Radiation Dose and Hazard Assessment

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Radiation dose

- Understanding the activity in Becquerels is the first step to finding out about any possible biological effects, but does not tell us a great deal by itself. This is because, apart from the absolute amount of energy absorbed in the body, the biological effects are related to:
  - The size of the exposed area or body: for the same absolute amount of radiation, a larger body will feel less effect, so the measures of radiation exposure must be inherently about the exposure per kilogram of tissue.
  - The radiation type: some types of radiation are intrinsically more damaging than others.
  - The distribution of the dose: some tissues of the body are more sensitive to radiation than others.
- Absorbed dose (D): the amount of energy absorbed per unit mass (unit: gray (Gy), 1 Gy = 1 J/kg = 100 rad = 10^4 erg/g)
- Dose equivalent (H, equivalent dose): consideration of the radiation type (radiation weighting factor, w_R) (unit: sievert (Sv), 1 Sv = 100 rem, $H = w_R \times D$)
- Effective dose ($\mathcal{E}$): consideration of the different tissues exposed (tissue weighting factor, w_T)

$$\mathcal{E} = \sum_T w_T \sum_R w_R \, D_{T,R} \equiv \sum_T w_T \, H_T$$

Weighting factors

- International Commission on Radiological Protection (ICRP)

$$\mathcal{E} = \sum_T w_T \sum_R w_R \, D_{T,R} \equiv \sum_T w_T \, H_T$$

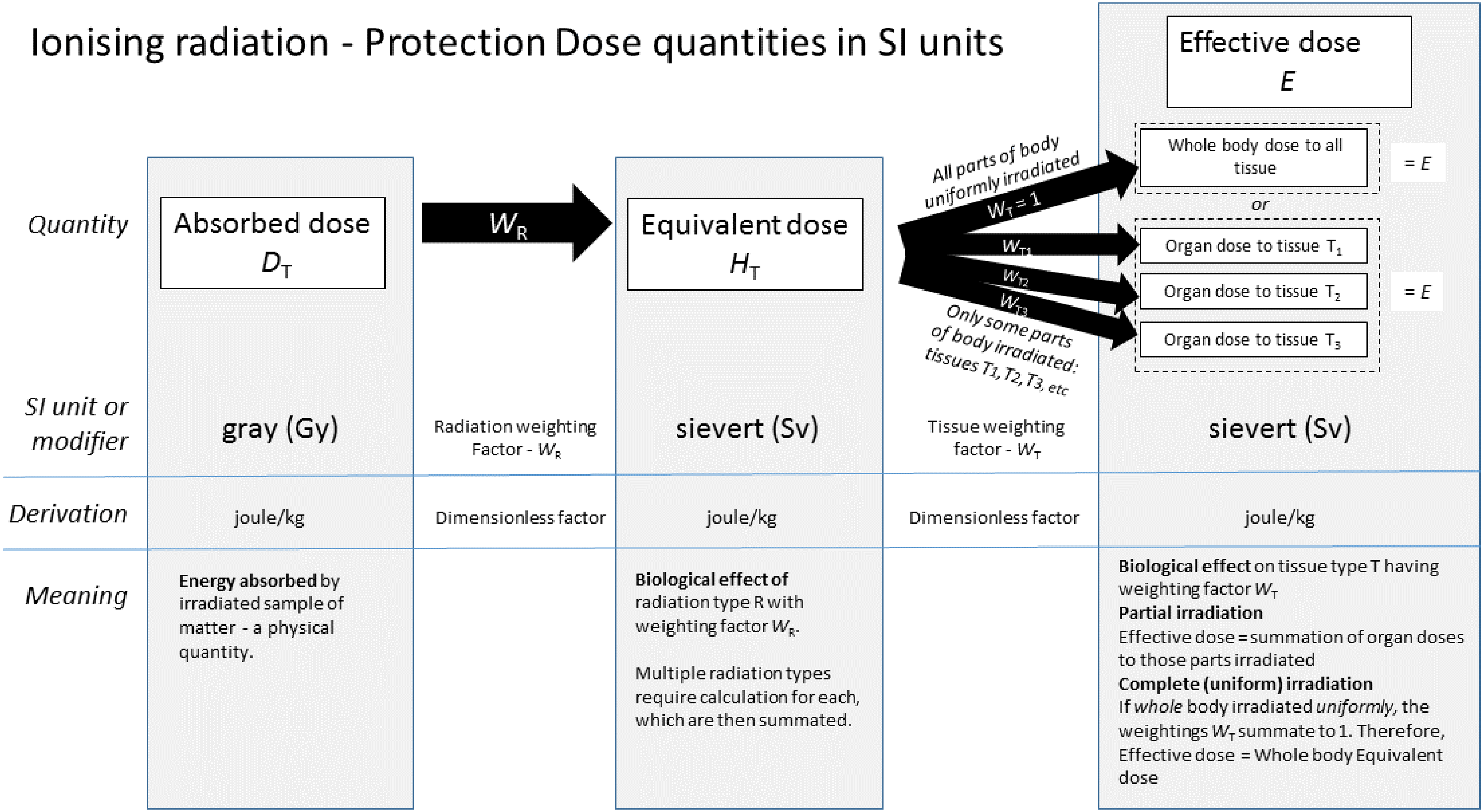
Tissue weighting factor

Organ or tissue	Factor
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Chest	0.12
Gonads	0.08
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Thyroid gland	0.04
Periosteum (bone surface)	0.01
Skin	0.01
Brain	0.01
Salivary glands	0.01
Other organs or tissue	0.12

Radiation weighting factor

Type of radiation	Factor
γ and X rays, all energies	1
Electrons and muons, all energies	1
Neutrons, energy under 10 keV	5
Neutrons, energy 10–100 keV	10
Neutrons, energy 100 keV–2 MeV	20
Neutrons, energy 2–20 MeV	10
Neutrons, energy over 20 MeV	5
Protons, all energies	2
α particles, fission fragments, heavy nuclei	20

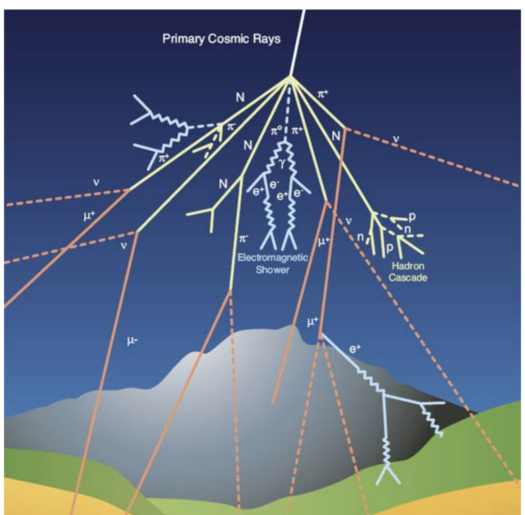
Relationships of protection dose quantities in SI units

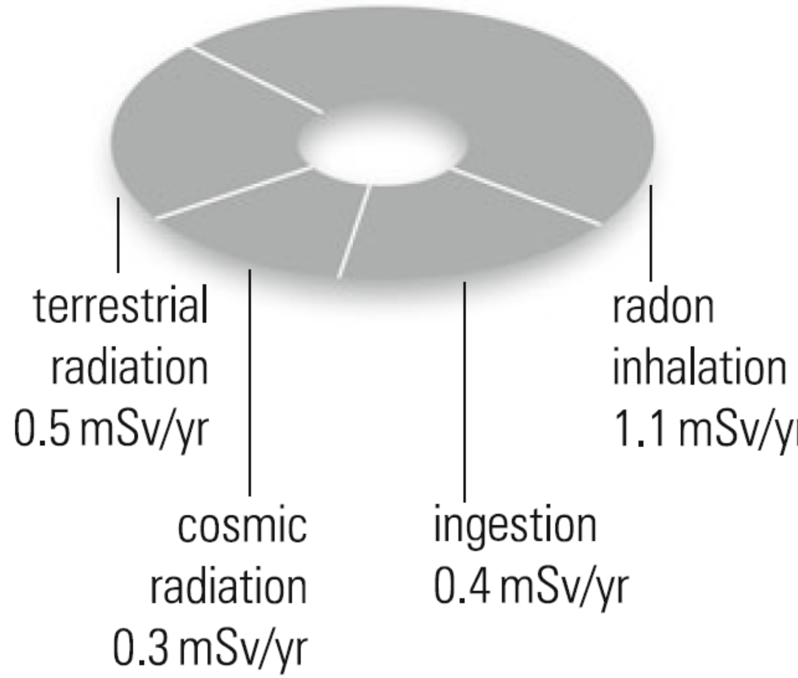


Exposures from the natural environment

- Cosmic rays
- Terrestrial radiation (from the Earth's crust)
- Incorporation (eating, drinking, and breathing)

