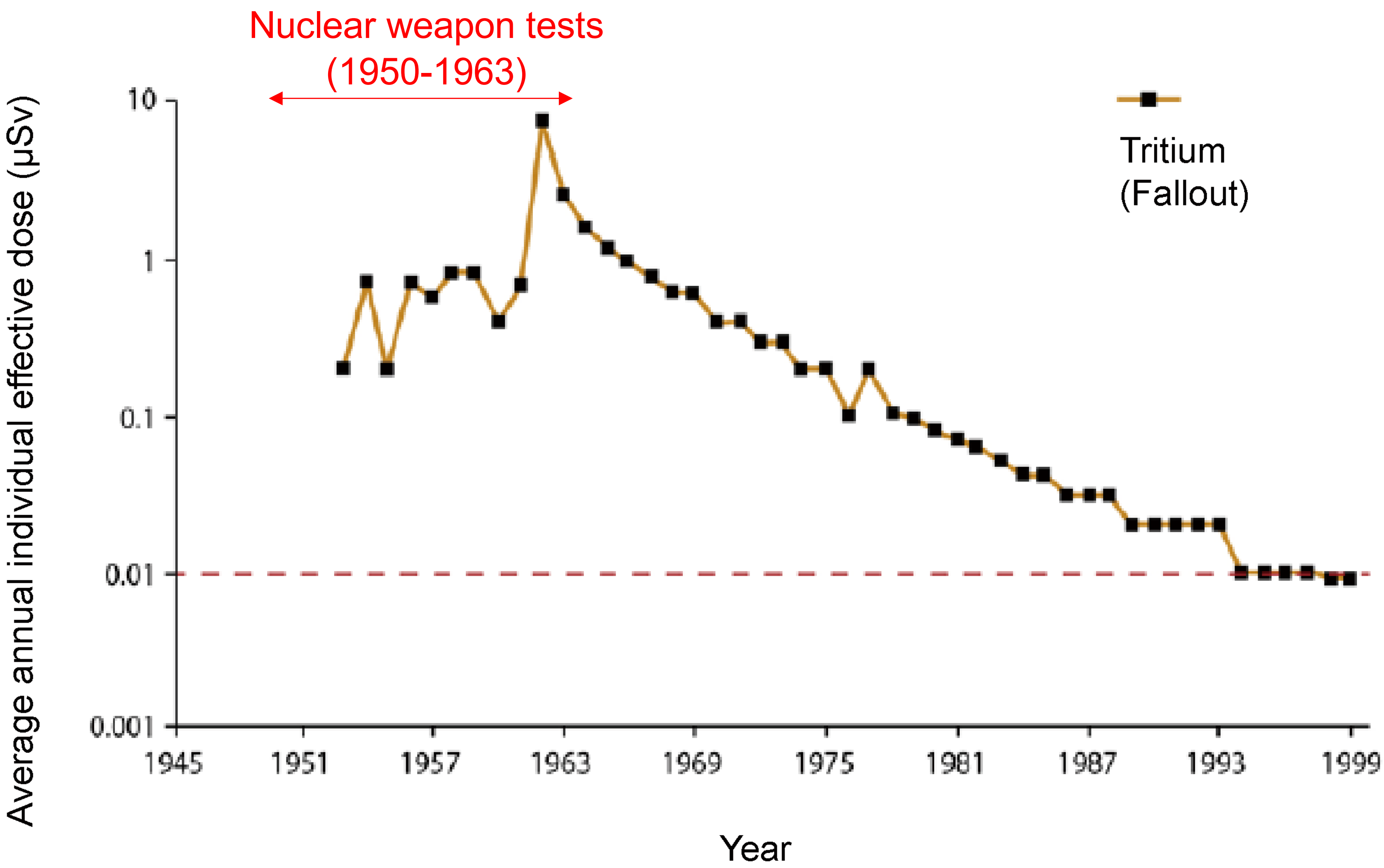
Amount of Tritium Existing in Nature





(Source of the upper illustration: "Tritium Research Society" 2014 by Atomic Energy Society of Japan. Sources of the lower illustration: Explanatory materials for the explanation meeting/public hearing by the sub-committee on handling of Advanced Liquid Processing System (ALPS) treated water, and the UNSCEAR 2016 Report)

Changes in Tritium in Radioactive Fallout over Time



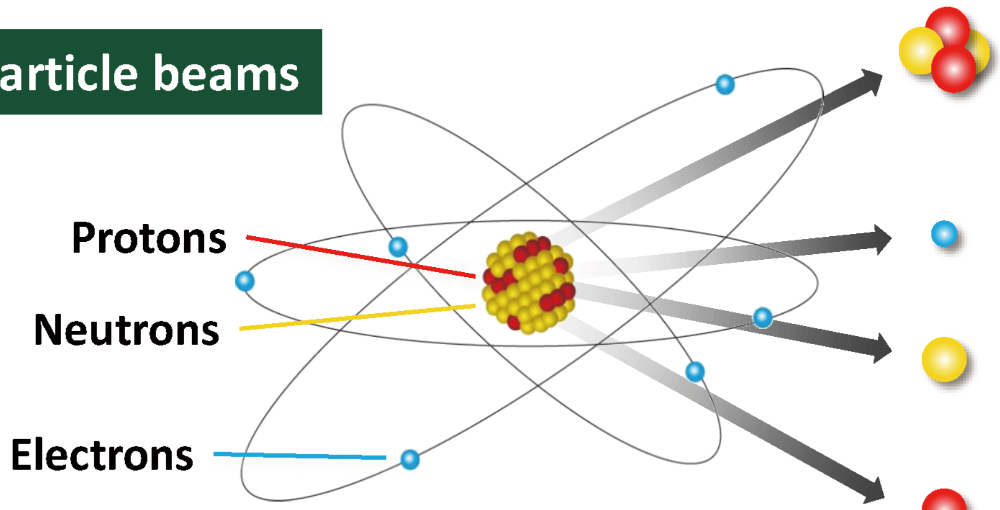
Source: UNSCEAR 2016 Report, Annex C-Biological effects of selected internal emitters-Tritium

