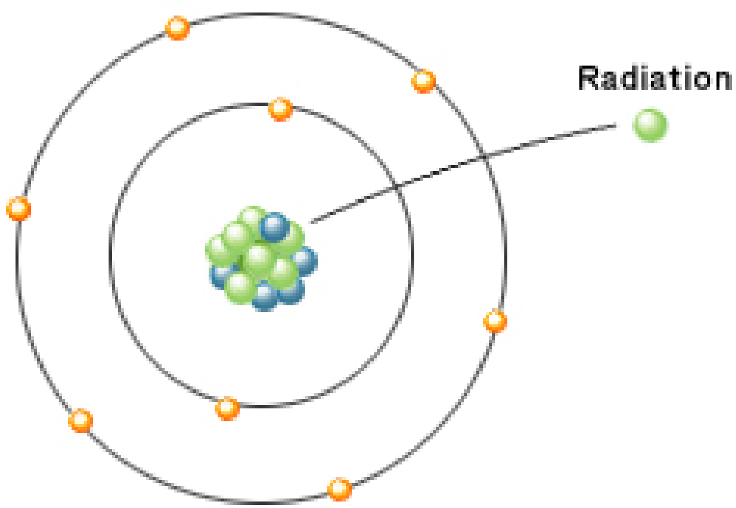
RADIATION RISK ASSESSMENT

EXPOSURE and TOXITY ASSESSMENT



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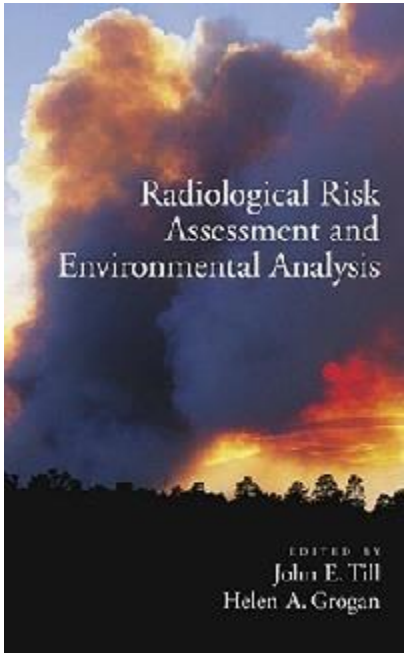
TOMSK -2013



The contents

- 1.Exposure assessment
- 1.1. The term “exposure” for chemicals and radionuclides
- 1.2. The basic steps for chemicals and radionuclides
- 2. TOXICITY ASSESSMENT
- What is the mechanism of radiation damage?

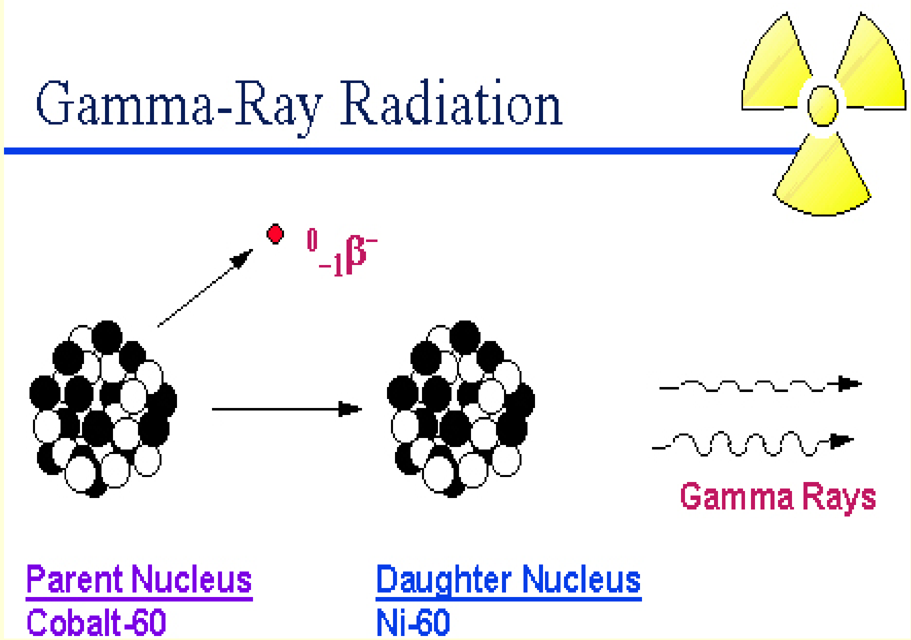
the four basic steps in the risk assessment process:

- 1. Data Collection and Evaluation
- 2. Exposure Assessment
- 3. Toxicity Assessment
- 4. Risk Characterization

Exposure Assessment

- is the process of estimating or measuring the magnitude, frequency and duration of **exposure** to an agent, along with the number and characteristics of the population **exposed**

How does the exposure assessment for radionuclides differ from that for chemicals?



the term "exposure" is used in a fundamentally different way for radionuclides as compared to chemicals

- . For chemicals, exposure generally refers to the intake (e.g., inhalation, ingestion, dermal exposure) of the toxic chemical, expressed in units of mg/kg-day. These units are convenient because the toxicity values for chemicals are generally expressed in these terms. For example, the toxicity value used to assess carcinogenic effects is the slope factor, expressed in units of risk of lifetime excess cancers per mg/kg-day. As a result, the product of the intake estimate with the slope factor yields the risk of cancer (with proper adjustments made for absorption, if necessary).

radionuclide intake is typically expressed in units of activity (i.e., Bq or Ci) rather than mass

- Intakes by inhalation, ingestion, and absorption are also potentially important exposure pathways for radionuclides, although radionuclide intake is typically expressed in units of activity (i.e., Bq or Ci) rather than mass. Radionuclides that enter through these internal exposure pathways may become systemically incorporated and emit alpha, beta, or gamma radiation within tissues or organs.
- Unlike chemical assessments, an exposure assessment for radioactive contaminants can include an explicit estimation of the radiation dose equivalent

EXAMPLE OF LOWER LIMITS OF DETECTION (LLD) FOR SELECTED RADIONUCLIDES USING STANDARD ANALYTICAL METHODS[a]

Isotope	Sample Media[b]	LLD pCi	LLD Bq		Methodology
Co-60	-Water	10	0.4		Gamma Spectrometry
	-Soil (dry wt.)	0.1	0.004		Gamma Spectrometry
	-Biota (wet wt.)[c]	0.1	0.004		Gamma Spectrometry
	-Air[d]	25	0.9		Gamma Spectrometry
Sr-90	-Water		1	0.04	Radiochemistry
Cs-137	-Water		10	0.4	Gamma Spectrometry
		0.3	0.01		Radiochemistry
	-Soil (dry wt.)	1	0.04		Gamma Spectrometry
		0.3	0.01		Radiochemistry
	-Biota (wet wt.)	1	0.04		Gamma Spectrometry
		0.3	0.01		Radiochemistry
	-Air	30	1		Gamma Spectrometry
Pb-210	-Water	0.2	0.007		Radiochemistry
	-Soil (dry wt.)	0.2	0.007		Radiochemistry
	-Biota (wet wt.)	0.2	0.007		Radiochemistry
	-Air	5	0.2		Radiochemistry
Ra-226	-Water	100	4		Gamma Spectrometry
		0.1	0.004		Radiochemistry
		0.1	0.004		Radon Daughter Emanation
	-Soil (dry wt.)	0.1	0.004		Radon Daughter Emanation
	-Biota (wet wt.)	0.1	0.004		Radon Daughter Emanation
	-Air	1	0.04		Alpha Spectrometry
Th-232	-Water	0.02	0.0007		Alpha Spectrometry
	-Soil (dry wt.)	0.2	0.007		Radiochemistry
	-Biota (wet wt.)	0.02	0.0007		Alpha Spectrometry
	-Air	0.3	0.01		Alpha Proportional Counter
U-234	-Water		0.02	0.0007	Alpha Spectrometry
U-235	-Soil (dry wt.)		0.1	0.004	Alpha Spectrometry
U-238	-Biota (wet wt.)		0.02	0.0004	Alpha Spectrometry
	-Air	0.2	0.007		Alpha Spectrometry

the dose equivalent

- is an expression that takes into consideration both the amount of energy deposited in a unit mass of a specific organ or tissue as a result of the radioactive decay of a specific radionuclide, as well as the relative biological effectiveness of the radiations emitted by that nuclide

the same basic steps

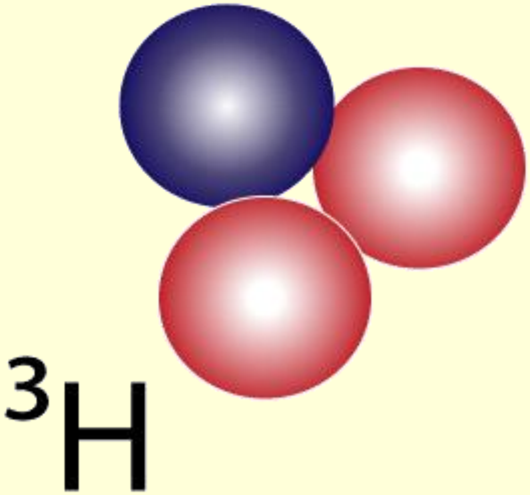
i.e., characterizing the exposure setting, identifying exposure pathways and potential receptors,

estimating exposure point concentrations,

estimating exposures/intakes.

- Exposure assessment for radionuclides is very similar to that
- for chemicals. Both nonradioactive chemical assessments
- and radionuclide assessments follow the same basic
- steps-i.e., characterizing the exposure setting, identifying
- exposure pathways and potential receptors, estimating
- exposure point concentrations, and estimating
- exposures/intakes. In addition to the exposure pathways
- considered for chemicals (e.g., ingestion of contaminated
- water, soil, or foodstuffs, and inhalation of contaminated
- air), external exposure to penetrating radiation (i.e., gamma
- radiation and x-rays) may be an important exposure
- pathway for certain radionuclides in near-surface soils.

- On the other hand, with the primary exception of tritium (H-3) as tritiated water or water vapor, dermal absorption is typically not a significant exposure pathway for radio- nuclides and generally need not be considered. (Other possible exceptions could include organic compounds containing radionuclides.