Radionuclide	Half-life (y)	Natural abundance (%)	Mass fraction of the element per 1 Bq kg^{-1} of the radionuclide
^{40}K	1.25×10^{9}	0.0117	3.2×10^{-5}
^{232}Th	1.41×10^{10}	~100	2.5×10^{-7}
^{238}U	4.47×10^{9}	99.28	8.1×10^{-8}
^{226}Ra	1600	~100	2.7×10^{-14}





Global average ~ 2.3 mSv/yr

Exposures from man-made sources (excluding smoking)

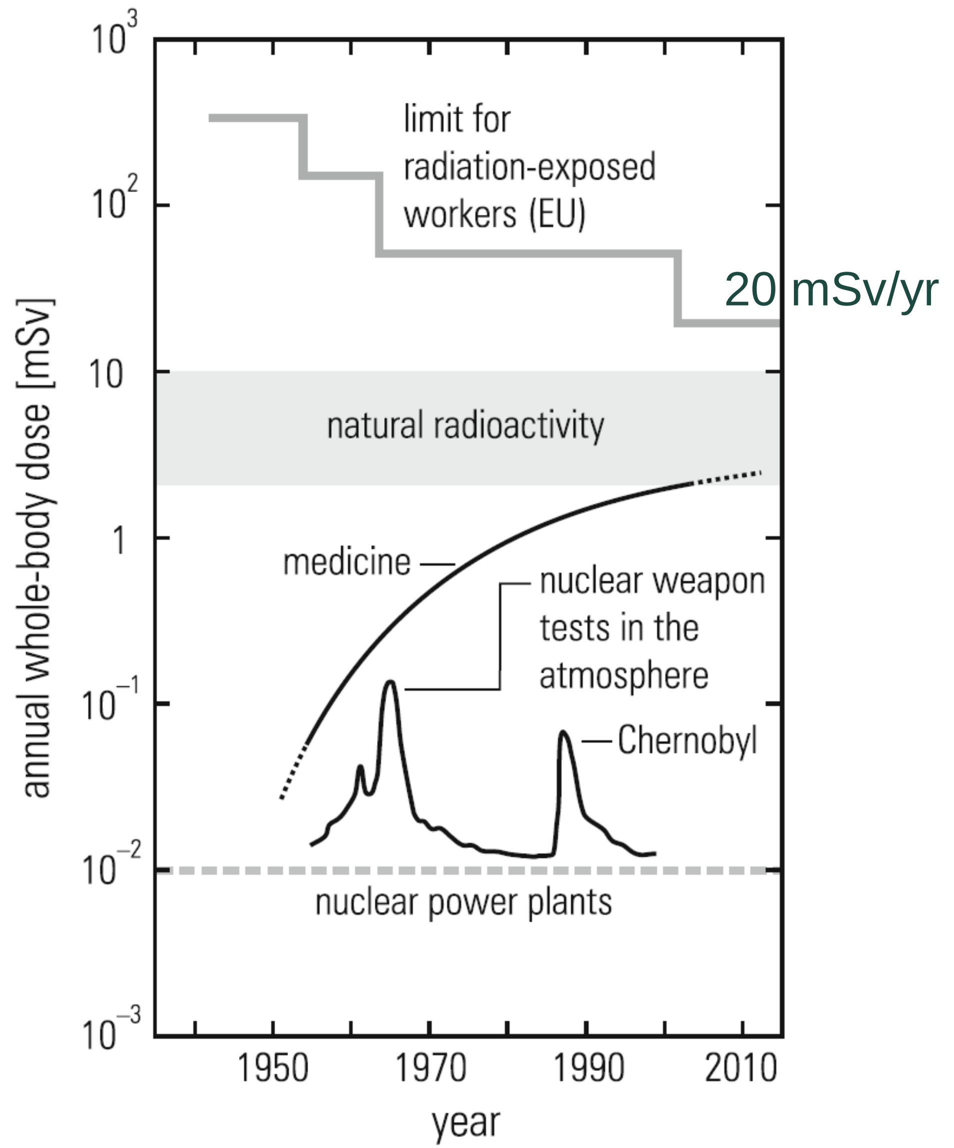
Source of dose	Approximate annual dose (mSv)
Medical X-ray diagnostics	1.9
Other nuclear medicine	0.05
Science and research	under 0.01
Occupational exposure	0.03
Reactor accident in Chernobyl (only 1986, figure for Western Europe)	0.5
Sum (without Chernobyl)	2.0

- The world average of the whole-body exposure can be estimated to be about 4.3 mSv/yr: about 2.3 mSv/yr from the natural environment and about 2.0 mSv/yr from technical installations (mainly medicine).

Typical dose rates or doses for some exposures (whole-body doses)

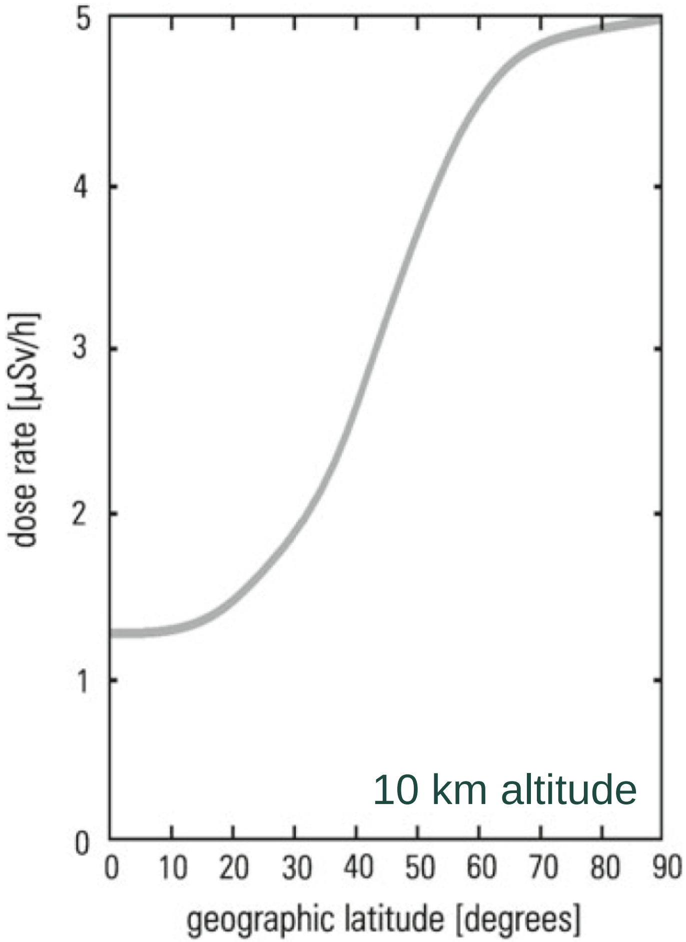
Type of exposure	Dose or dose rate
X-ray exposure of teeth	10 μSv
Flight Frankfurt to New York	30 μSv
X-ray examination of the chest	70 μSv
Dose limit for general public for discharges from nuclear power plants	300 μSv/yr
Normal smoker	500 μSv/yr
Mammography	500 μSv
γ-ray image of the thyroid gland	800 μSv
Limit for a surveyed area	1 mSv/yr
Heavy smoker (more than 20 cigarettes per day)	1 mSv/yr
Natural radiation	2.3 mSv/yr
Lower limit for a controlled area (see Appendix B)	6 mSv/yr
Positron-emission tomography	8 mSv
Computed tomography of the chest	10 mSv
Limit for radiation-exposed workers in Europe	20 mSv/yr
Limit for radiation-exposed workers in the USA	50 mSv/yr
Limit for emergencies	50 mSv
Maximum worker's dose over the whole life span	400 mSv
Possible future round-trip to Mars (500 days)	1000 mSv
Lethal dose	4000 mSv

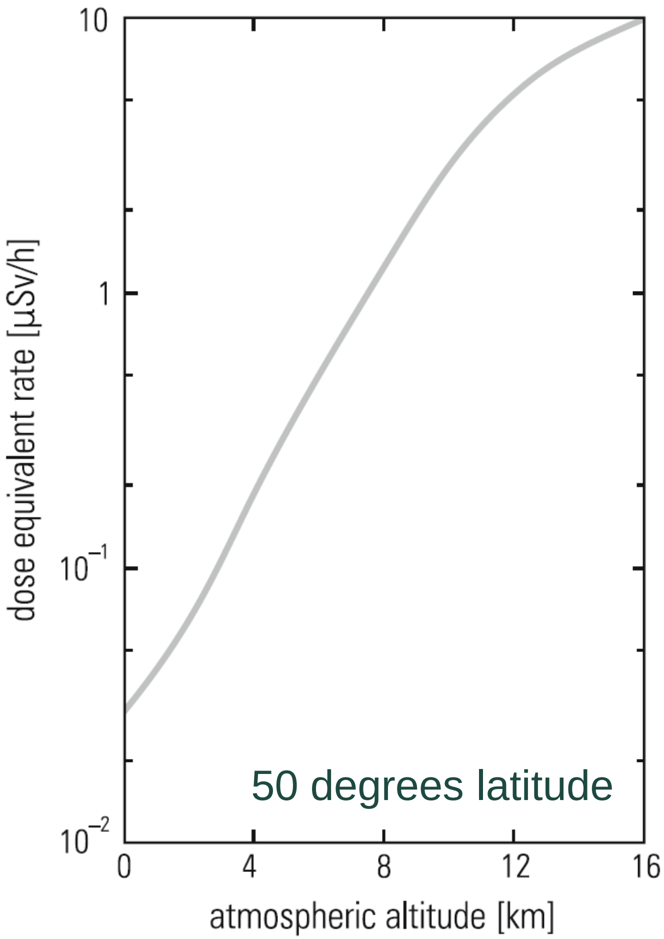
Annual dose (Western Europe)



Exposures from air travel

- Personnel flying at altitudes of 10~12 km are exposed to an annual dose of 2.5 mSv (for 500 flight hours per year).