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Types of Ionizing Radiation

Ionizing radiation — Radiation that causes ionization

Particle beams



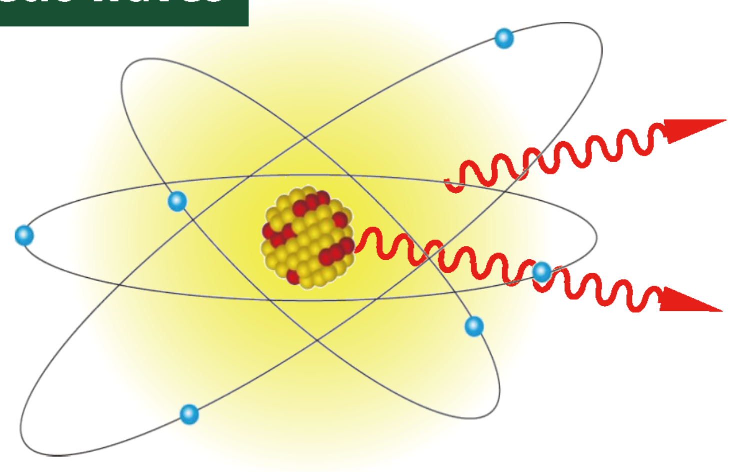
α-particles (helium nuclei ejected from a nucleus)

β-particles (electrons ejected from a nucleus)

Neutron beams (produced in nuclear reactors, accelerators, etc.)

Proton beams (produced in accelerators, etc.)

Electromagnetic waves

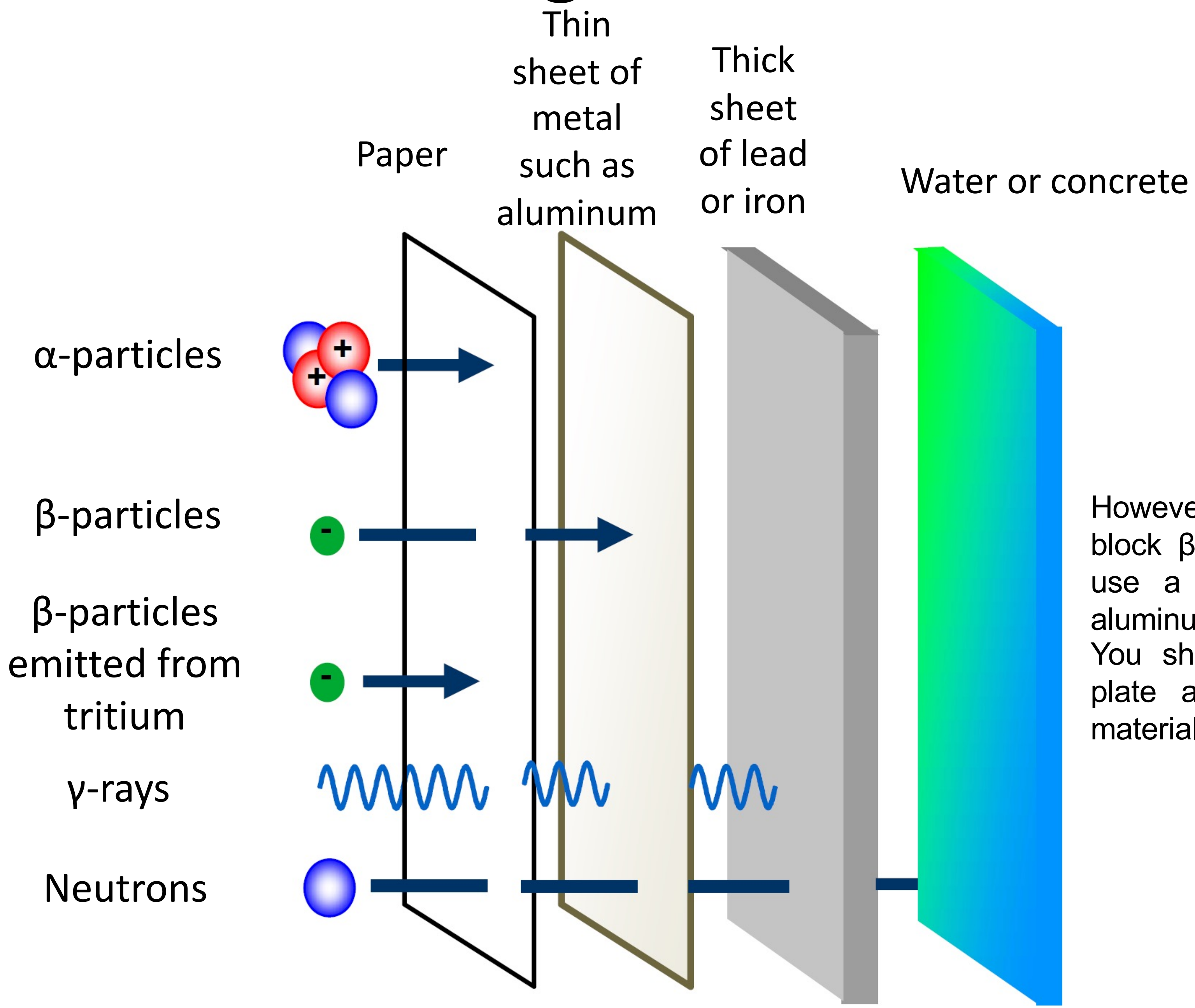


X-rays (generated outside a nucleus)

γ-rays (emitted from a nucleus)