Typical exposure pathways for radionuclides;

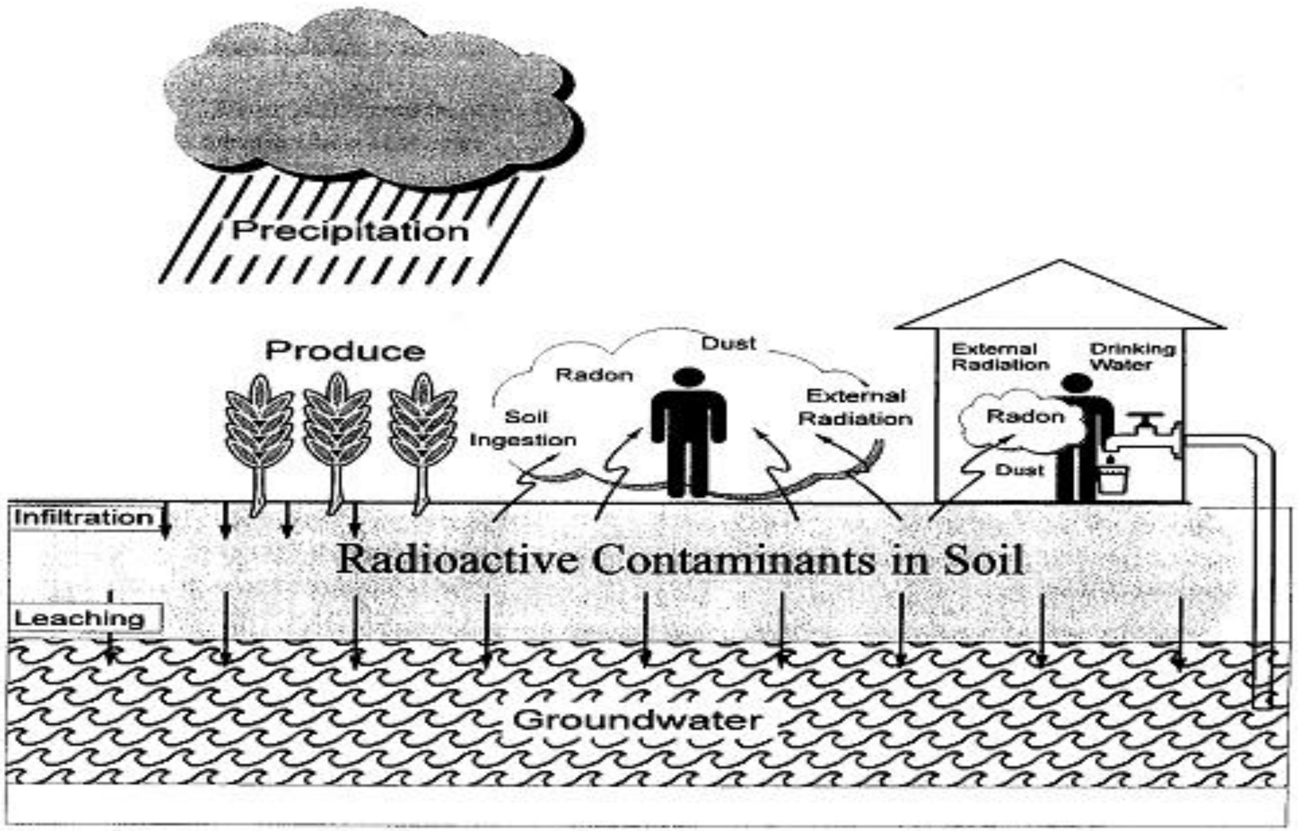


Figure 1. Typical Radionuclide Exposure Pathways

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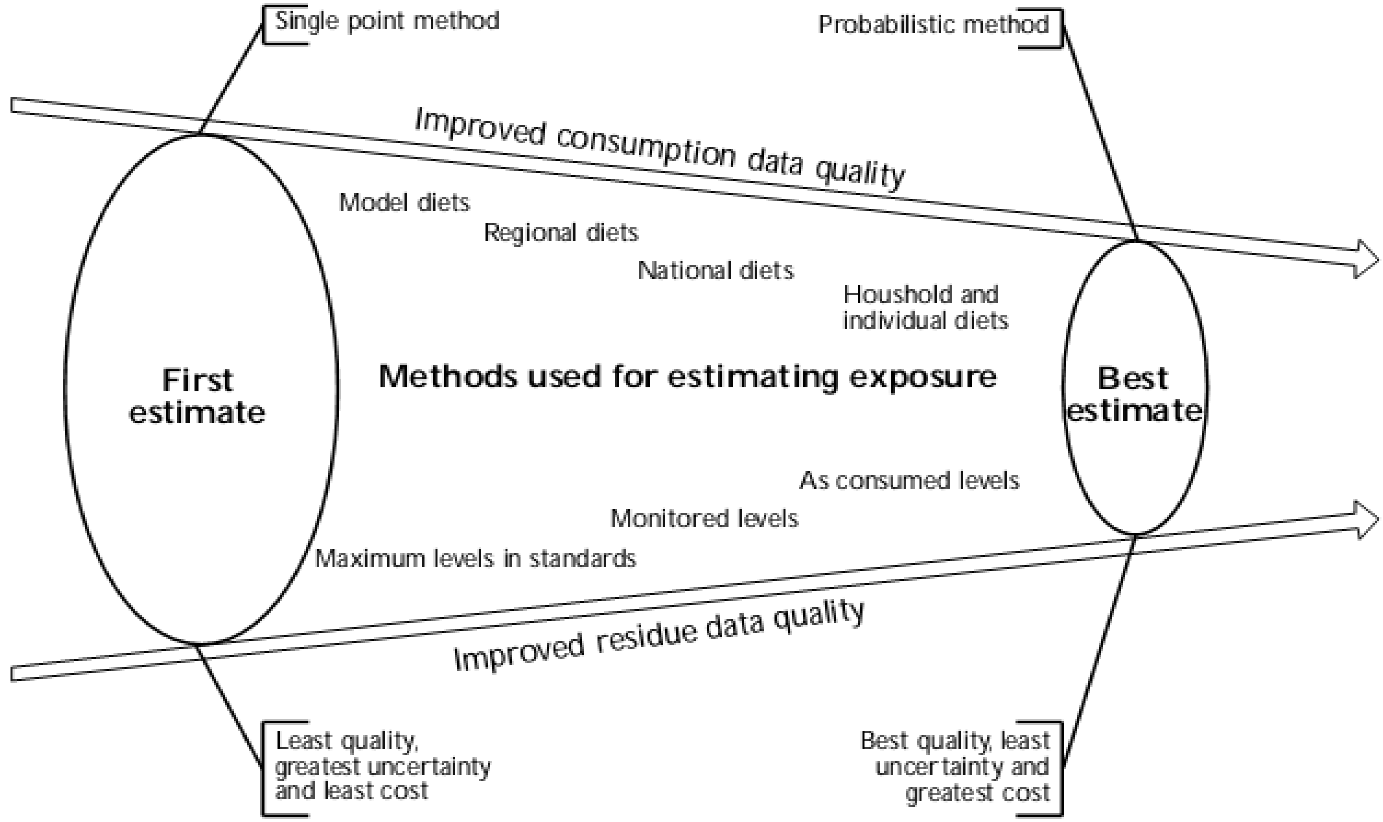
Can exposure pathways be added or deleted based site-specific conditions?

- Yes. Inclusion or deletion of exposure pathways should be based upon site-specific conditions, including local hydrology, geology, potential receptors, and current and potential future land use, among other factors. Accordingly, some exposure pathways may not be appropriate for a given site and may be deleted, if justification is provided.

ingestion of contaminated fish, ingestion of contaminated meat or milk

- In other cases, exposure pathways that are typically not significant may be important for the site-specific conditions (e.g.,
- ingestion of contaminated fish for recreational scenarios,
- ingestion of contaminated meat or milk from livestock for agricultural scenarios) and should be included in the assessment.

Figure 2.1 Relationship between sources of data used and quality of the dietary exposure assessment



ACRONYMS, SYMBOLS, AND UNITS

- A(t) = Activity at Time t
- Bq = Becquerel
- Ci = Curie
- D = Absorbed Dose
- DCF = Dose Conversion Factor Per Unit Intake
- HE = Effective Dose Equivalent
  HT = Dose Equivalent Averaged Over Tissue or Organ T
  HE,50 = Committed Effective Dose Equivalent Per Intake
  HT,50 = Committed Dose Equivalent Averaged Over Tissue T
- LET = Linear Energy Transfer
- LLD = Lower Limit of Detection
- MeV = Million Electron Volts
  pCi = PicoCurie (10-12 Ci)
- Q = Quality Factor in Definition of Dose Equivalent
- RBE = Relative Biological Effectiveness
- SI = International System of Units
- Sv = Sievert
- T = Tissue or Target Organs
- wT = Weighting Factor in the Definition of Effective Dose Equivalent and Committed Effective Dose Equivalent

How should Radon-222 (radon) and Radon-220 (thoron) exposures and risks be evaluated?

- Radon-222 (Rn-222) and Radon-220 (Rn-220) are radioactive gases that are isotopes of the element radon (Rn). Each is produced by the radioactive decay of an isotope of radium (Ra).
- most (but not all) radon exposure and risk assessments deal with radon (Rn-222) arising from radium (Ra-226) contamination.

calculation methods or multimedia radionuclide transport and exposure models

- Numerous computerized mathematical models to predict the fate and transport of radionuclides in the environment
- single-media models (e.g., ground water transport

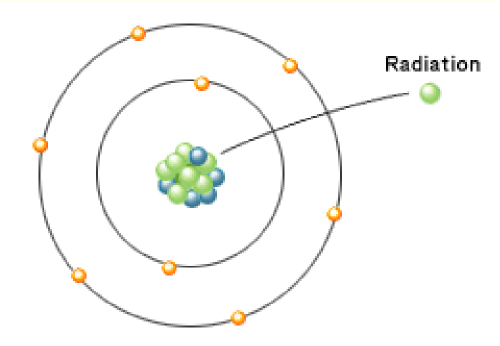
Ground- Water Modeling Compendium
Technical Guide to Ground- Water Model Selection at Sites Contaminated with RadioactiveSubstances

TOXICITY ASSESSMENT

What is the mechanism of radiation damage?