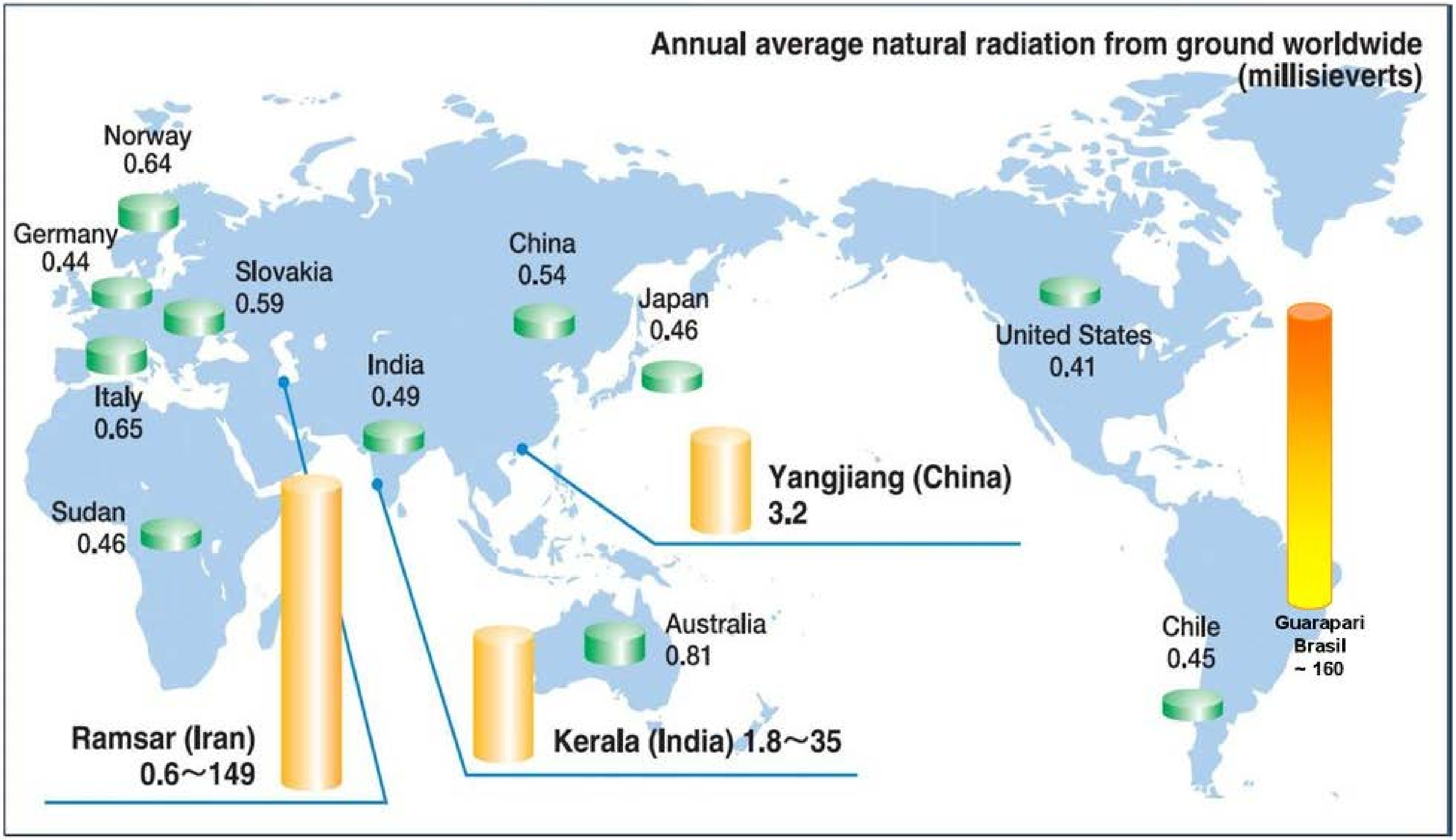




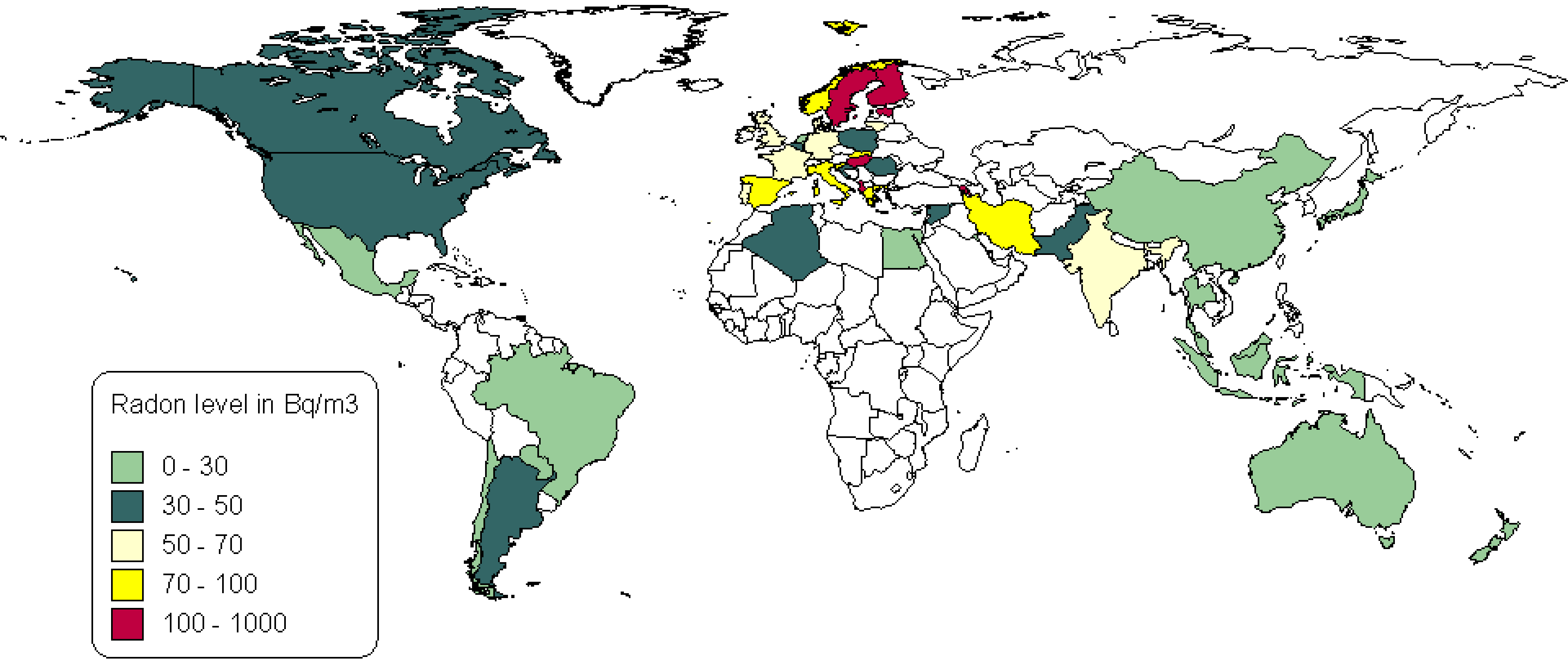
Exposures from smoking

- It is well known that smoking has adverse effects on health, but it is less widely known that radioactive exposures play a significant part in the negative effects.
- Radioactive isotopes, particularly radioactive lead-210 (^{210}Pb) enter the tobacco plant via its roots from the soil, and also radon (^{222}Rn) will enter the tobacco leaves from the air. This eventually leads to significant exposures of the lungs.
- The isotopes ^{210}Pb and ^{222}Rn decay after a number of radioactive transmutations into the radioisotope polonium (^{210}Po) ending eventually in stable lead (^{206}Pb).
- Smokers are victims of the fact that tar is sticky: these radioisotopes tend to stick to the airbourne droplets of tar in the smoke.