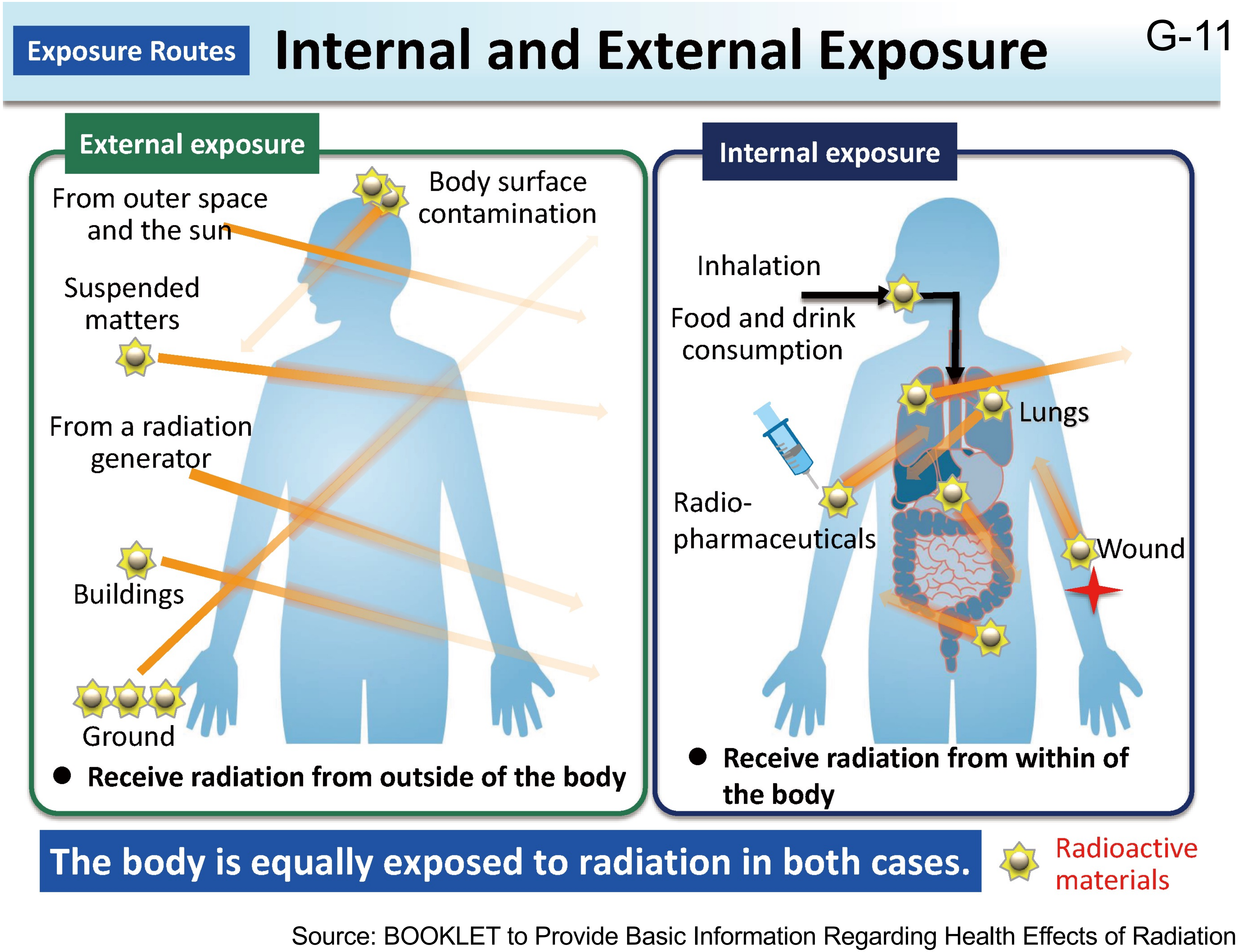
Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Penetrating Power of Radiation