Subject

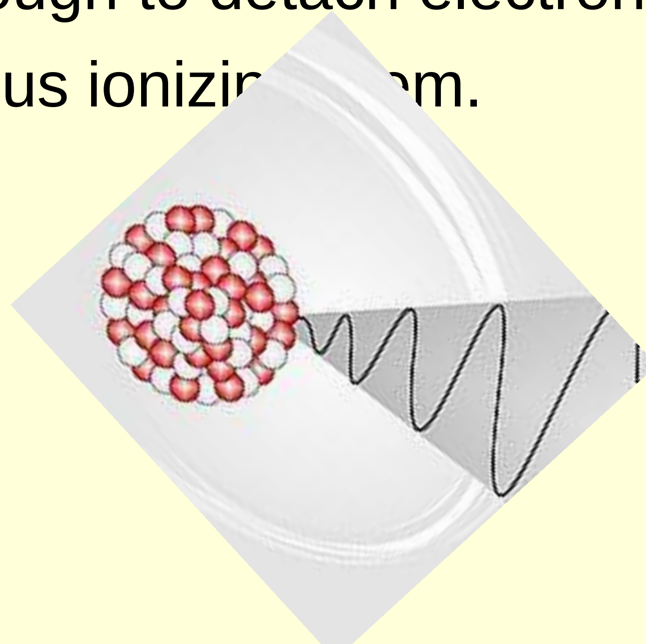
Biological Effects of Ionizing Radiation



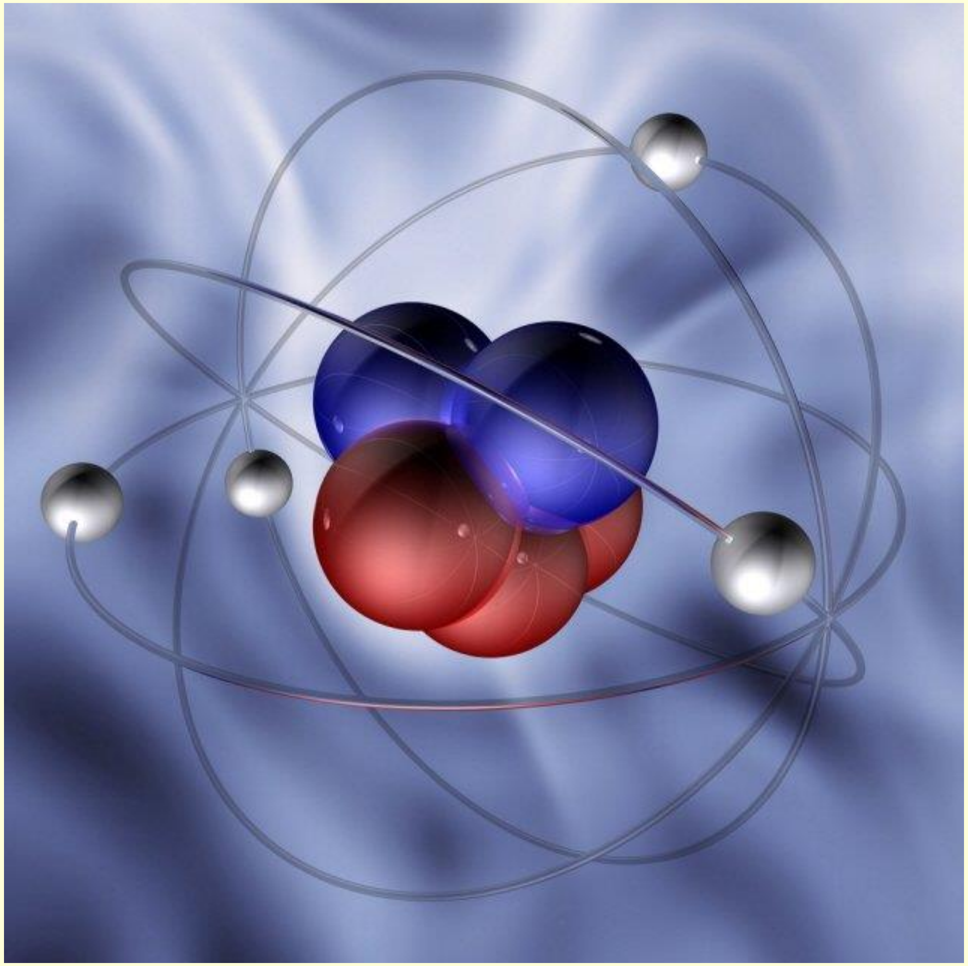
Ionizing radiation

- It's any radiation that leads to the formation of a positively charged and negatively charged ions.

- It's consists of particles or electromagnetic waves energetic enough to detach electrons from atoms or molecules, thus ionizi em.

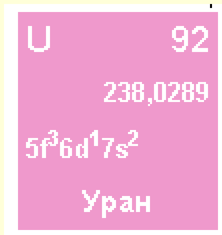


Nuclide is a nucleus characterized by a certain number of protons and neutrons and certain energy state



Radionuclide is an atom with an **unstable** nucleus

Isotopes are different types of nuclides of the same chemical element, each having a different number of neutrons

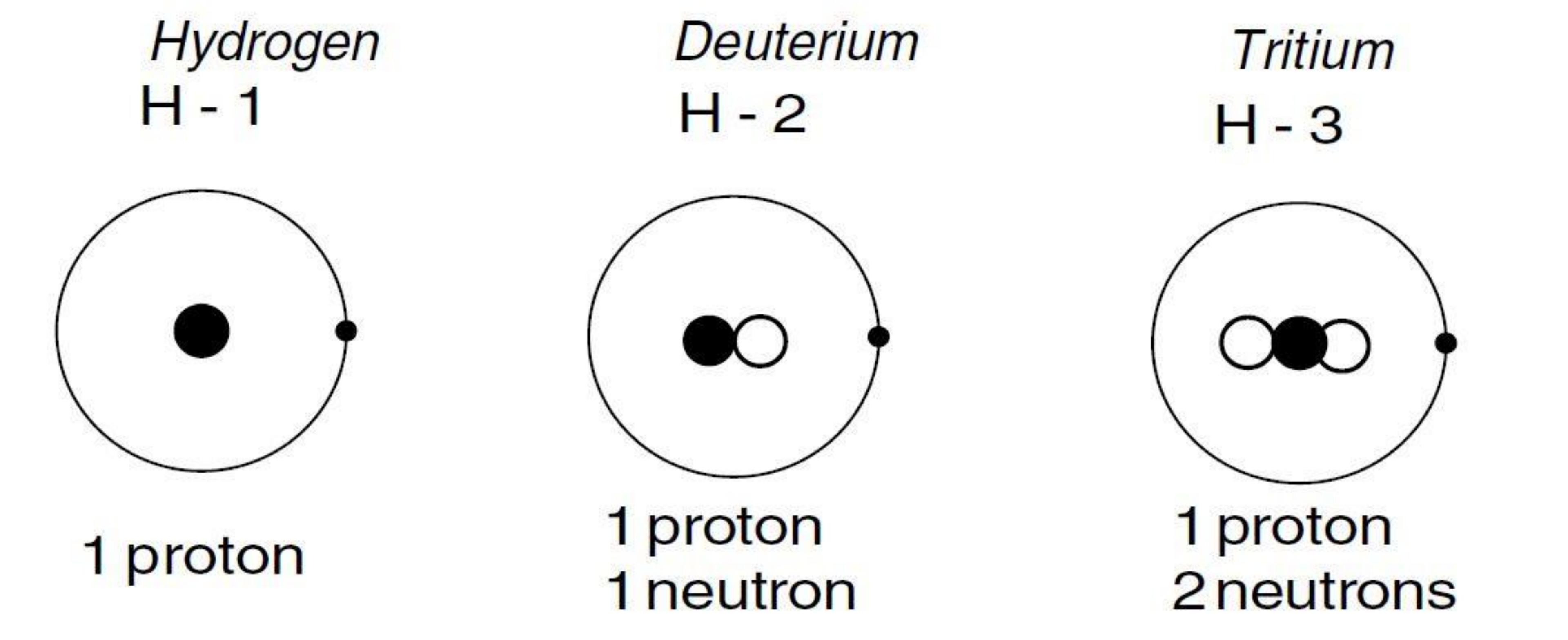


Natural uranium consists of a combination of three isotopes:

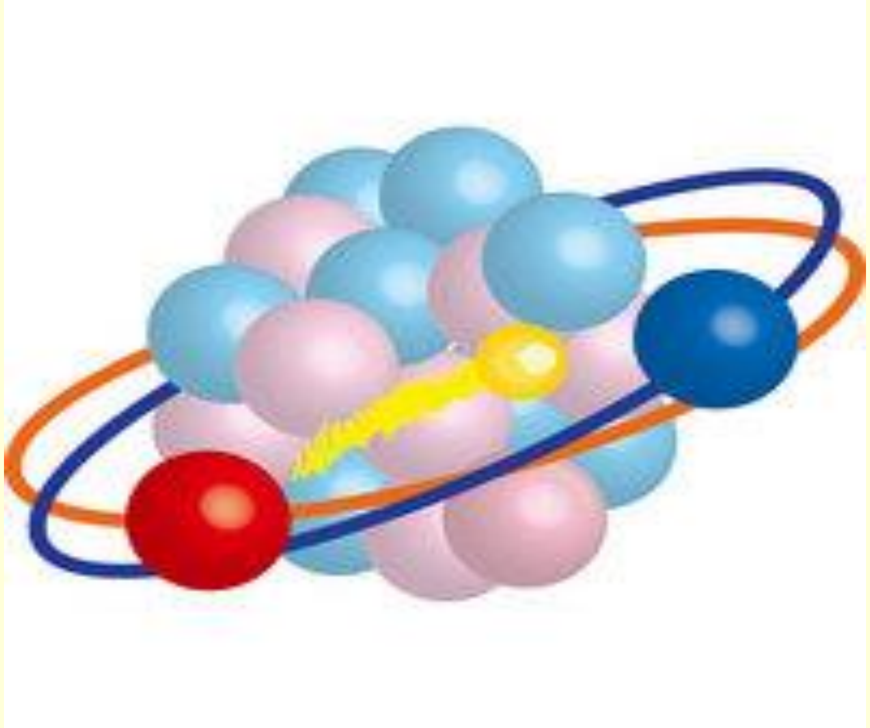
^{238}**U** — 99,28 %, ^{235}**U** — 0,71 % и ^{234}**U** — 0,005 %

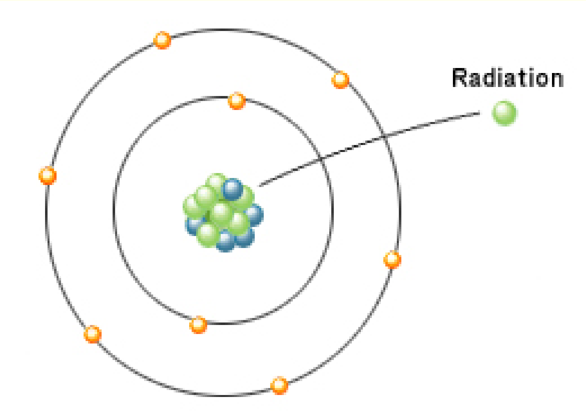
In addition there are 11 artificial radioactive isotopes with mass numbers from 227 to 240.