Background radiation in the world

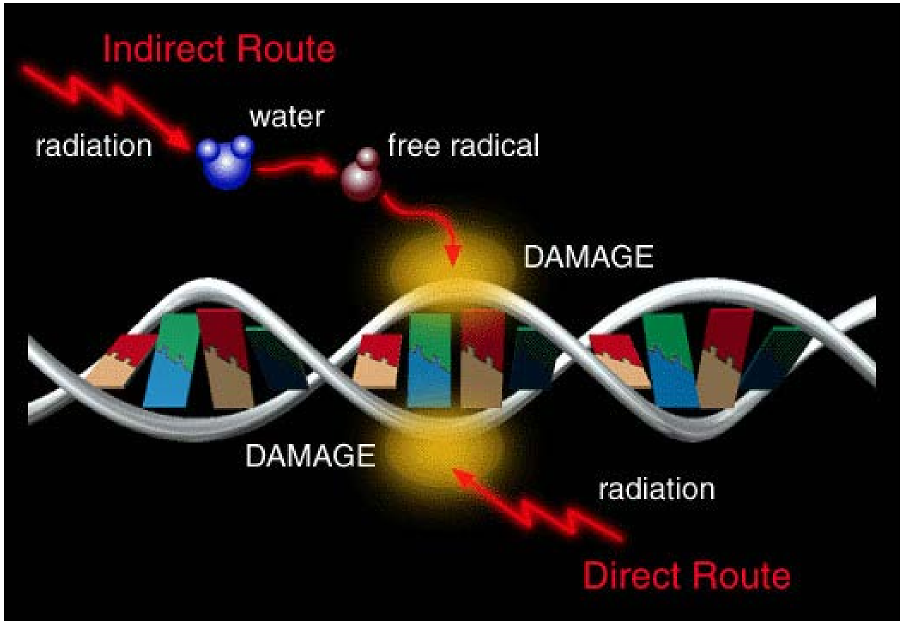


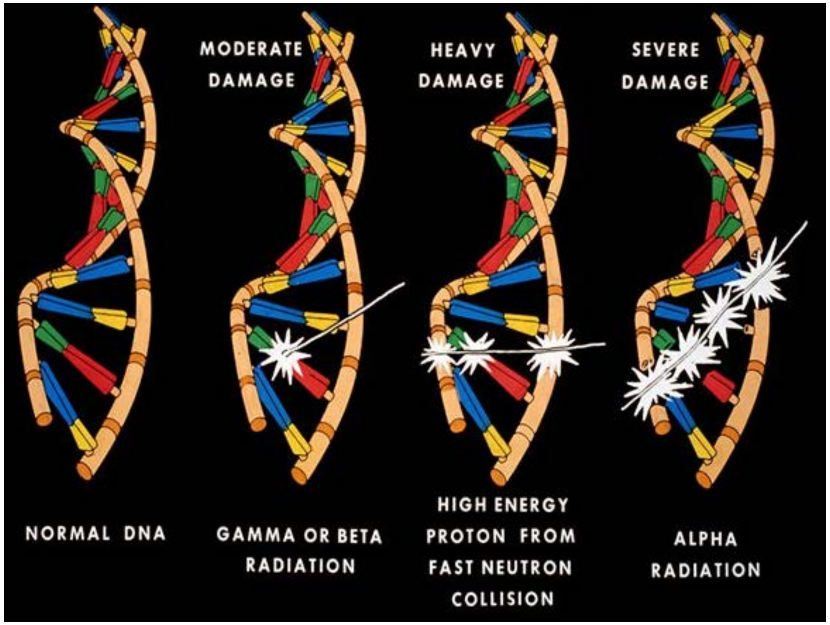
World radon map



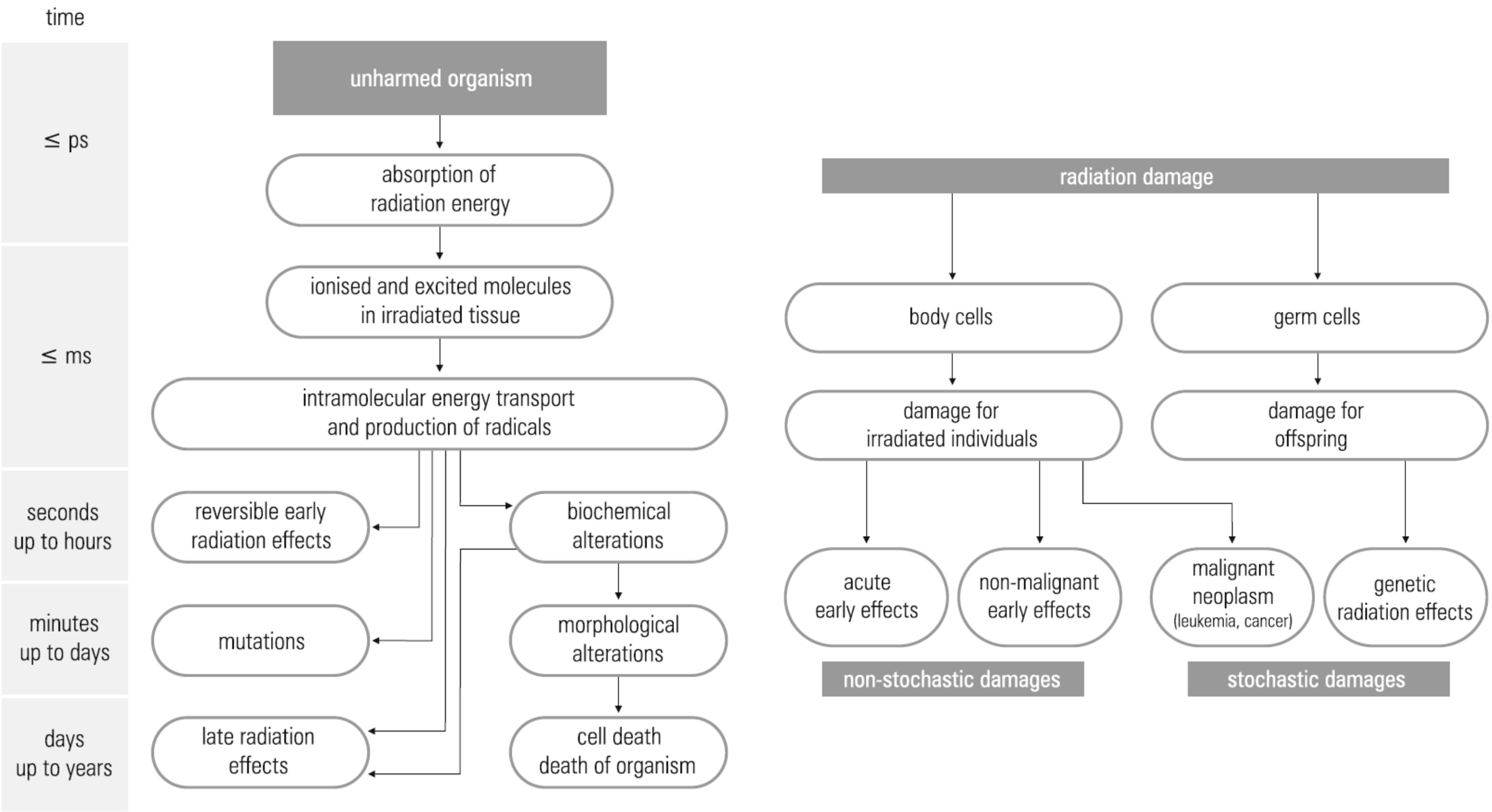
Radiation damage

- Any radiation exposure can potentially have negative effects on health. This can be considered as the basic principle of radiation protection.
- The biological effect of ionizing radiation is a consequence of the energy transfer, by ionization and excitation, to cells in the body.
- Factors of radiation effects on individual cells: (1) the dose rate, (2) the collisional stopping power (LET, linear energy transfer), and others such as the state of the cell's life cycle, the exposure time, age, general health, and nutritional status.