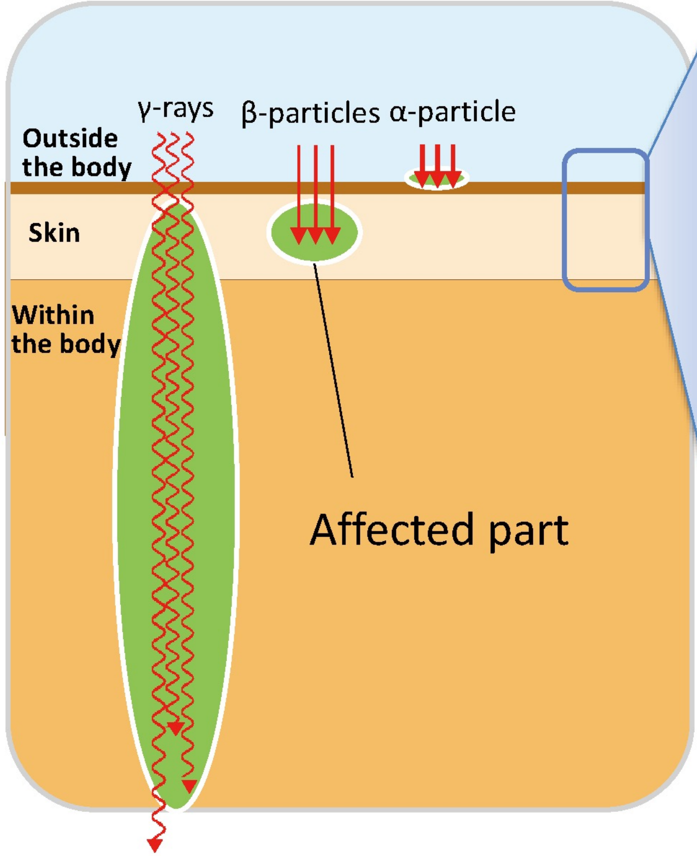


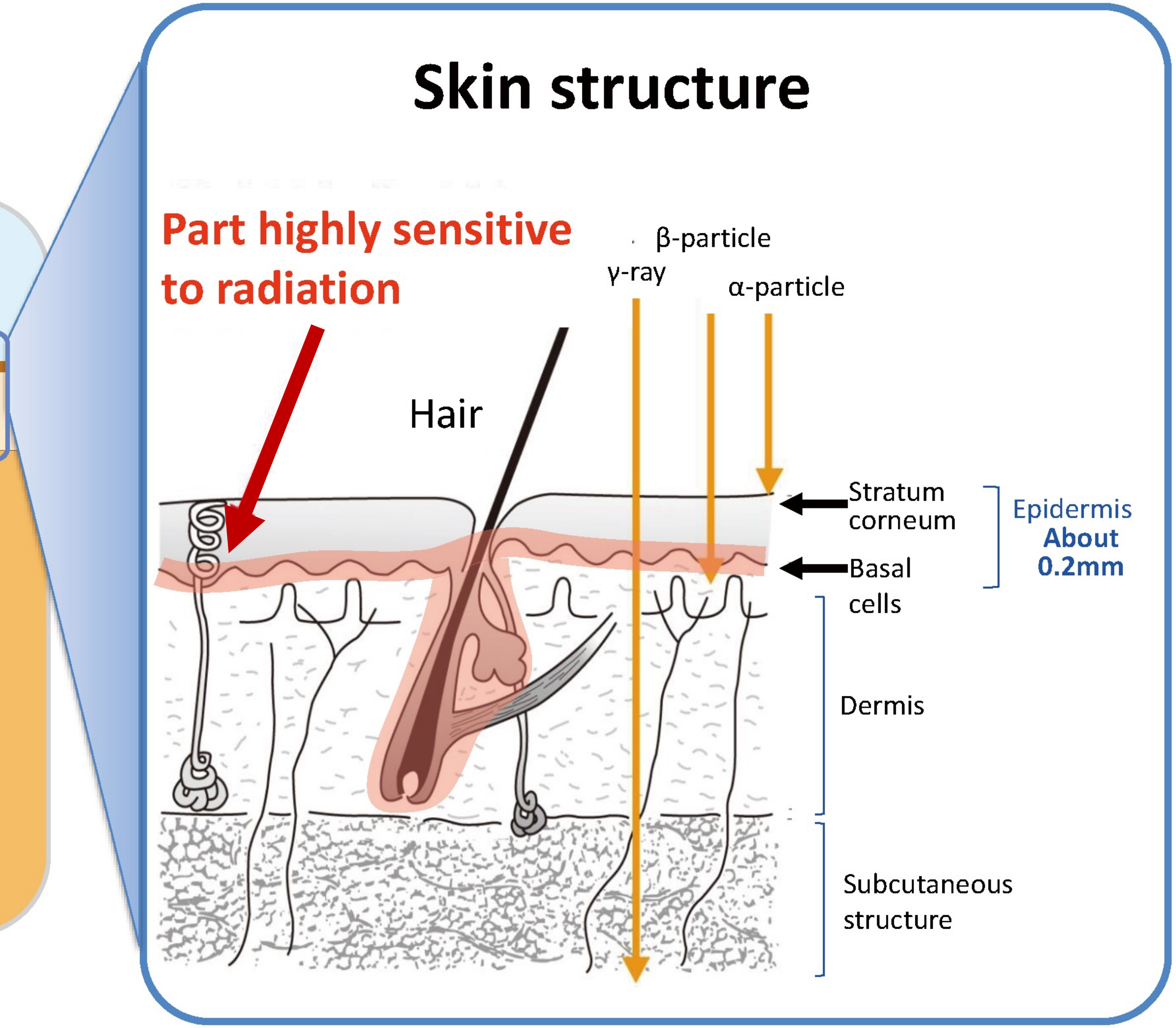
However, when you want to block β-particles, you should use a plastic sheet or an aluminum plate.
You should not use a lead plate as the first shielding material against β-particles.

Cited from METI ANRE website（https://www.enecho.meti.go.jp）


Exposure Routes
Internal and External Exposure
G-11
External exposure
From outer space and the sun
Body surface contamination
Suspended matters
From a radiation generator
Buildings
Ground
● Receive radiation from outside of the body
Internal exposure
Inhalation
Food and drink consumption
Lungs
Radio-pharmaceuticals
Wound
● Receive radiation from within of the body
The body is equally exposed to radiation in both cases.
Radioactive materials
Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

External Exposure and Skin





Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Internal Exposure

(i) Ingestion

From the mouth (swallowing)
Absorption through the digestive tract

(ii) Inhalation

Incorporation from the respiratory airways
Absorption from the lungs and the surface of the airways