Hydrogen is found in the form of three isotopes, which have individual names: ^{1}H - **protium**, ^{2}H - **deuterium**, ^{3}H - **tritium** (radioactive isotope)


Hydrogen
H - 1
1 proton
Deuterium
H - 2
1 proton
1 neutron
Tritium
H - 3
1 proton
2 neutrons

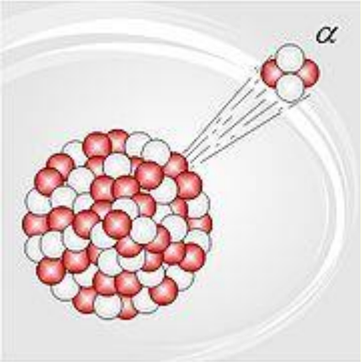
Radioactivity is the process of spontaneous transformation of unstable nuclides accompanied by ionizing radiation



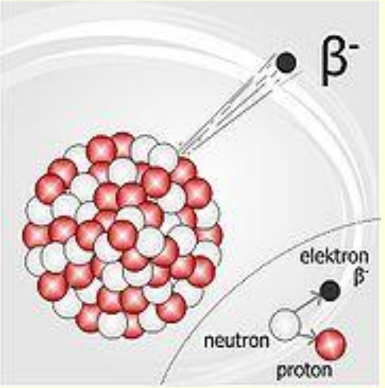


corpuscular or electromagnetic

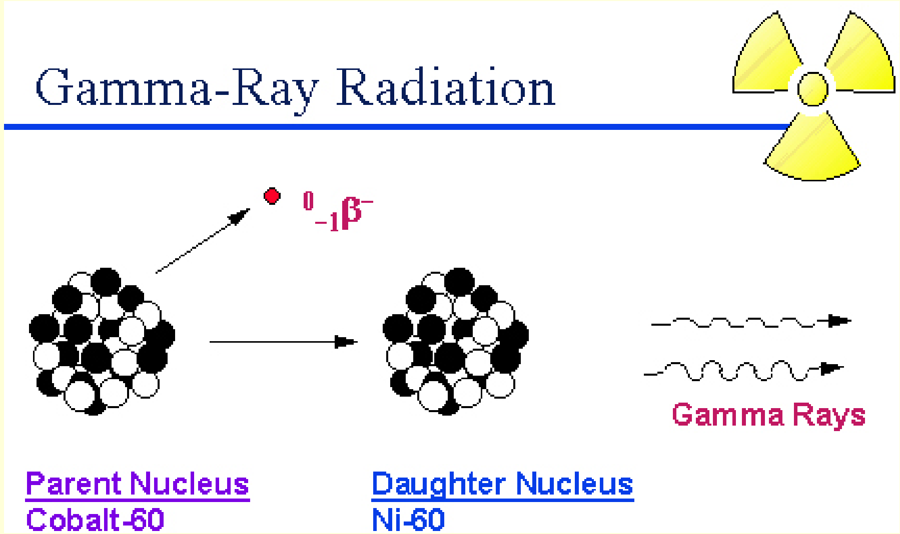
- **alpha particles**



- **beta particles**

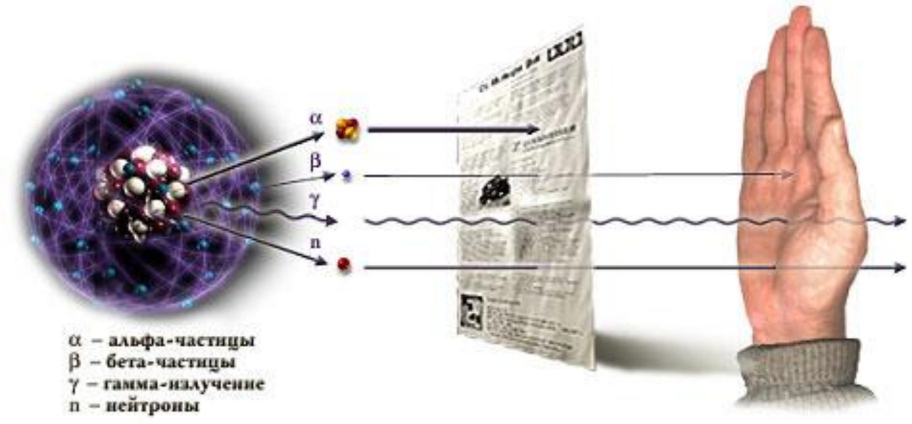


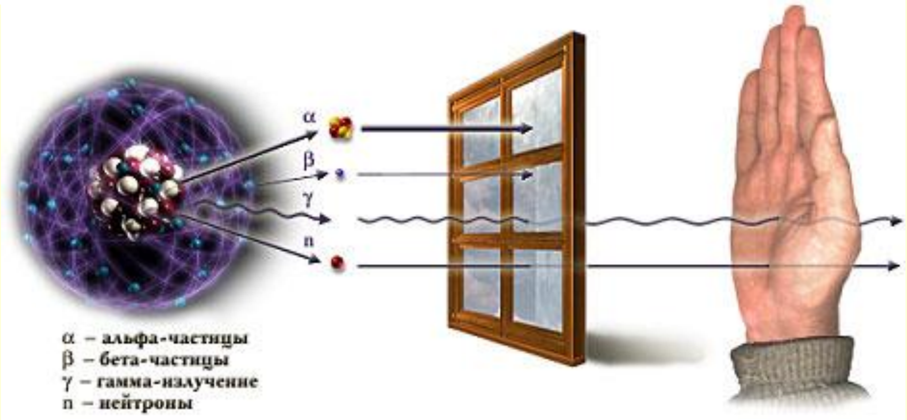
corpuscular or **electromagnetic**



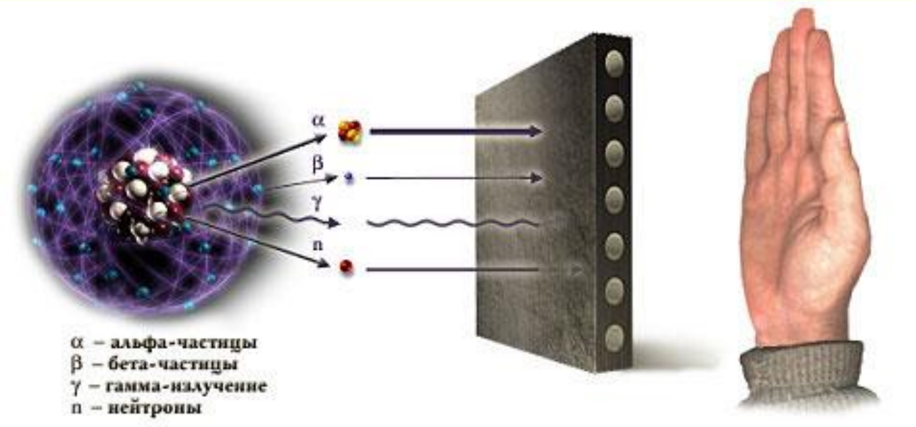
- **x rays**
- **gamma radiation**

Penetrating power





Only the gamma rays penetrate to the organs of human body



Activity and Dose

- The unit for the activity of a radioactive source was named after **Becquerel** (abbreviated **Bq**) and is defined as:

1 Bq = 1 disintegration per sec

Activity and Dose

- In a number of countries, the old unit, the **curie** (abbreviated **Ci** and named after Marie Curie) is still used.

The curie-unit was defined as the activity in **one gram** of radium.

- The number of disintegrations per second in one gram of radium is 37 billion. The relation between the **curie** and the **becquerel** is given by:

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

Absorbed Dose

- The energy absorbed in a material per unit mass of the material.
- SI unit: **gray** (Gy)
- Traditional unit: **rad** (1 Gy=100 rad)

Relative Biological Effectiveness

- **RBE**

  Ratio of the absorbed dose from a standard radiation (250 kVp x-rays) to produce a given biological effect to the absorbed dose from a radiation of interest to produce the same effect.

Quality Factor

- **Quality factor (Q)**

  Consensus value of RBEs for a particular type of radiation.

Examples:

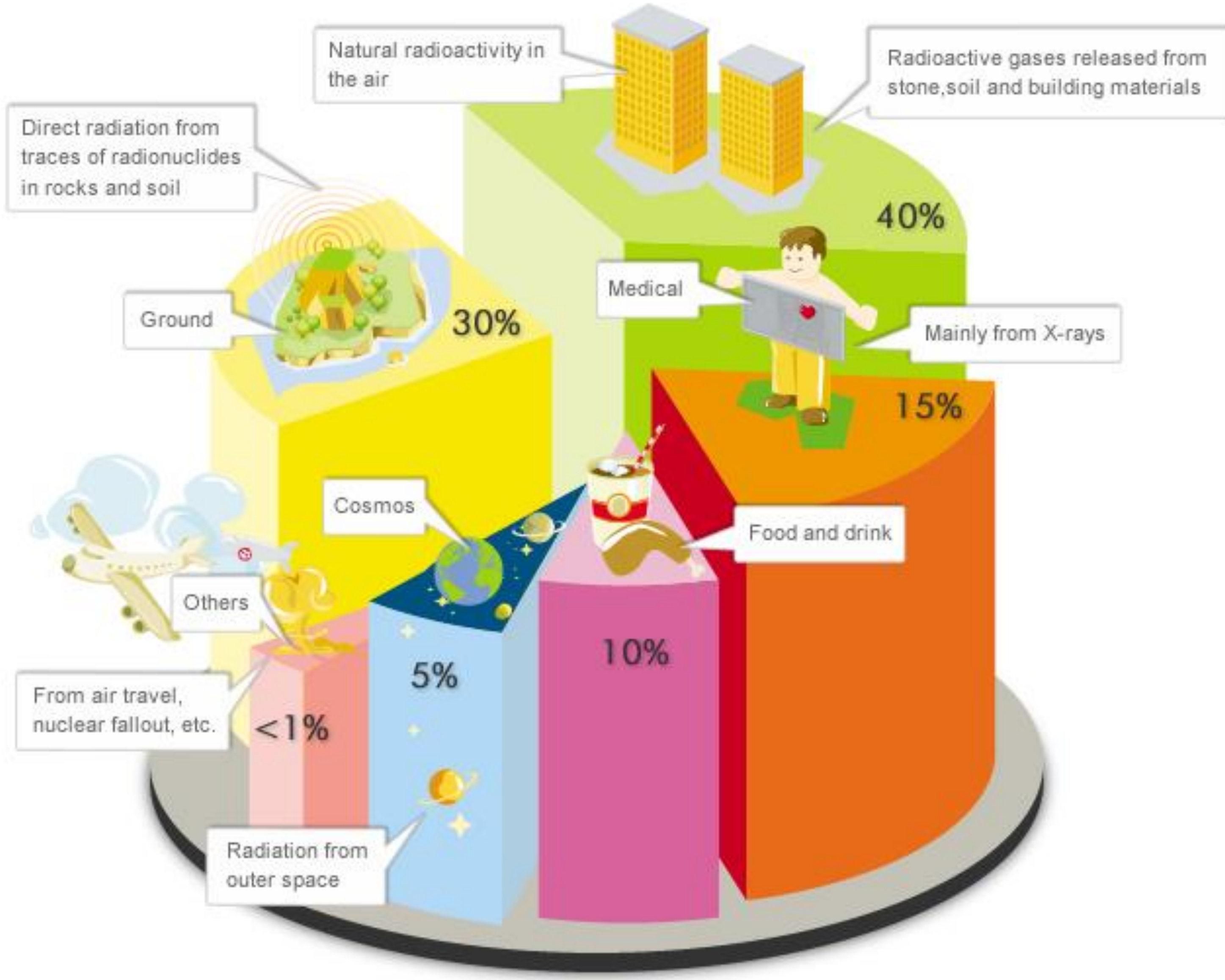
radiation	Q
betas and electrons	*1*
x and gammas rays	*1*
neutrons	*10*
alphas	*20*