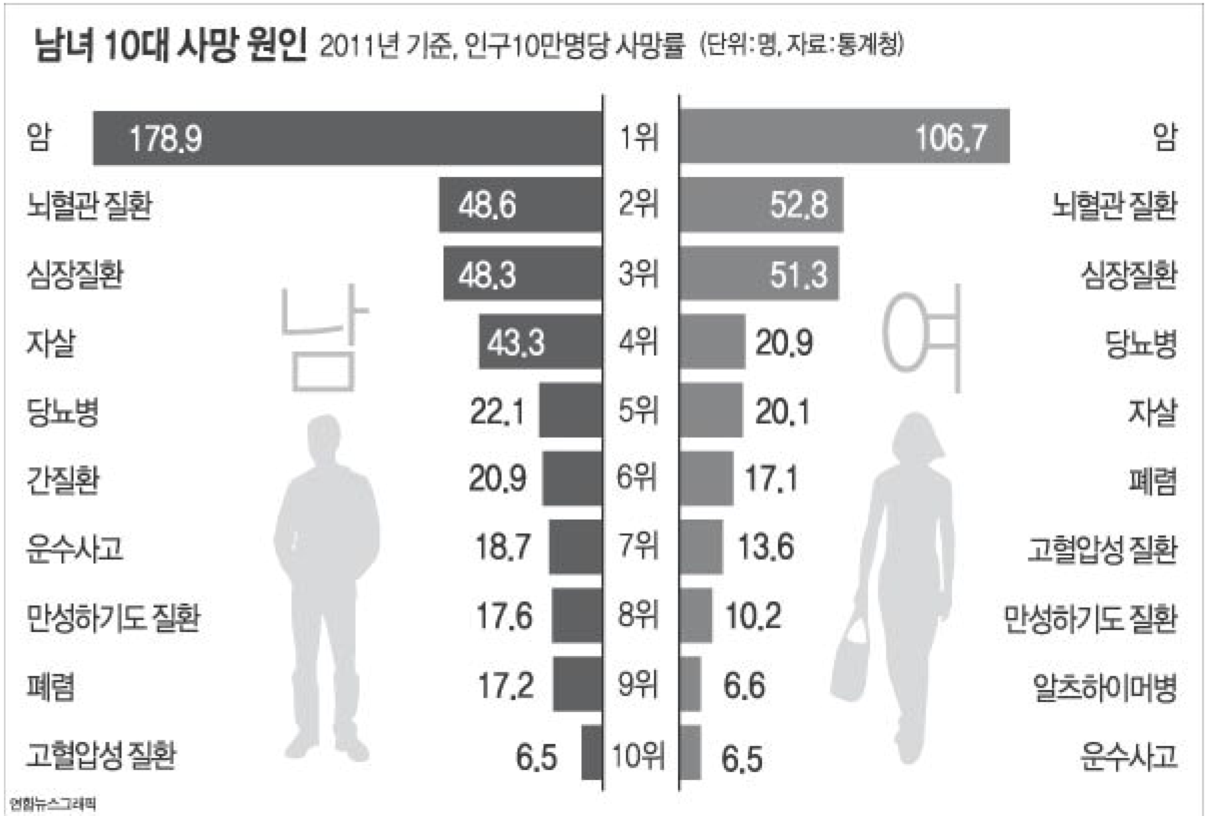




Timing and classification of radiation damage

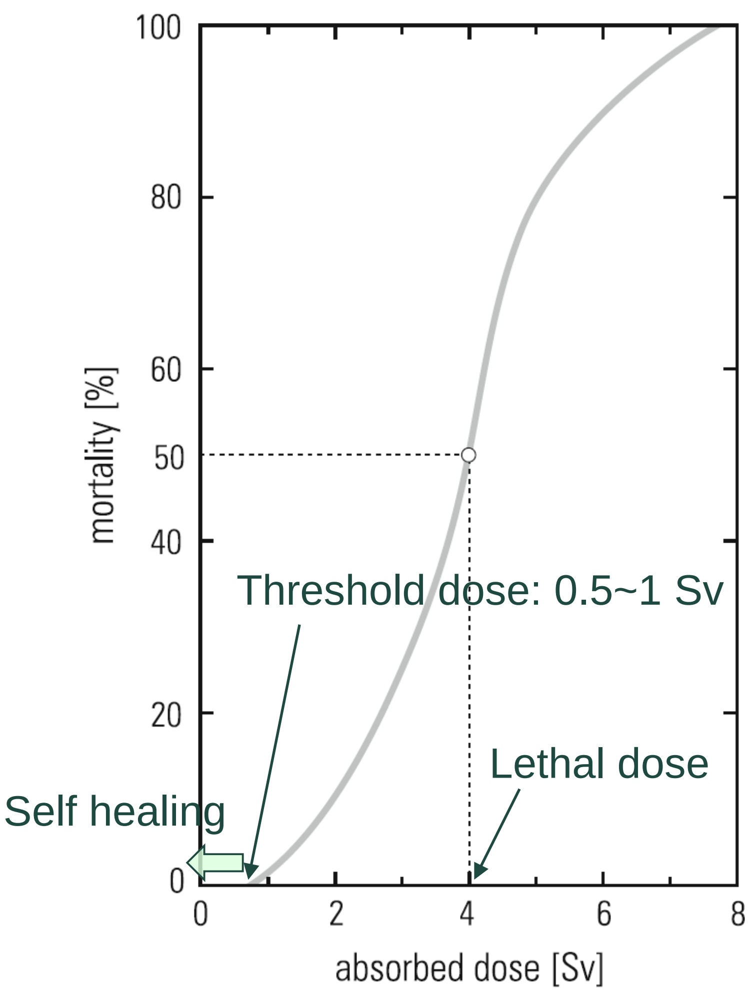


Mortality by cause in Korea

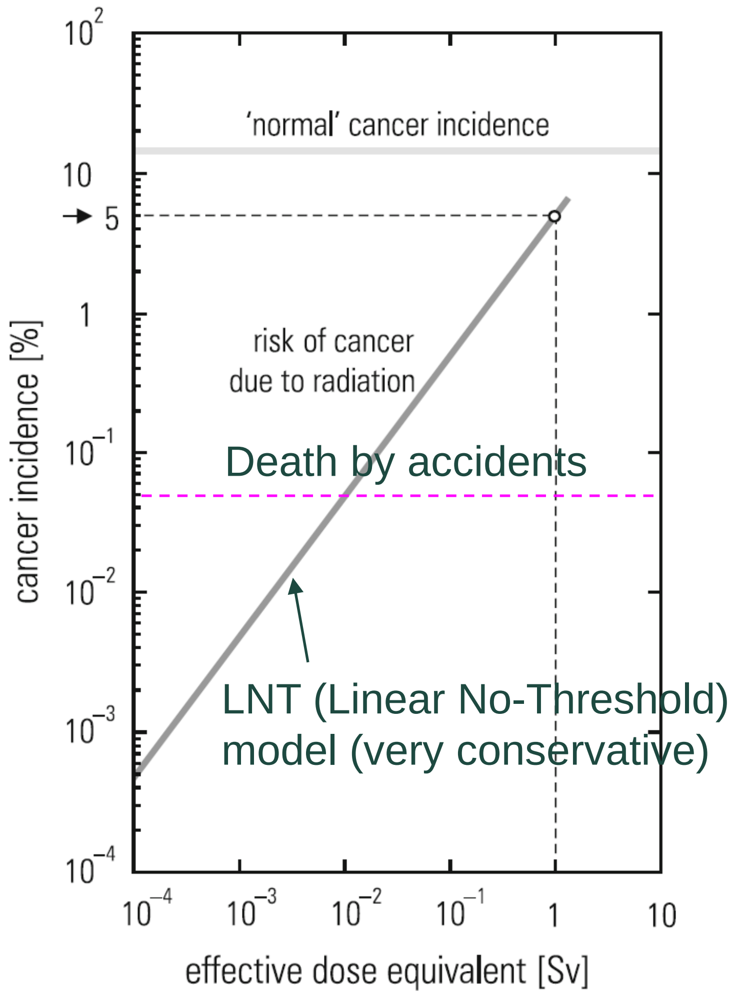


Effects of radiation on human death and cancer incidence

Early effect: mortality after 30 days for different whole-body doses for humans



Delayed (or "late") effect: probability of cancer incidence vs absorbed dose



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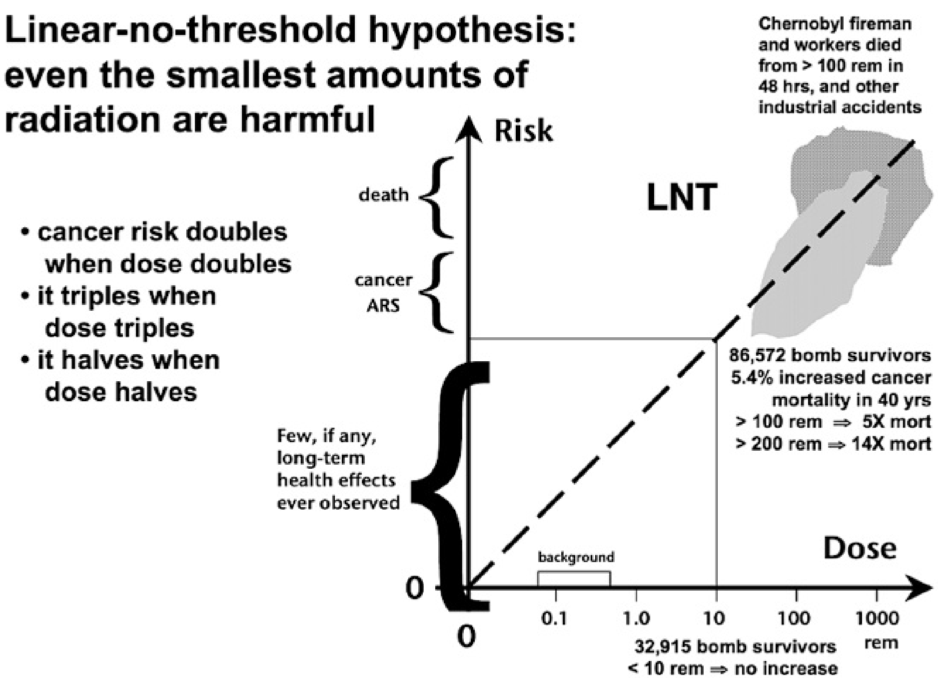
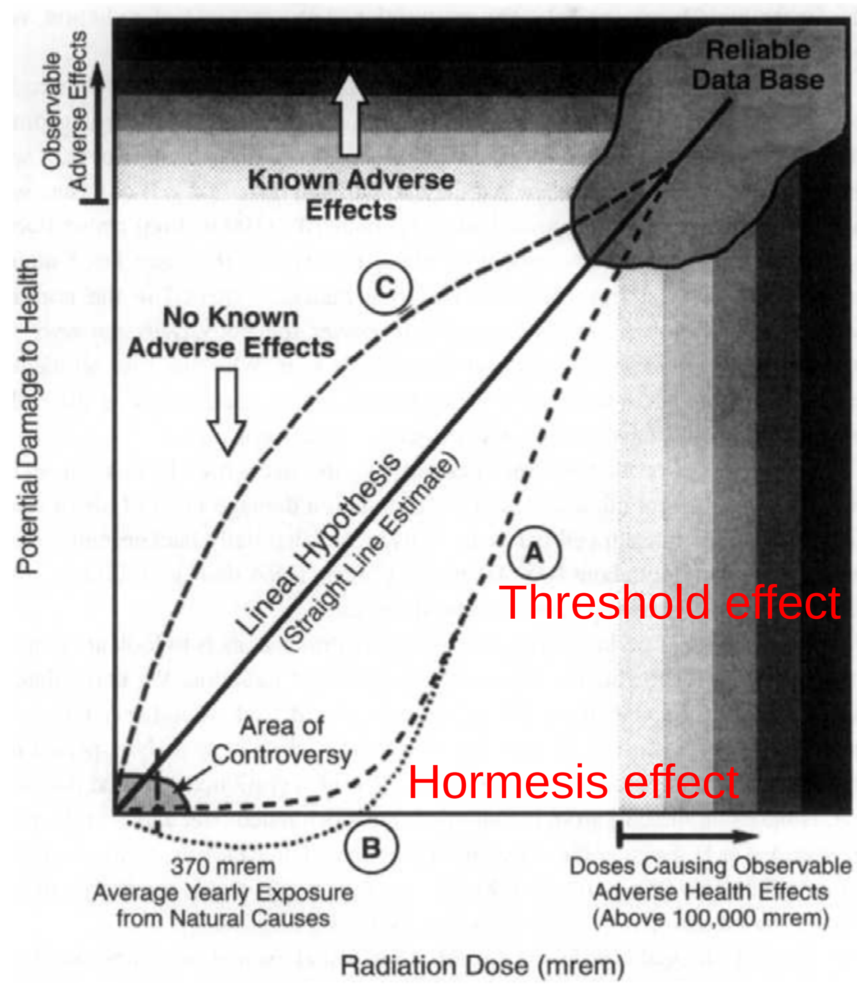
Models for determining the human health effects of radiation dose