(iii) Percutaneous absorption

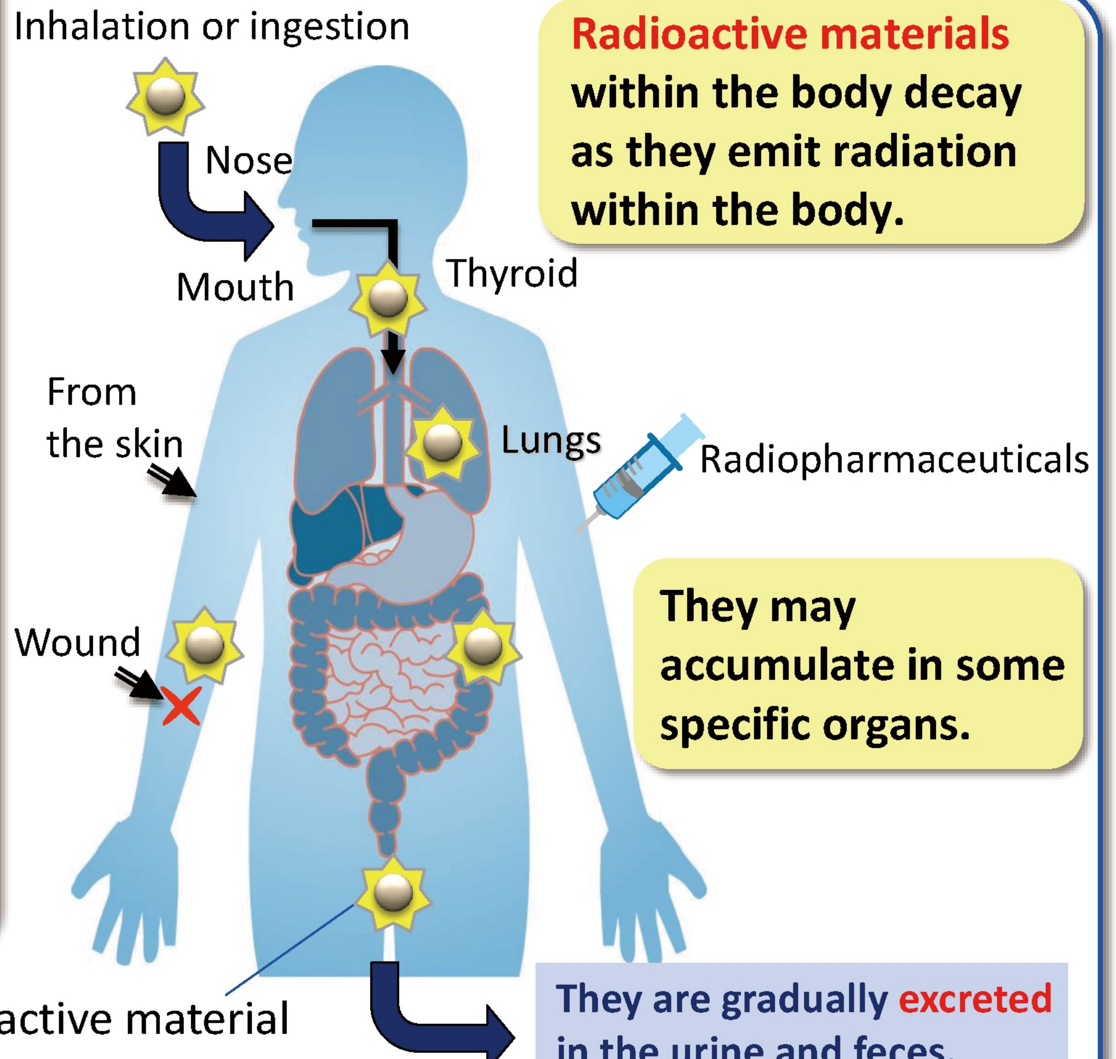
Absorption from the skin

(iv) Wound contamination

Contamination from a wound

(v) Intake of radiopharmaceuticals

Injection, oral administration (→ (i))
Inhalation of gas (→ (ii))



Radioactive materials within the body decay as they emit radiation within the body.

They may accumulate in some specific organs.

They are gradually excreted in the urine and feces.

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Internal Exposure and Radioactive Materials

The characteristics of radioactive materials that especially cause problems in internal exposure

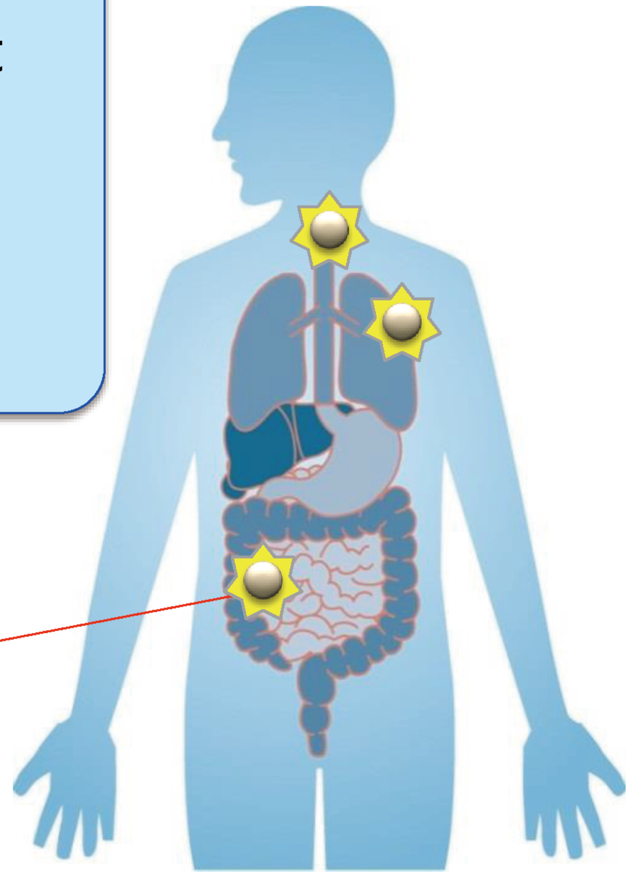
(i) α-emitters > β-emitters or γ-emitters