Equivalent Dose

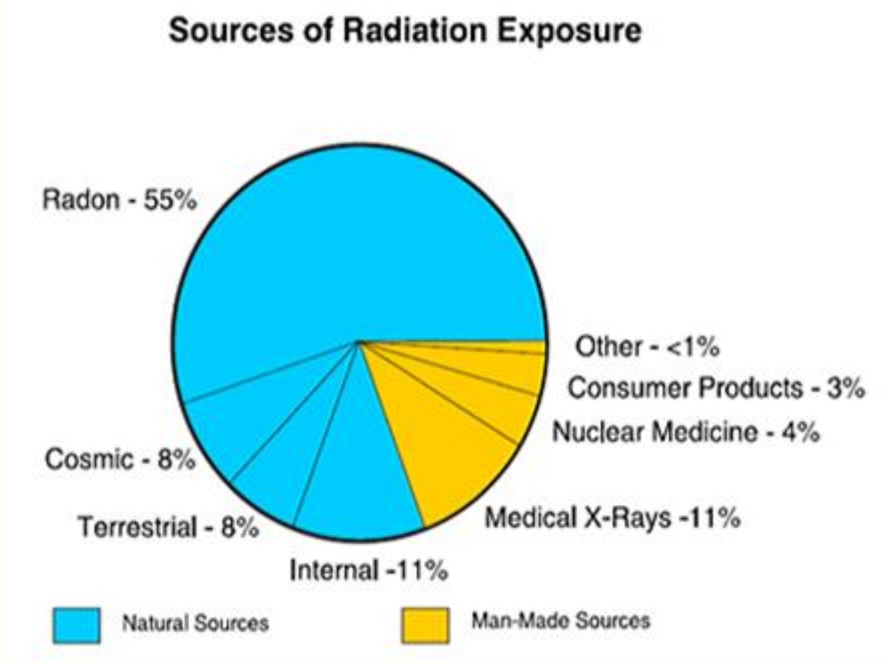
- **Dose equivalent (H):** allows the description of the biological effect of an absorbed dose.

$$\textbf{H = Absorbed Dose} \times \textbf{Q}$$

- SI unit: **sievert** (Sv)
- Traditional unit: **rem** (1 Sv = 100 rem)


Natural radioactivity in the air
Radioactive gases released from stone,soil and building materials
40%
Direct radiation from traces of radionuclides in rocks and soil
Ground
30%
Medical
Mainly from X-rays
15%
Cosmos
Food and drink
Others
10%
5%
From air travel, nuclear fallout, etc.
<1%
Radiation from outer space

Sources of radiation can be divided into two groups:



- **Natural Background Radiation**
- **Man-Made Radiation**

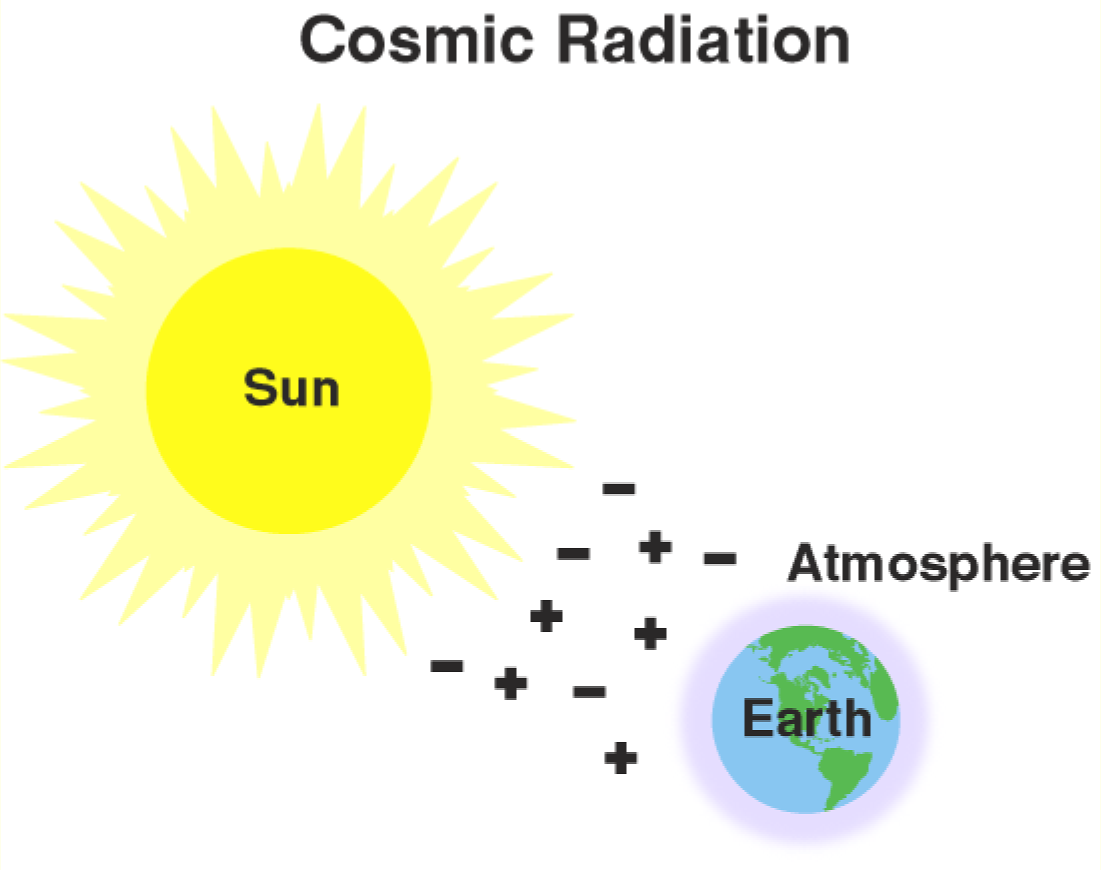
Radiation is part of nature.

All living creatures from the beginning of time exposed to radiation.

Natural Background Radiation

- **Cosmic Radiation**
- **Terrestrial Radiation**
- **Internal Radiation**

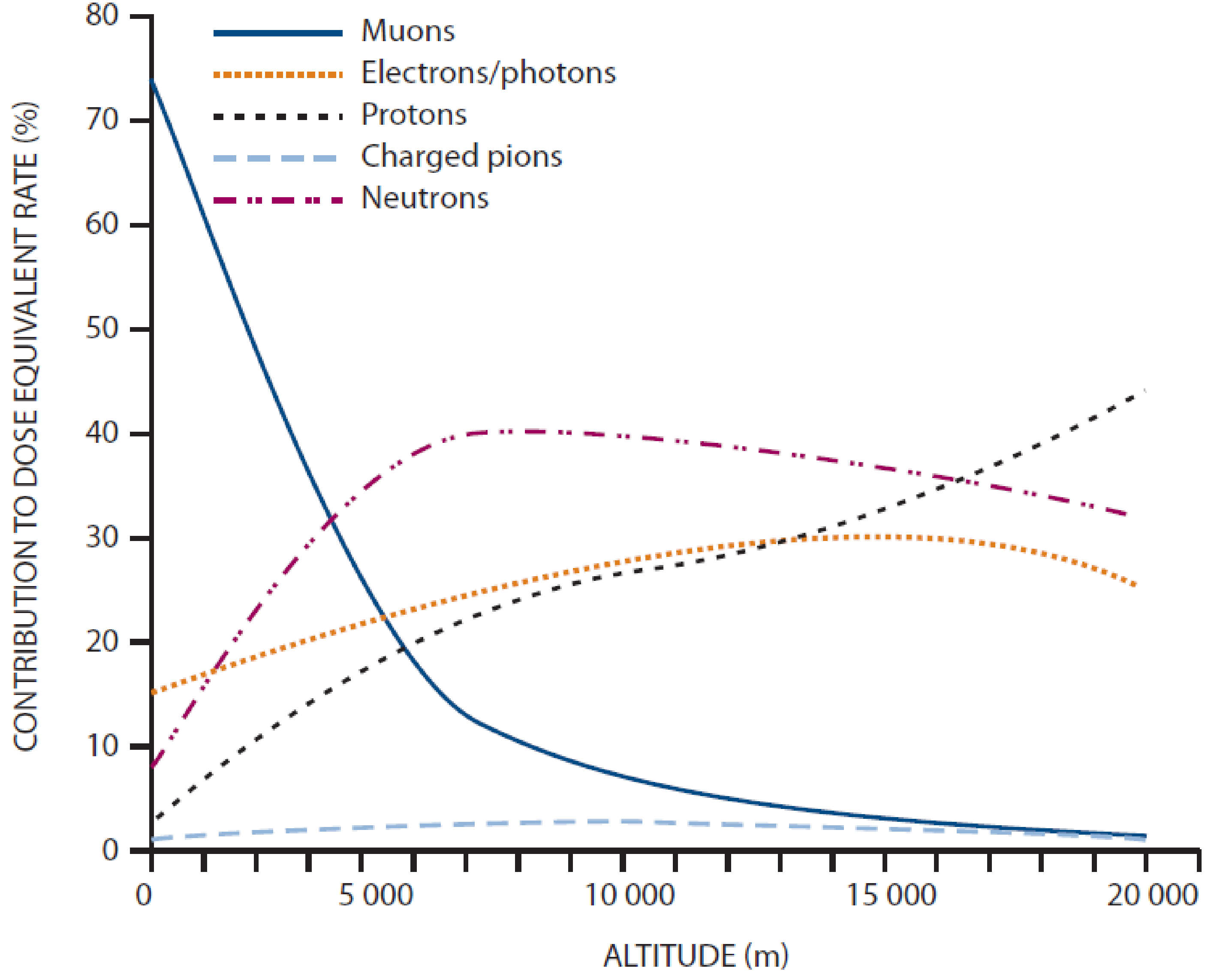
Cosmic Radiation



- The earth, and all living things on it, are constantly bombarded by radiation from outer space.