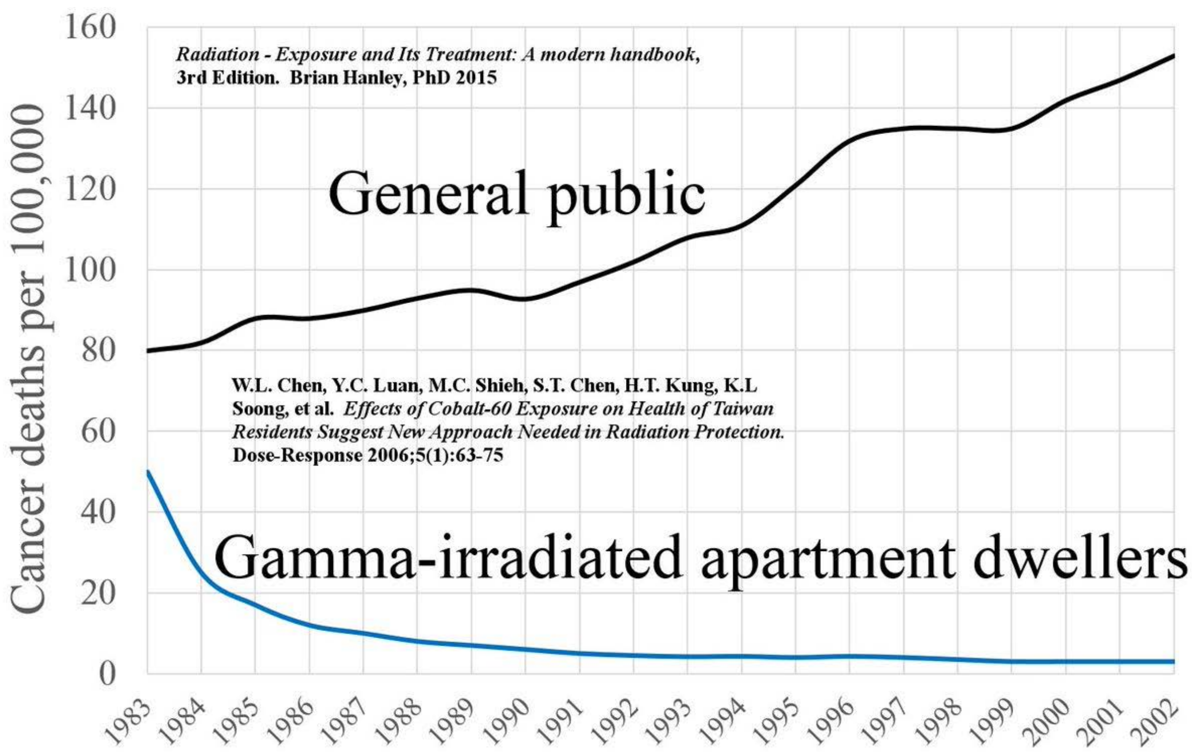
- Clear evidence for the radiation dose greater than 100 mSv.
- There are still debates for the effect of radiation dose under 100 mSv.





Evidence of hormesis

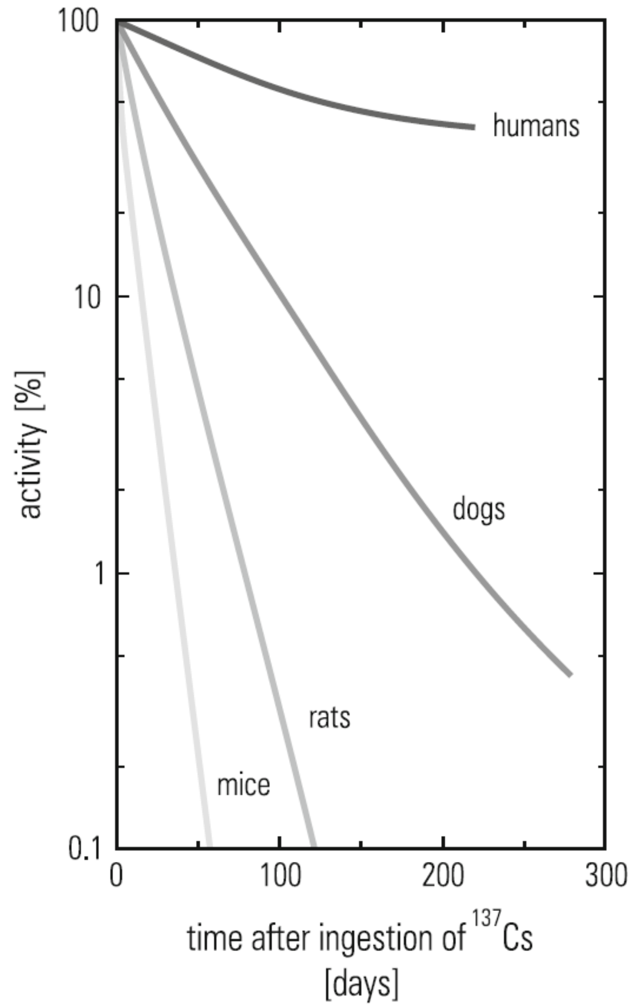
- In Taiwan in the early 1980s, radioactive cobalt-60 (half-life 5.3 years) was accidentally included in some steel building materials, and these materials were then used to build 1,700 apartments. Over the course of two decades, some 10, 000 people occupied these apartments, receiving doses between a few millisieverts per year and a few tens of millisieverts per year (average total dose ~ 0.4 Sv).