(ii) Materials that enter easily but are difficult to excrete

(iii) Materials that are likely to accumulate in specific organs

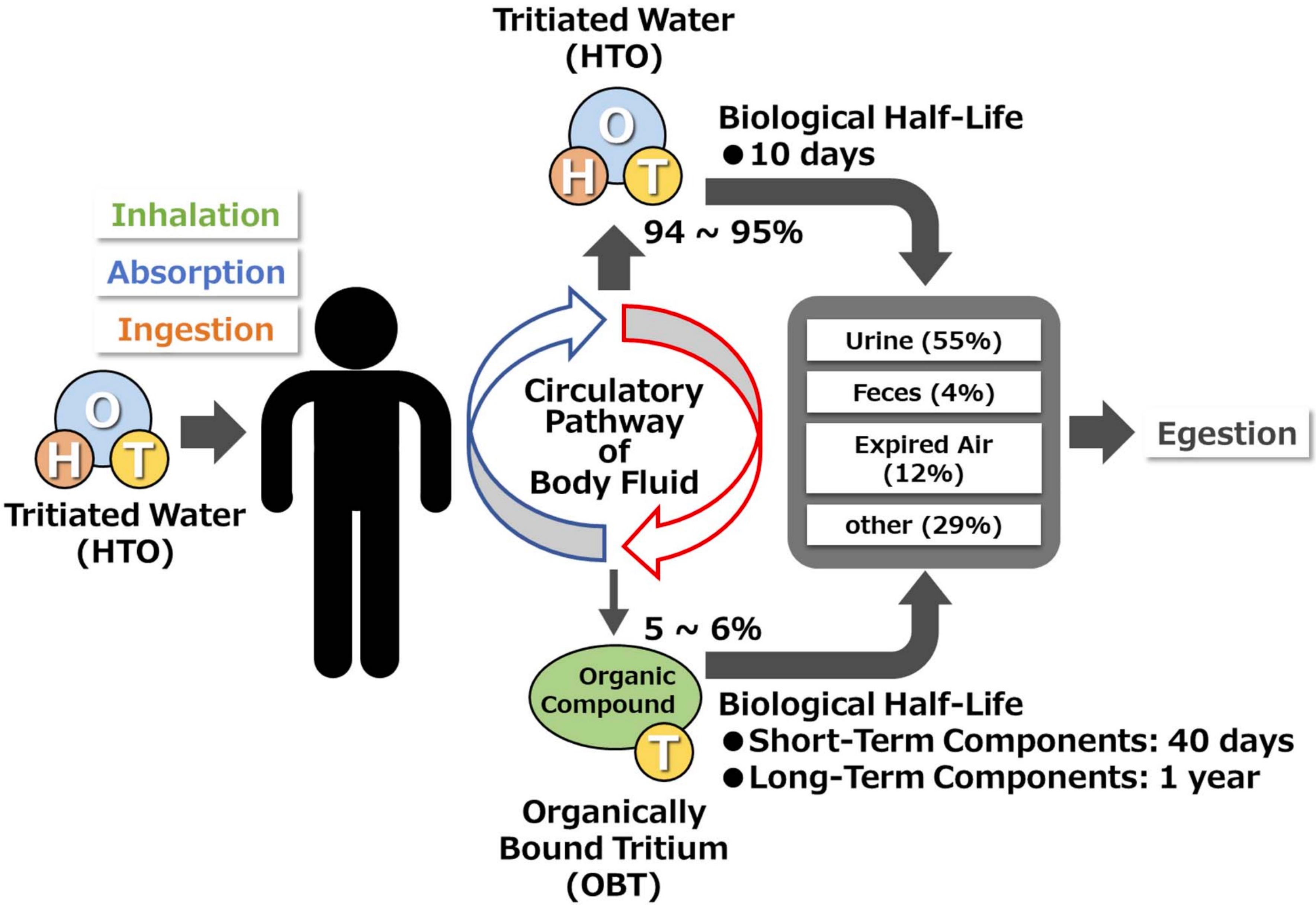
$$\frac{1}{T_e} = \frac{1}{T_p} + \frac{1}{T_b}$$

T_e : Effective half-life
T_p : Physical half-life
T_b : Biological half-life



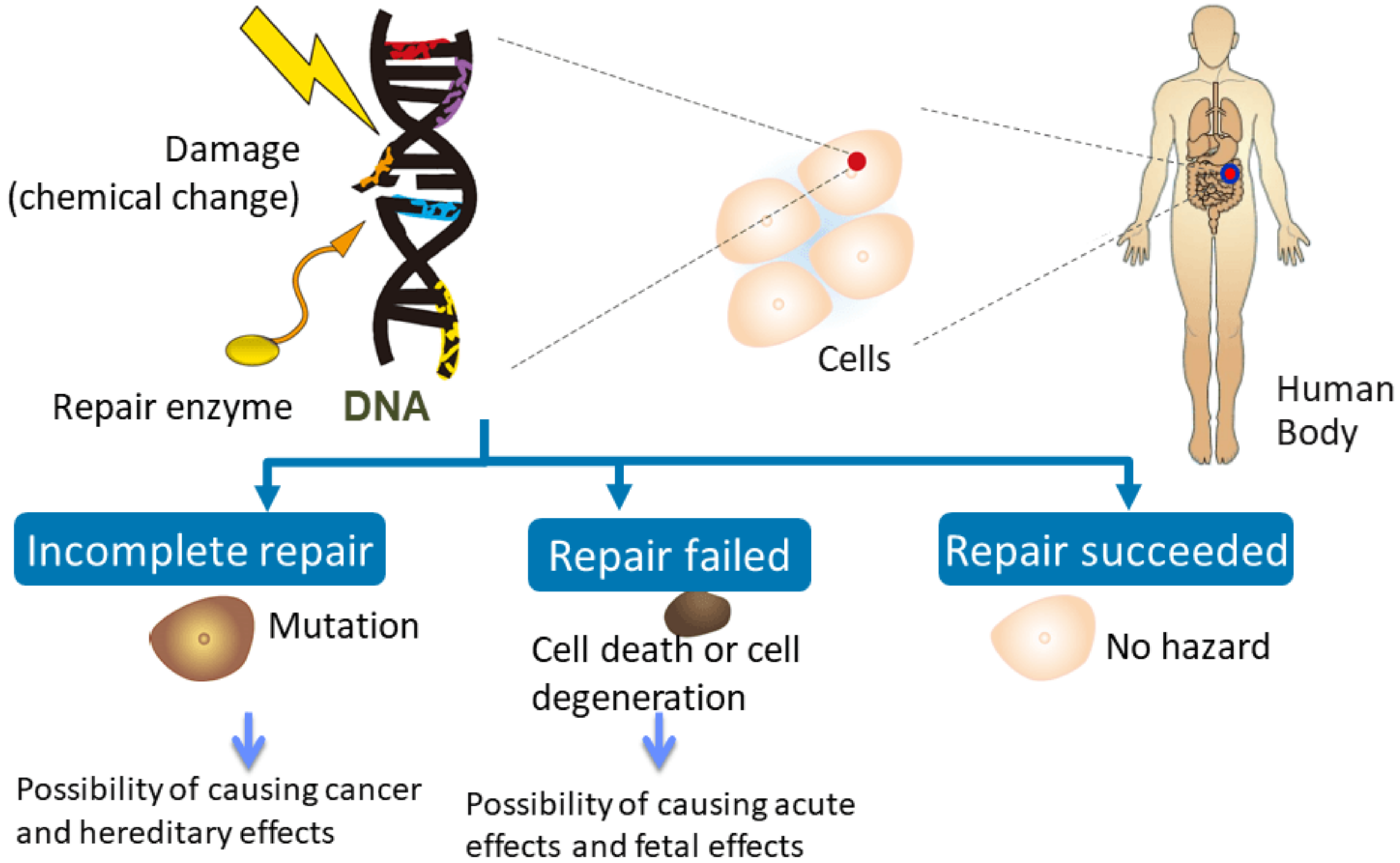
Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Metabolism of Tritiated Water in the Human Body