- Charged particles from the sun and stars interact with the earth's atmosphere and magnetic field to produce a shower of

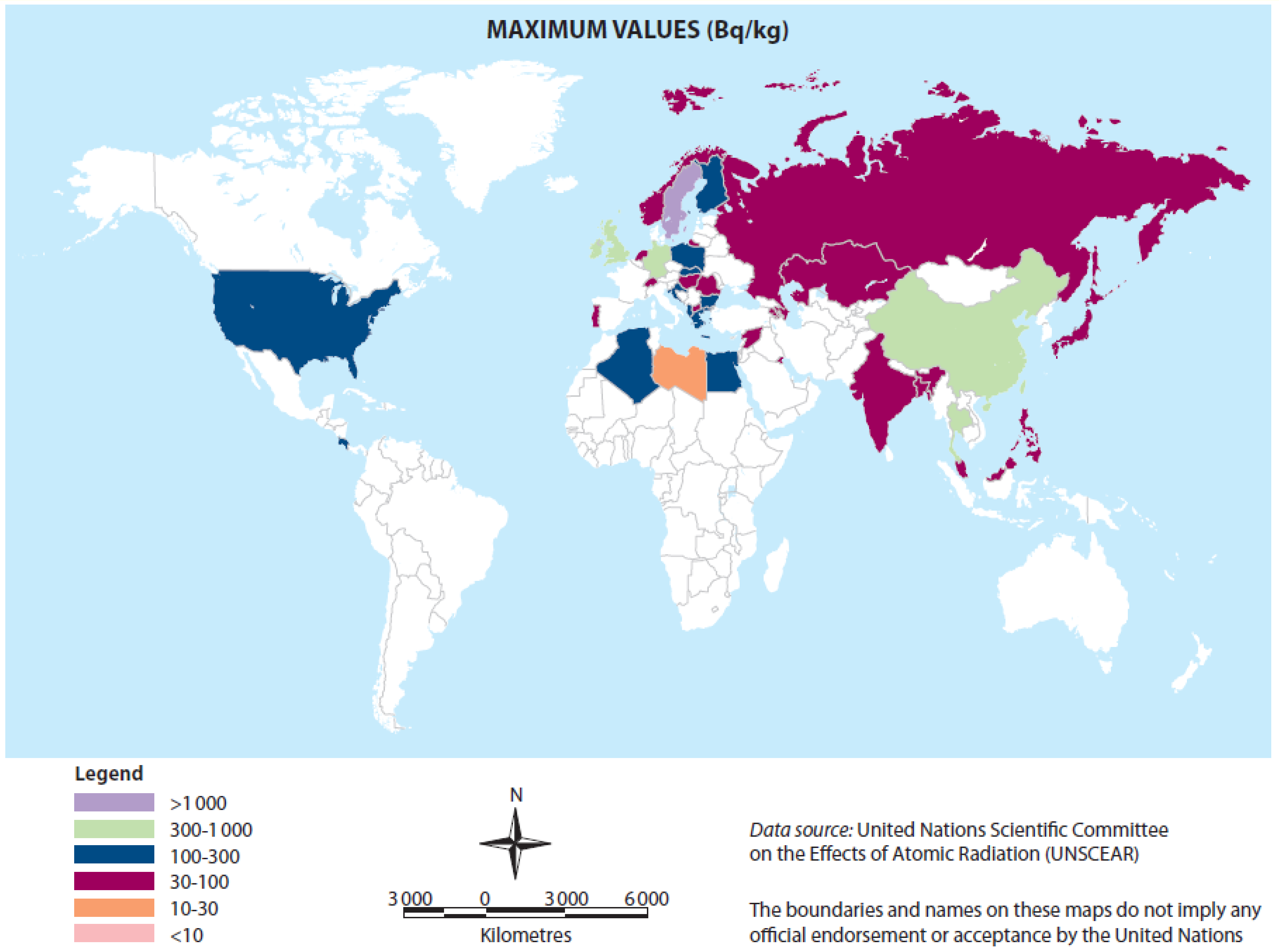
Components of the dose equivalent rate due to cosmic rays in the atmosphere



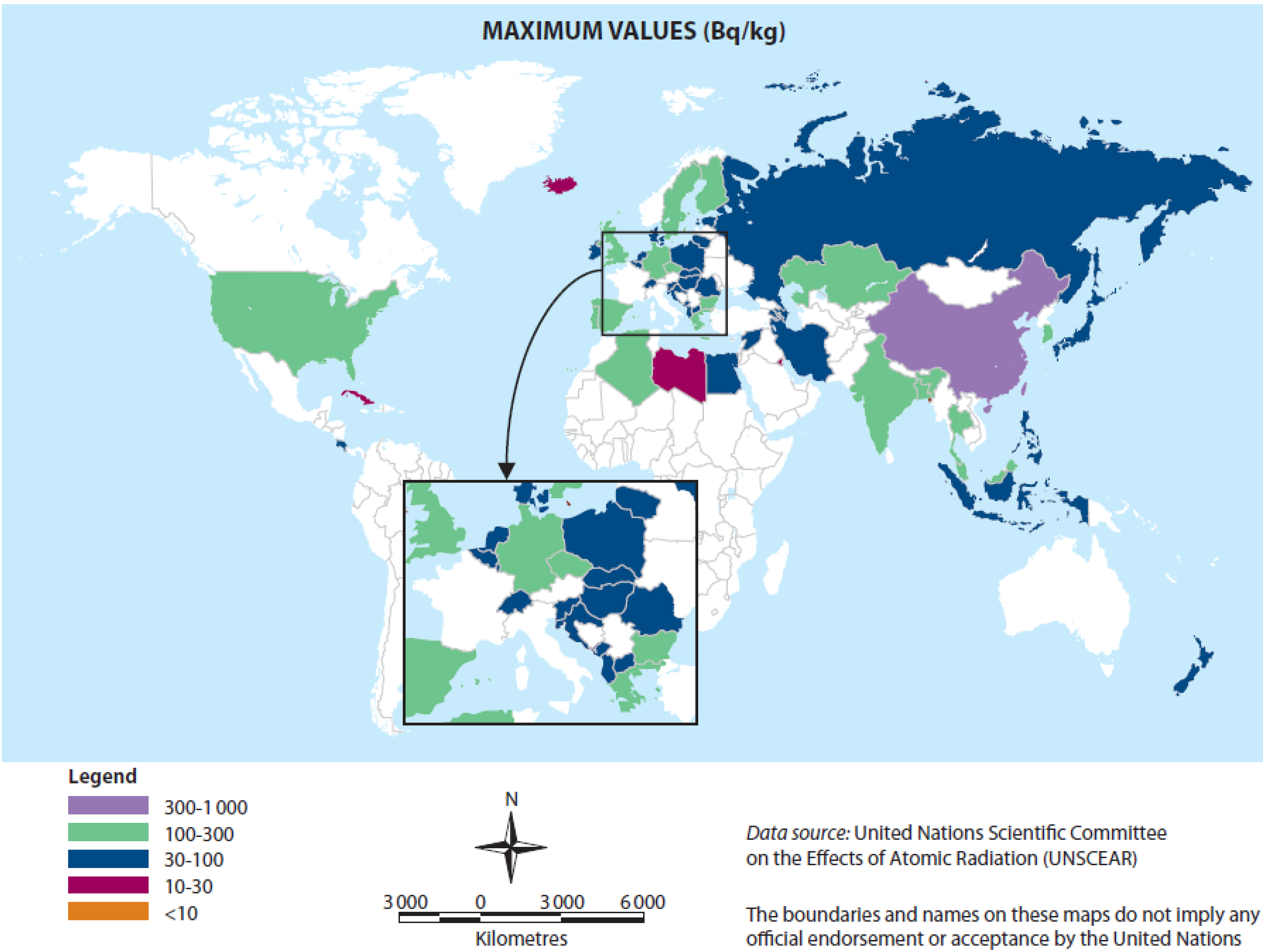
Terrestrial Radiation

- Radioactive elements are found in **soil**, **water**, and **vegetation**.
- Important radioactive elements include uranium and thorium and their radioactive decay products which have been present since the earth was formed billions of years ago.
- Some radioactive material is ingested with **food** and **water**. Radon gas, a radioactive decay product of uranium is inhaled.