Biological half-life

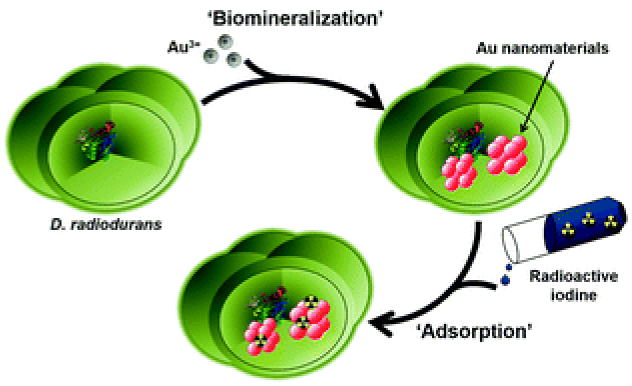
- The human body will have some ability to excrete incorporated material, and this ability will vary according to the substance involved.

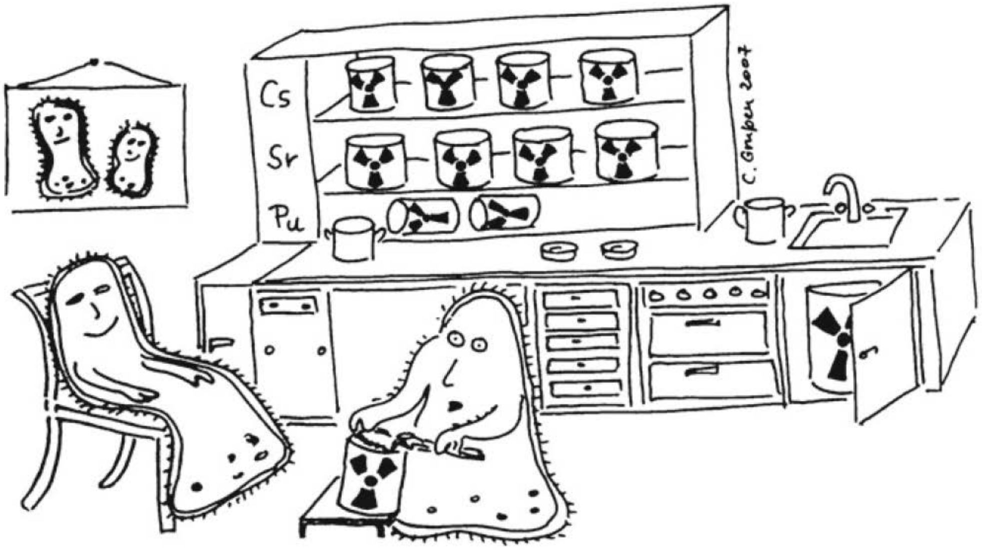
Physical half-life of ^{137}Cs ~ 30 yrs



Radiation resistance

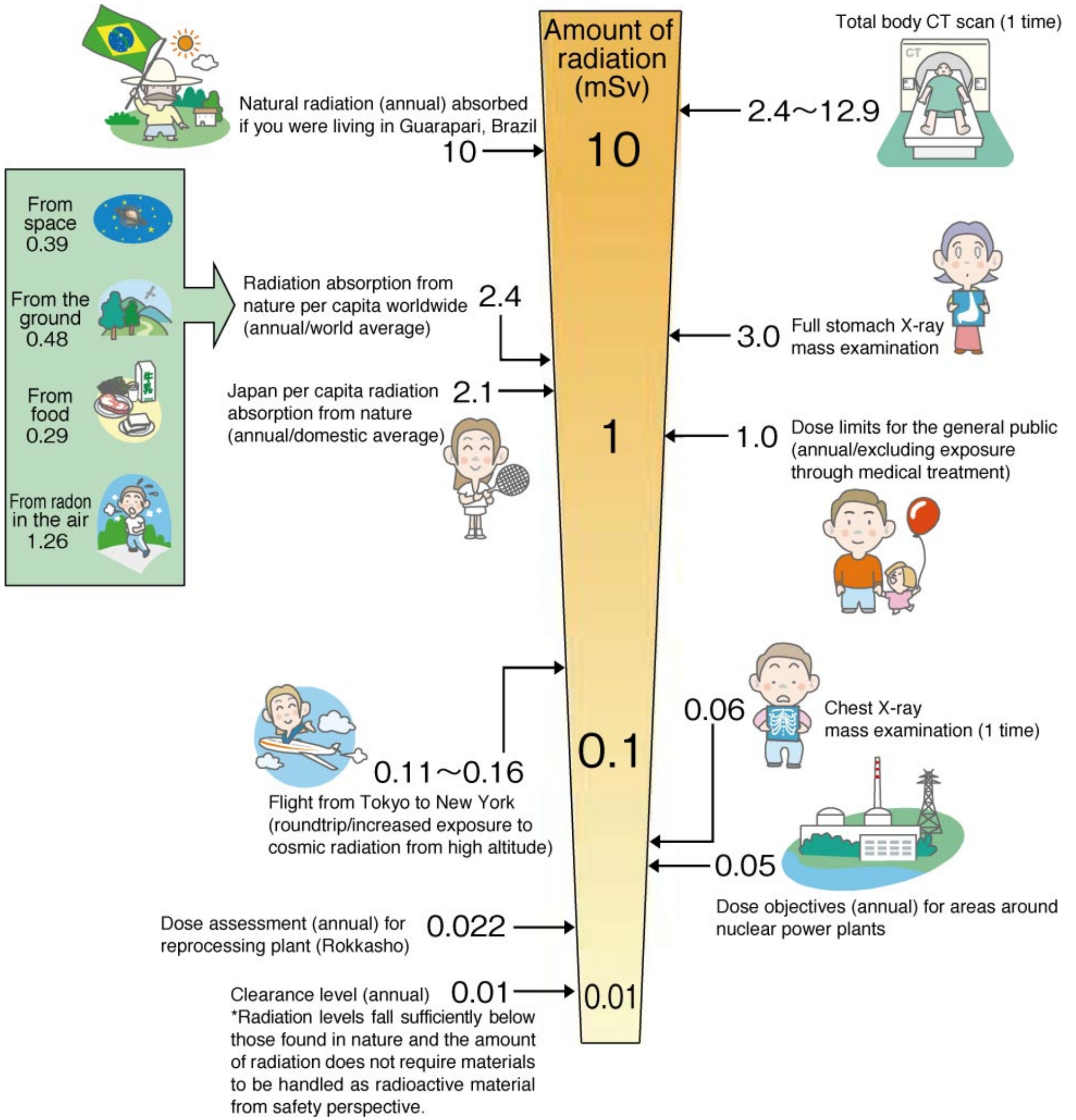
- The lethal dose, remembering that doses are inherently per-kilogram measures, for all mammals is about the same (humans: 4 Sv, dogs: 4 Sv, monkeys: 5 Sv, rabbits: 8 Sv, marmots: 10 Sv).
- In contrast to that, spiders (with a lethal dose of 1,000 Sv) and viruses (2,000 Sv) are much more resistant against ionizing radiation.
- The bacteria deinococcus radiodurans and deinococcus radiophilus can survive enormous doses (30,000 Sv) because of their extraordinary ability to repair radiation damage. They have even been found in the hot reactor cores of nuclear power plants.





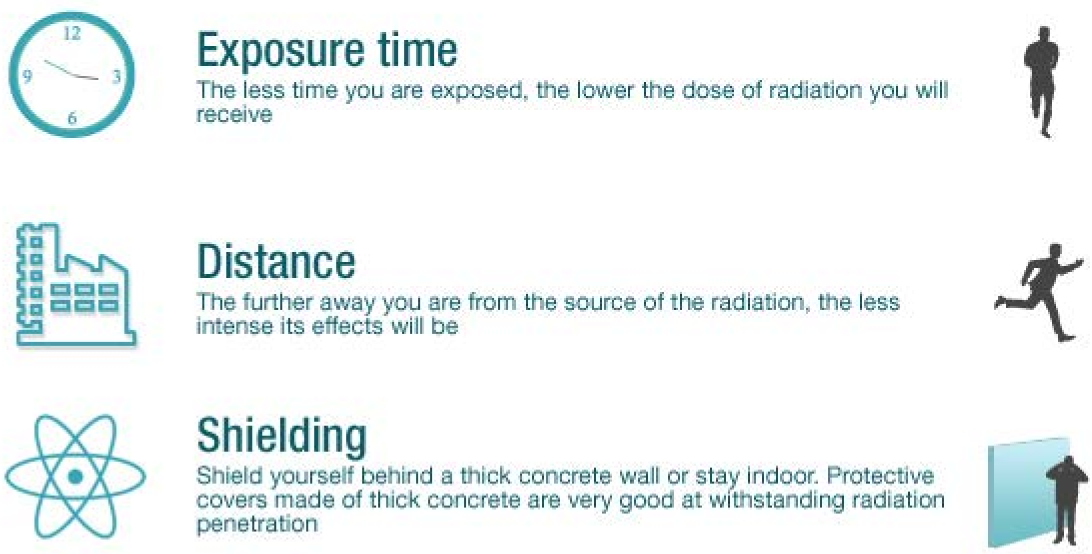
"So, Deino, shall we have some delicious caesium-137 for dessert?"