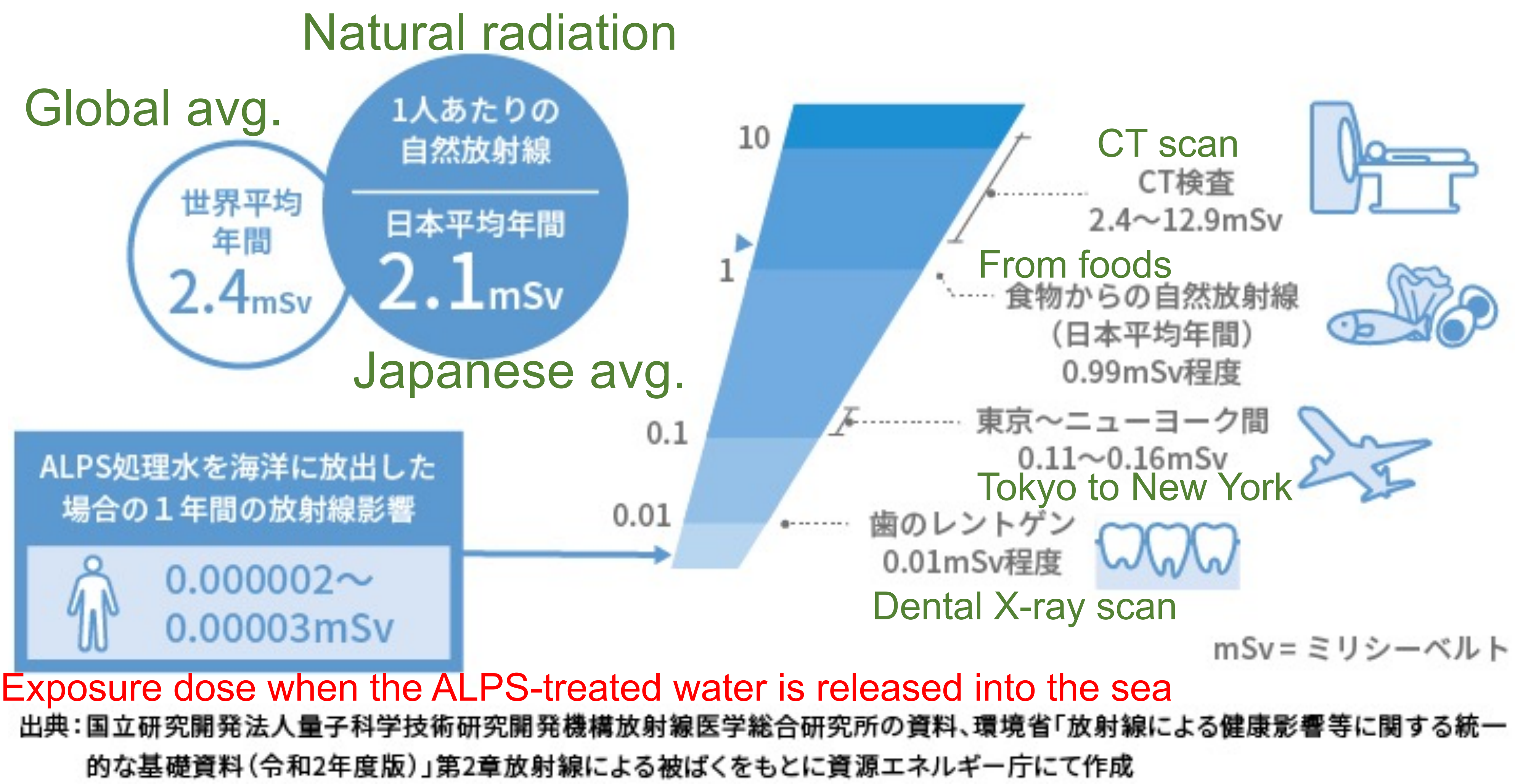
H. Matsumoto *et al., J Radiat Res.*, 2021

DNA→Cells→Human Body



Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation

Comparison of Exposure Doses per Year



Cited from METI website（https://www.meti.go.jp/earthquake/nuclear/hairo_osensui/shirou_alps.html）

Radiation around Us

Breakdown of Natural Exposure Doses (Japanese)

Type of exposure	Breakdown of radiation sources	Effective dose (mSv/year)
External exposure	Cosmic rays	0.3
	Ground radiation	0.33
Internal exposure (inhalation)	Radon-222 (indoors and outdoors)	0.37
	Radon-220 (thoron) (indoors and outdoors)	0.09
	Smoking (Lead-210, Polonium-210, etc.)	0.01
	Others (uranium, etc.)	0.006
Internal exposure (ingestion)	Mainly Lead-210 and Polonium-210	0.80
	Tritium	0.0000082
	Carbon-14	0.01
	Potassium-40	0.18
Total		2.1

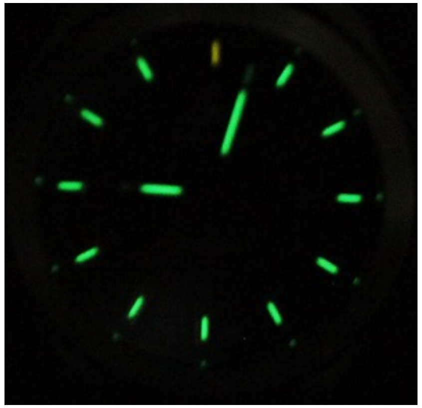
Source: Prepared based on "Environmental Radiation in Daily Life (2011)," Nuclear Safety Research Association