Reported concentrations of ^{238}U in soil



Reported concentrations of ^{232}Th in soil

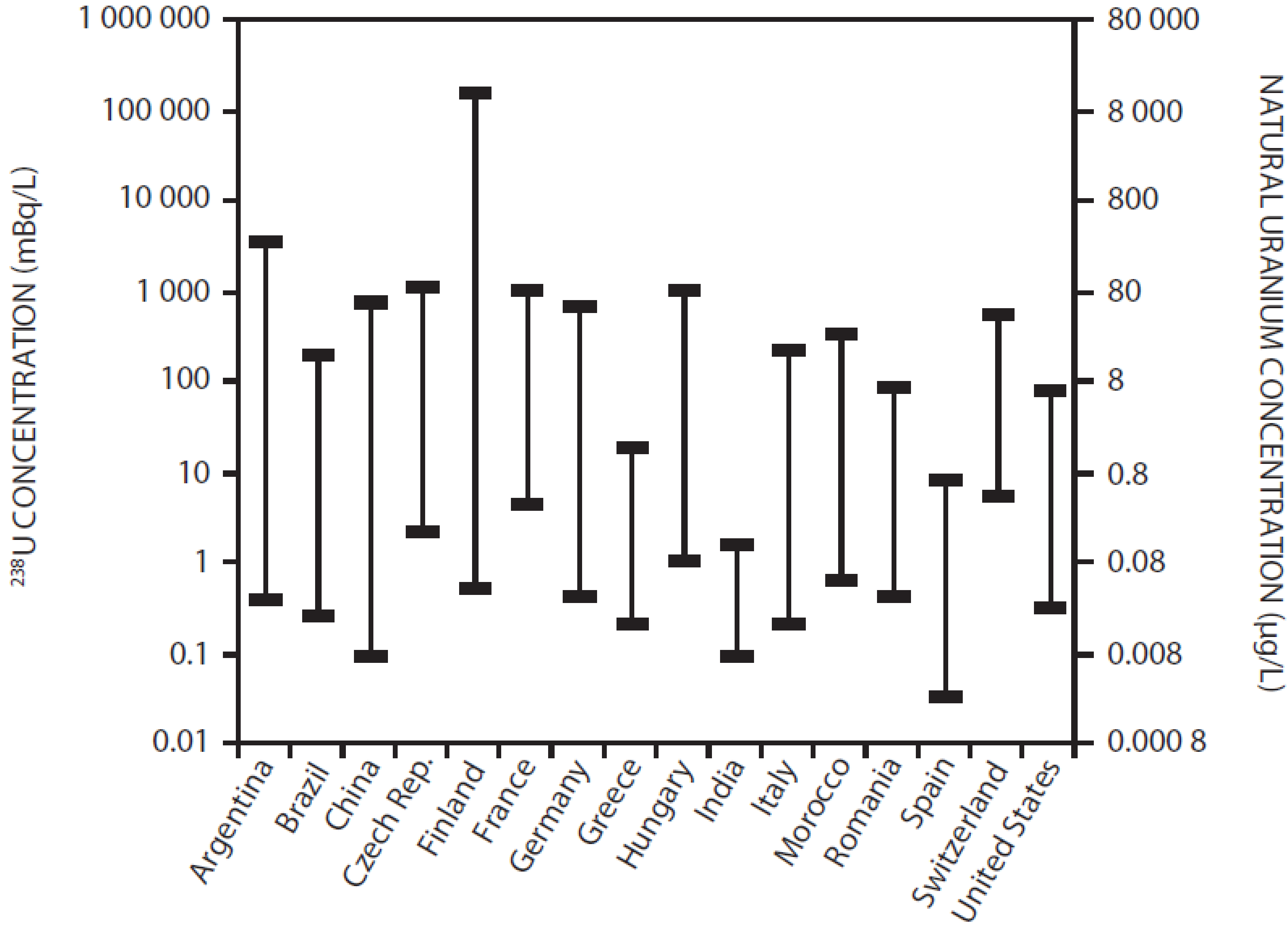


Data source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

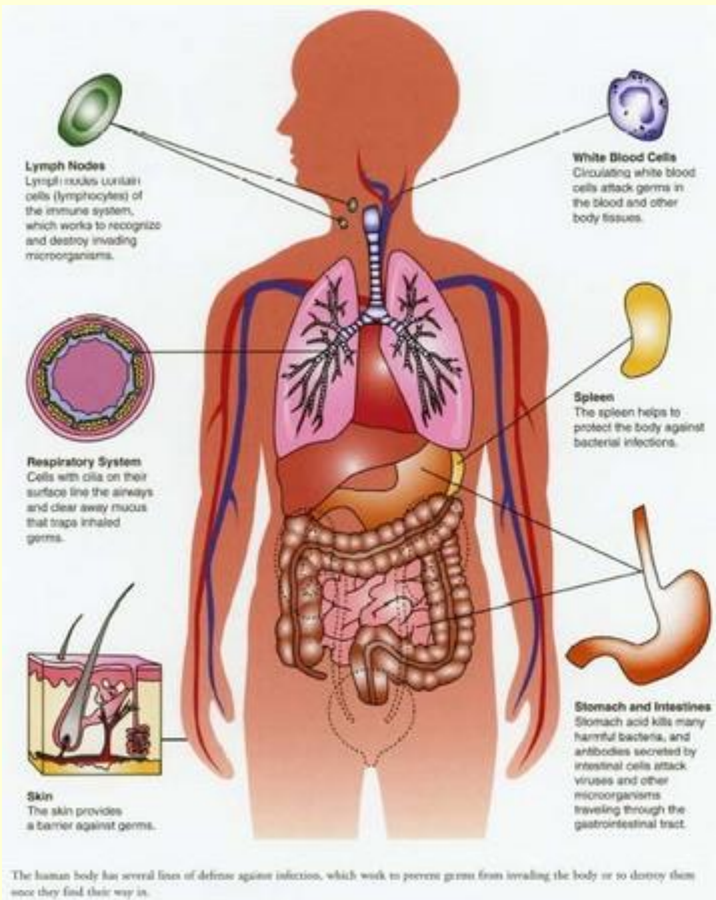
The boundaries and names on these maps do not imply any official endorsement or acceptance by the United Nations

Tailings from uranium mining and milling (10^6 t)

Ranges of ^{238}U concentration in drinking water



Internal Radiation



The human body has several lines of defense against infection, which work to prevent germs from invading the body or to destroy them once they find their way in.

- People are exposed to radiation from radioactive material **inside** their bodies.
- Besides radon, the most important internal radioactive element is naturally occurring potassium-40 but uranium and thorium are also present inside the body.

Man-Made Radiation

Machines

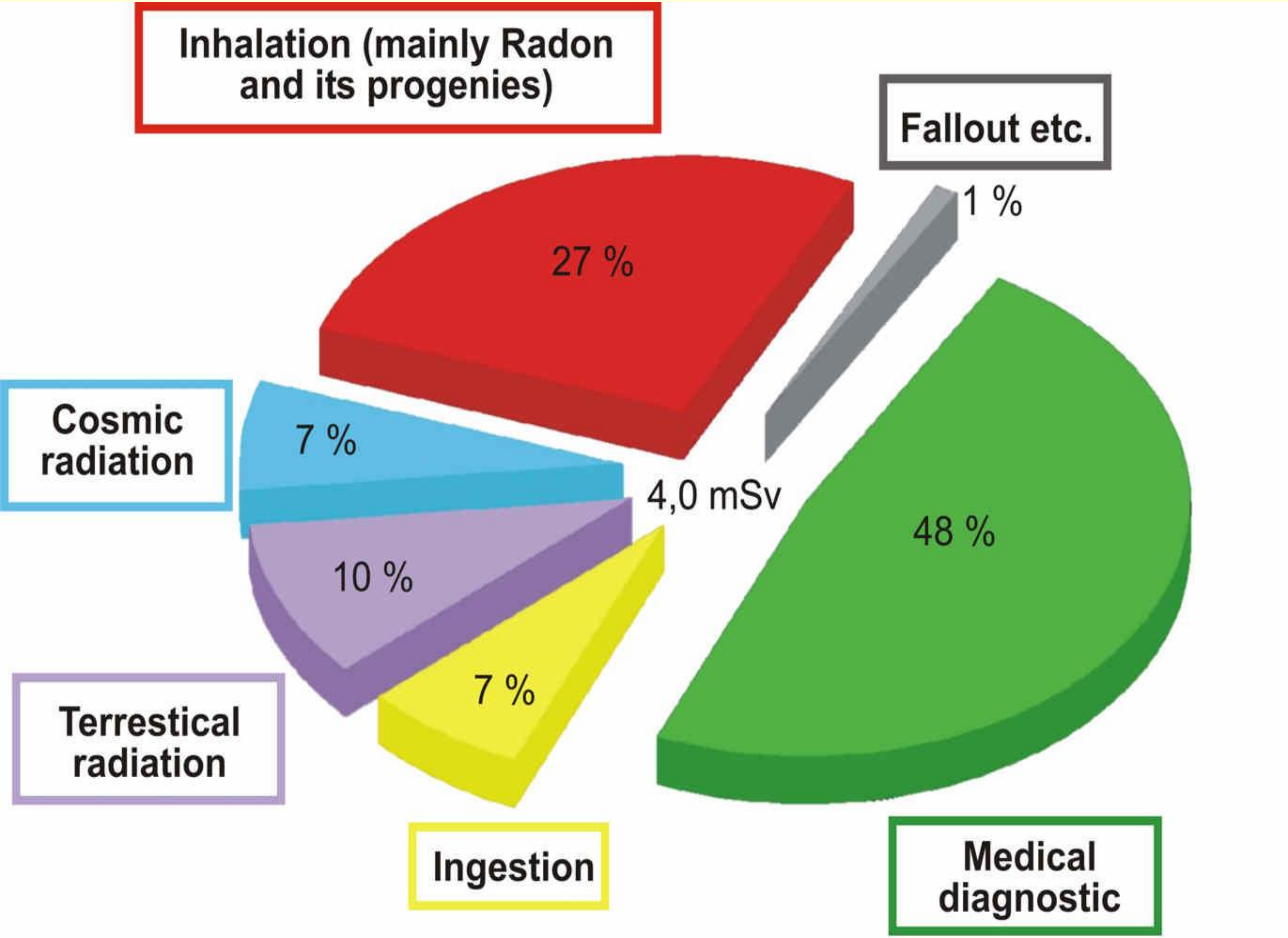
- **Medicine**
  - **diagnostic**: x ray, fluoroscopes, CAT scans
  - **therapeutical**: accelerators
- **Industry and**