Radiation in daily life

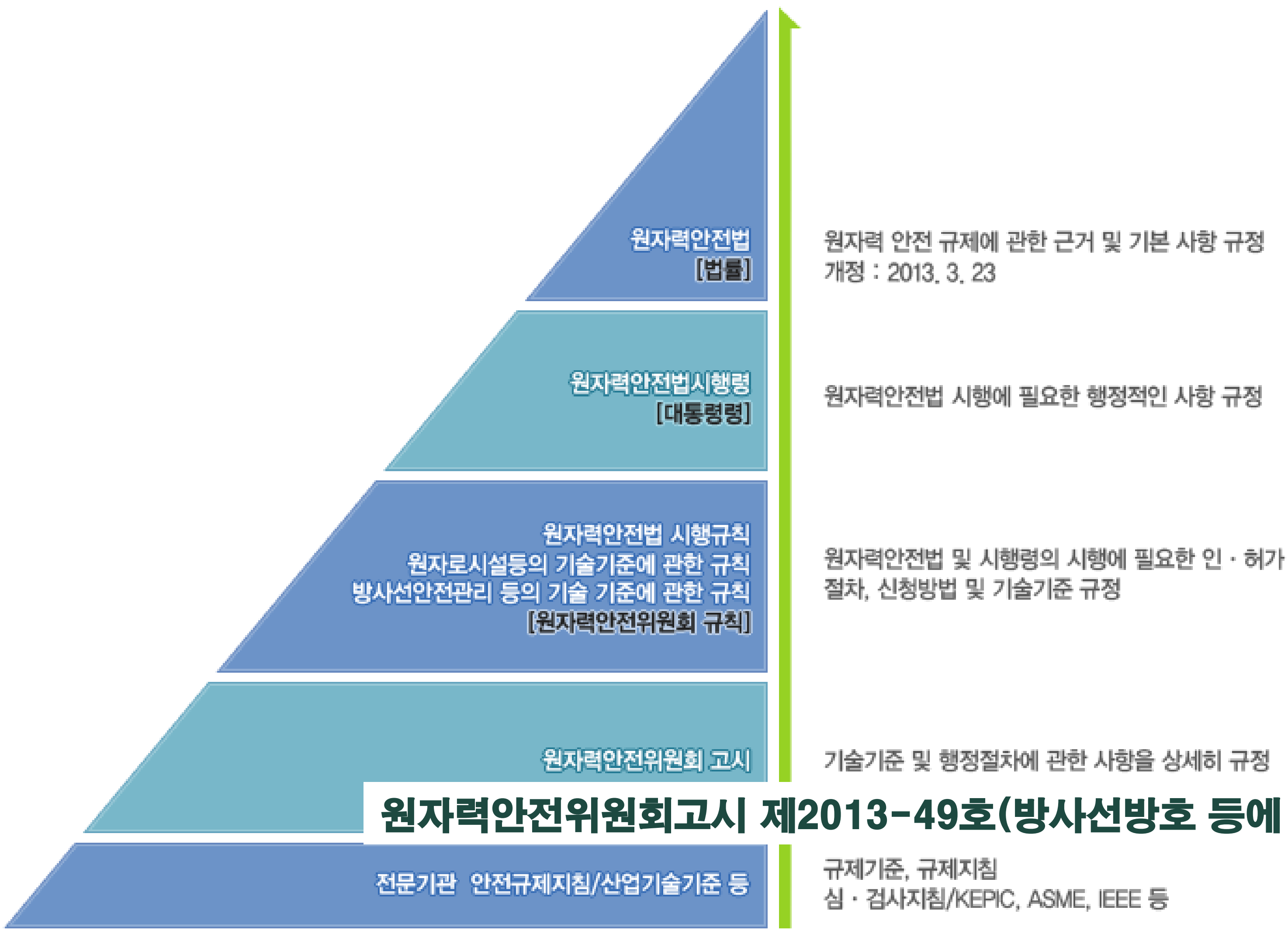


Principles of radiation protection

- Justification of practice: adopt no practice unless it produces a net benefit
- Optimization of protection: if exposure is justified, then keep it as low as reasonably achievable (ALARA), economic and social factors being taken into account
- Limitation of exposure: dose to individuals should not exceed the limits recommended



우리나라의 방사선 안전 규제: 원자력안전위원회



원자력안전위원회고시 제2013-49호(방사선방호 등에 관한 기준)

원자력안전위원회 고시 제2013-49호

방사선 가중치[1](제2조제5호 관련)

종류 및 에너지 범위	방사선 가중치(W_R)
ㅇ광자(전에너지)	1
ㅇ전자 및 뮤온(전에너지)[2]	1
ㅇ중성자, 에너지 < 10 keV	5
10 keV – 100 keV	10
100 keV – 2 MeV	20
2 MeV – 20 MeV	10
> 20 MeV	5
ㅇ반조양자이외의 양자 (에너지>2 MeV)	5
ㅇ알파입자, 핵분열 파편, 무거운 원자핵	20

조직 가중치[1](제2조제6호 관련)

조직 또는 장기	조직가중치(W_T)	조직 또는 장기	조직가중치(W_T)
생식선	0.20	간	0.05
골수(적색)	0.12	식 도	0.05
대 장	0.12	갑상선	0.05
폐	0.12	피 부	0.01
위	0.12	뼈표면	0.01
방 광	0.05	기타 조직	0.05[2,3]
유 방	0.05		

[별표 3]

방사성물질의 연간섭취한도, 유도공기중농도 및 배출관리기준

(제6조, 제7조, 제8조 및 제16조 관련)

1 란	2 란	3 란	4 란	5 란	6 란	7 란	8 란
핵 종	흡 입				섭 취		
	화학적 형태	연간 섭취한도	유도 공기중농도	배기중의 배출관리기준	화학적 형태	연간 섭취한도	배수중의 배출관리기준
		Bq	Bq/m³	Bq/m³		Bq	Bq/m³
Hydrogen H-3	G, 삼중수소가 결합된 물 (피부흡수 포함)	1E+09	3E+05	3E+03	삼중수소가 결합된 물	1E+09	4E+07
	G, 유기적으로 결합된 삼중수소	5E+08	2E+05	2E+03	유기적으로 결합된 삼중수소	5E+08	2E+07
	G, 원소상태의 삼중수소	1E+13	5E+09	4E+07			
	G, 삼중수소가 결합된 메탄	1E+11	5E+07	4E+05			
Beryllium Be-7	M, 기타 모든 화합물	5E+08	2E+05	1E+03	모든 화합물	7E+08	2E+07
	S, 산화물, 할로겐화물 및 질산염	4E+08	2E+05	1E+03			
Be-10	M, Be-7과 동일	3E+06	1E+03	8E+00	Be-7과 동일	2E+07	6E+05
	S, Be-7과 동일	1E+06	4E+02	2E+00			
Carbon C-11	G, 증기	6E+09	3E+06	2E+04	표지 유기화합물	8E+08	3E+07
	G, 이산화물	9E+09	4E+06	3E+04			
	G, 일산화물	2E+10	7E+06	6E+04			
C-14	G, 증기	3E+07	1E+04	1E+02	표지 유기화합물	3E+07	1E+06
	G, 이산화물	3E+09	1E+06	1E+04			
	G, 일산화물	3E+10	1E+07	9E+04			

Radiation dose limit

- ICRP (International Commission on Radiation Protection) 권고안을 각국에서 채택하여 사용

Publication 60 (1990)

	workers	public
annual acceptable risk	8×10^{-4}/yr	5×10^{-5}/yr
radiation risk factor	4×10^{-2}/Sv	5×10^{-2}/Sv
effective dose-equivalent limit - averaged over 5 years - annual maximum	20 mSv/yr 50 mSv/yr	1 mSv/yr -
tissue dose equivalents - lens - skin - hands and feet	150 mSv/yr 500 mSv/yr 500 mSv/yr	15 mSv/yr 50 mSv/yr -