Tritium Exposure Accidents

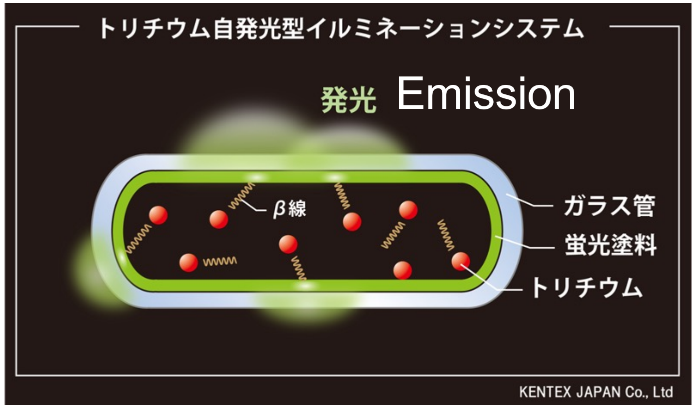
2 watch factories in Europe in the 1960s

- A factory worker ingested tritium over 7.4 years.
  Exposure dose was estimated at 3-6 Sv.
  → Developed isochromic anemia, and subsequently died of pancytopenia.

- A factory worker ingested tritium over 3 years.
  Exposure dose was estimated at 10-20 Sv.
  → Died of pancytopenia after following a similar disease as the same as above



Tritium radioluminescence

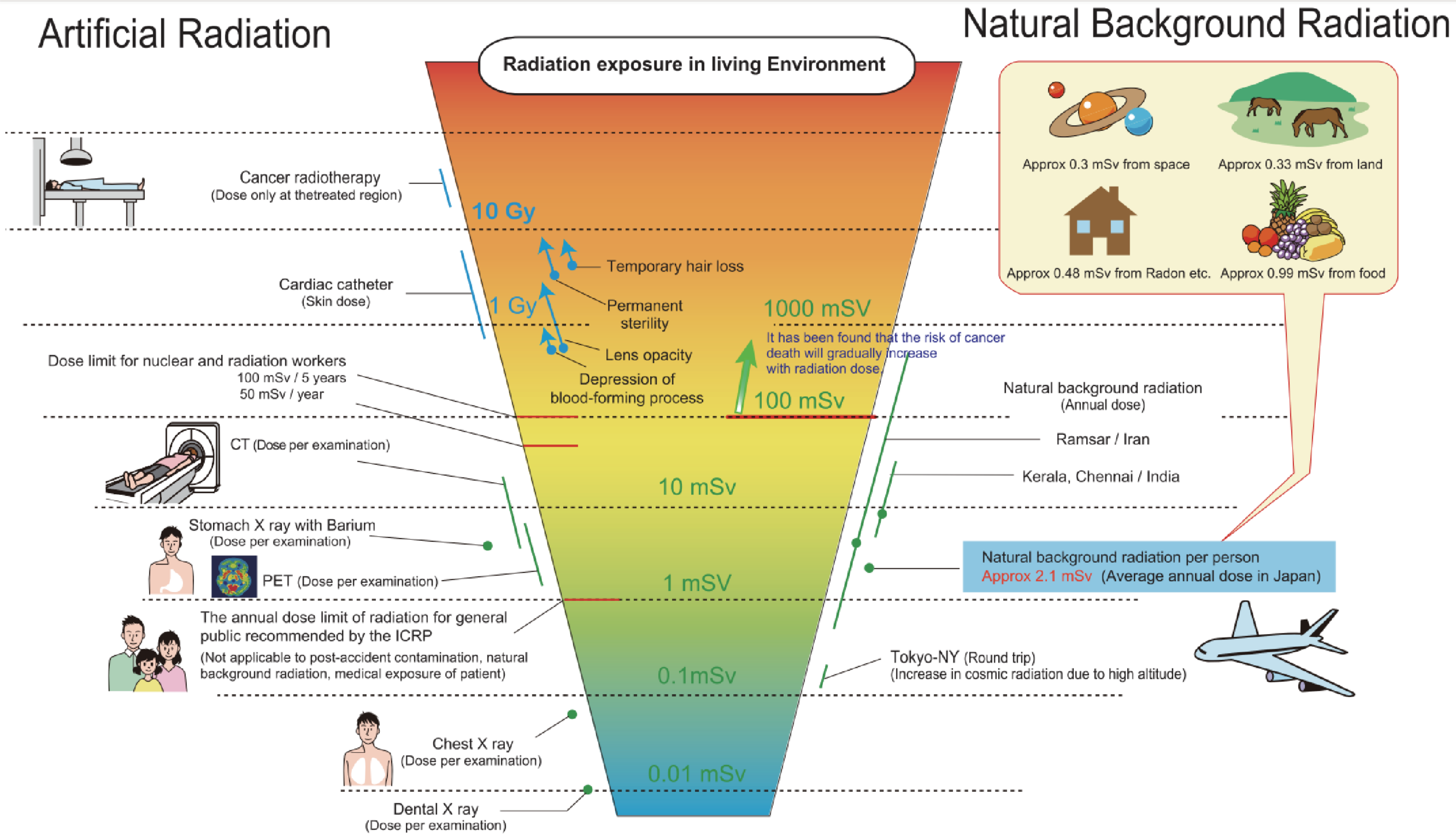


Glass tube
Fluorescent paint
Tritium

Images are cited from KENTEX website (https://www.kentex-jp.com)

Radiation around Us

Comparison of Exposure Doses (Simplified Chart)



Sources:
- The 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report
- The 2007 ICRP (International Commission on Radiological Protection) Report
- The exposure guideline of the Japan Association of Radiological Technologists
- "Life Environmental Radiation (Calculation of the National Dose)," new edition

Prepared by the National Institute of Radiological Sciences based on the sources above (May 2018)

mSv: millisieverts

Source: BOOKLET to Provide Basic Information Regarding Health Effects of Radiation