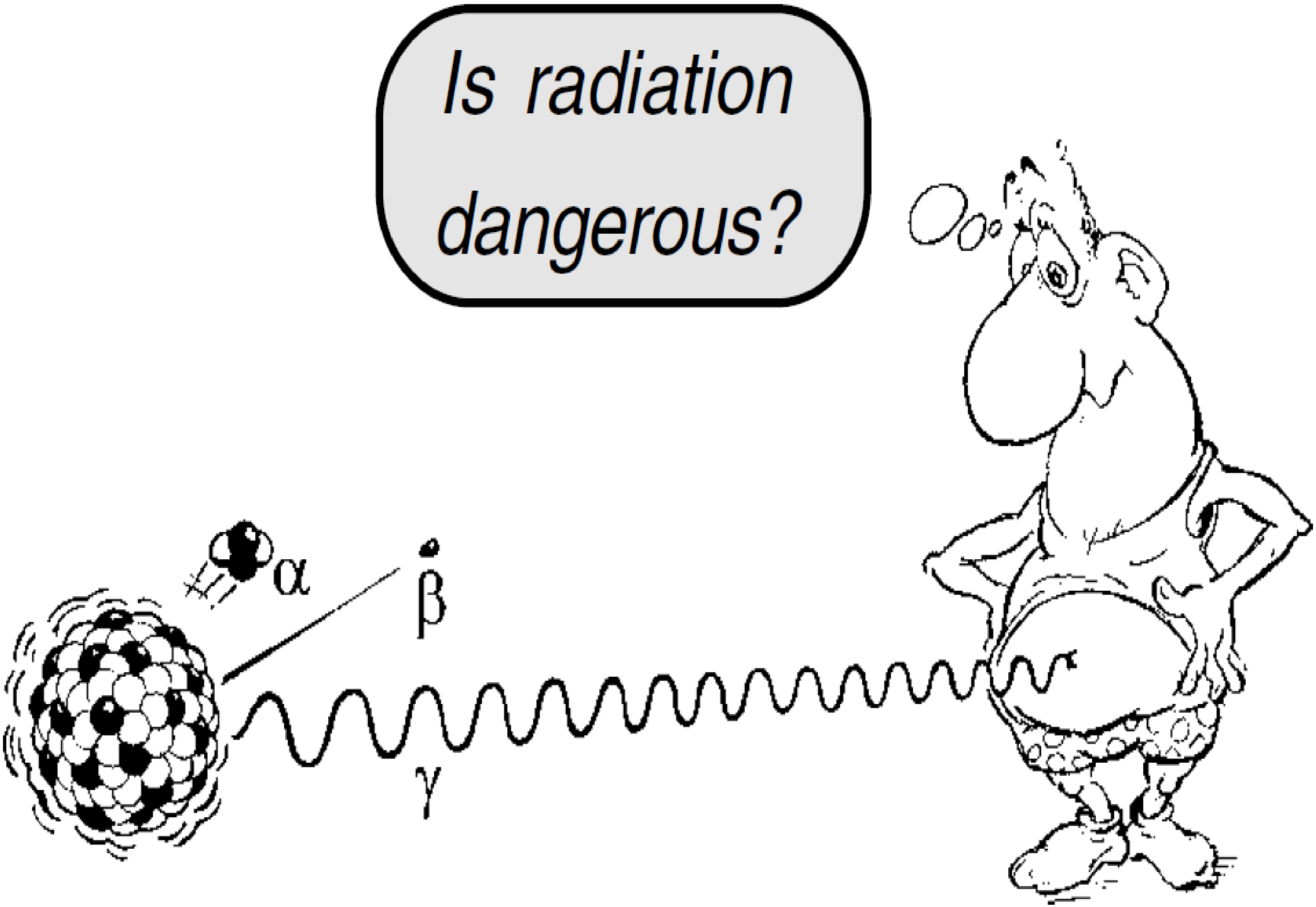
celerators

Man-Made Radiation

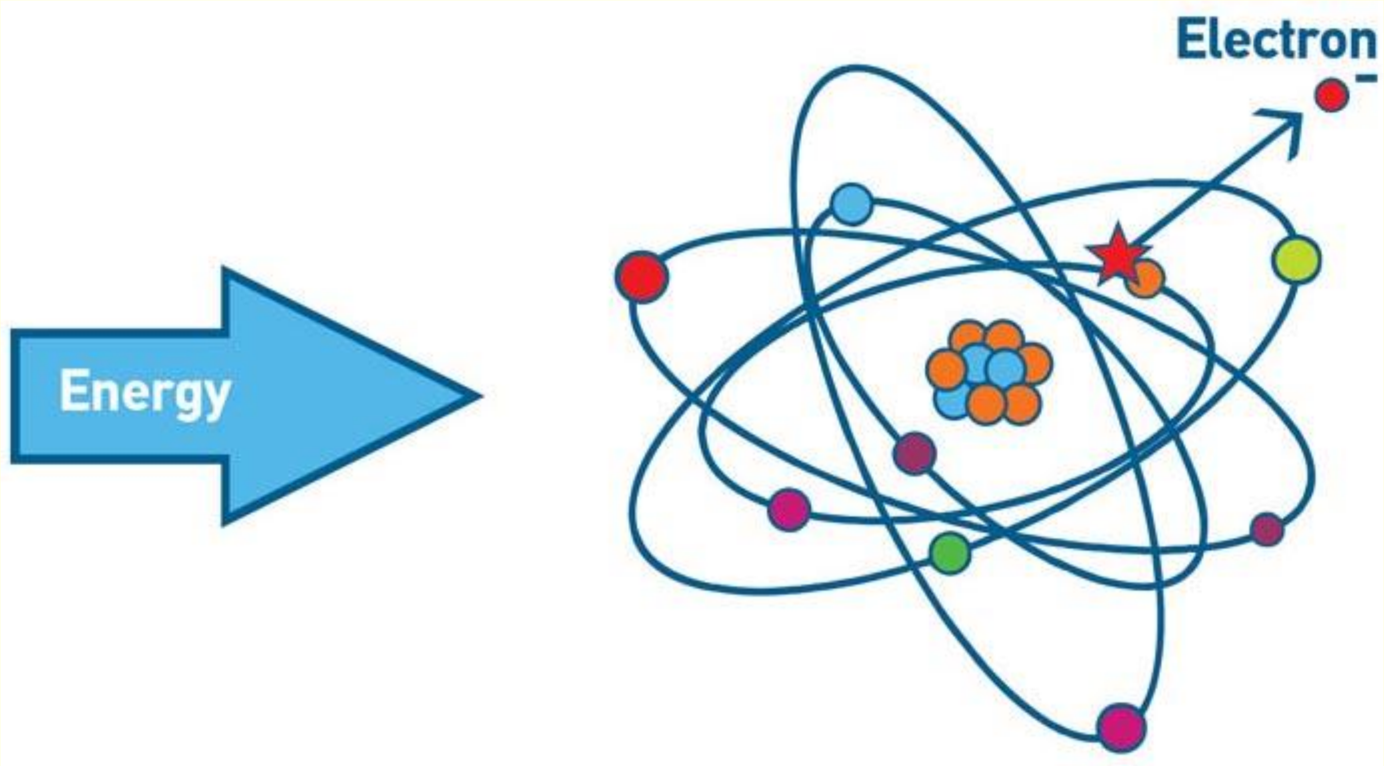
Radioactive Material

- **Industry:**
  Electric generation nuclear power plants
- **Consumer products:**
  luminous dials, fire detectors, exit lights
- **Defense:**
  nuclear weapons, security devices


Inhalation (mainly Radon and its progenies)
Fallout etc.
1 %
27 %
Cosmic radiation
7 %
4,0 mSv
48 %
10 %
7 %
Terrestical radiation
Ingestion
Medical diagnostic


Is radiation dangerous?
α
β
γ

BIOLOGICAL EFFECTS OF IONISING RADIATION



- Ionising radiations have many beneficial applications, but they can also have **detrimental** consequences for **human health** and for the environment.

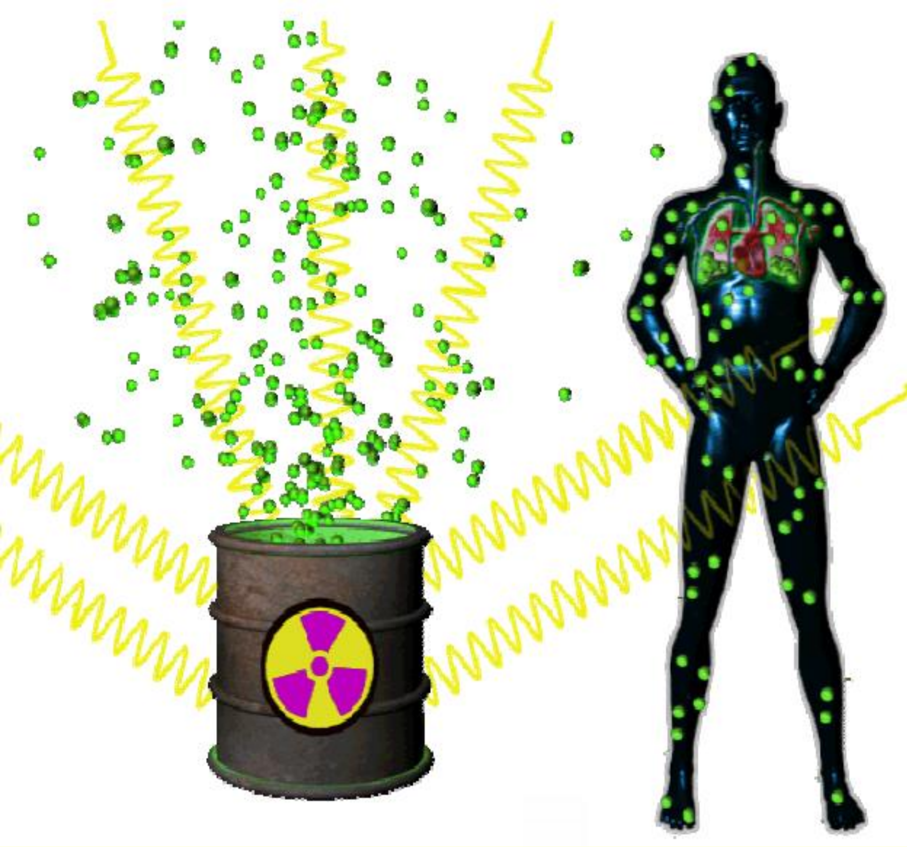
History of Biological Effects

Wilhelm Röntgen

- When x-rays were first discovered there was no reason to suspect **any danger**. After all, who would believe that a ray similar to light but unseen could be harmful?
- Researchers initially did not suspect **damage** from radiation, many clinical and experimental procedures resulted in workers and patients suffering effects such as skin burns and hair loss. Often these injuries were not attributed to x-ray exposure, in part because there was usually a several week latent period before the onset of **injury**.

History of Biological Effects

- Warnings of **injuries** were first sounded when *Thomas Edison* and *Nikola Tesla* reported about **eye irritations** from experimentation with x-rays.
- *Maria Skłodowska–Curie* died from a severe form of **cancer** almost certainly connected with exposure to radiation.
- Actress *Midori Naka* was present during the atomic bombing of Hiroshima. Her death on August 1945 was the first death ever to be officially certified as a result of **radiation poisoning**.

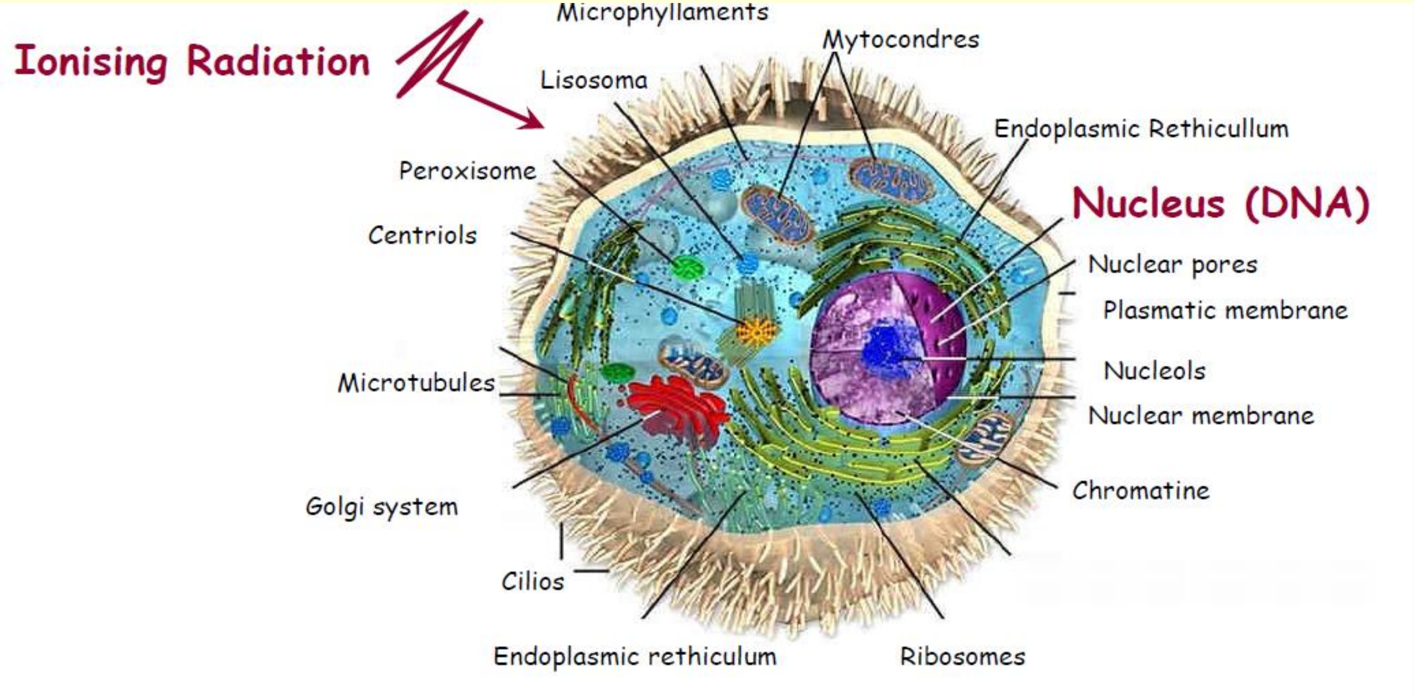


- The interaction of ionizing radiation with the **human body**, either from external sources or from internal contamination of the body by radioactive substances, leads to **biological effects** which may later show up as clinical symptoms.

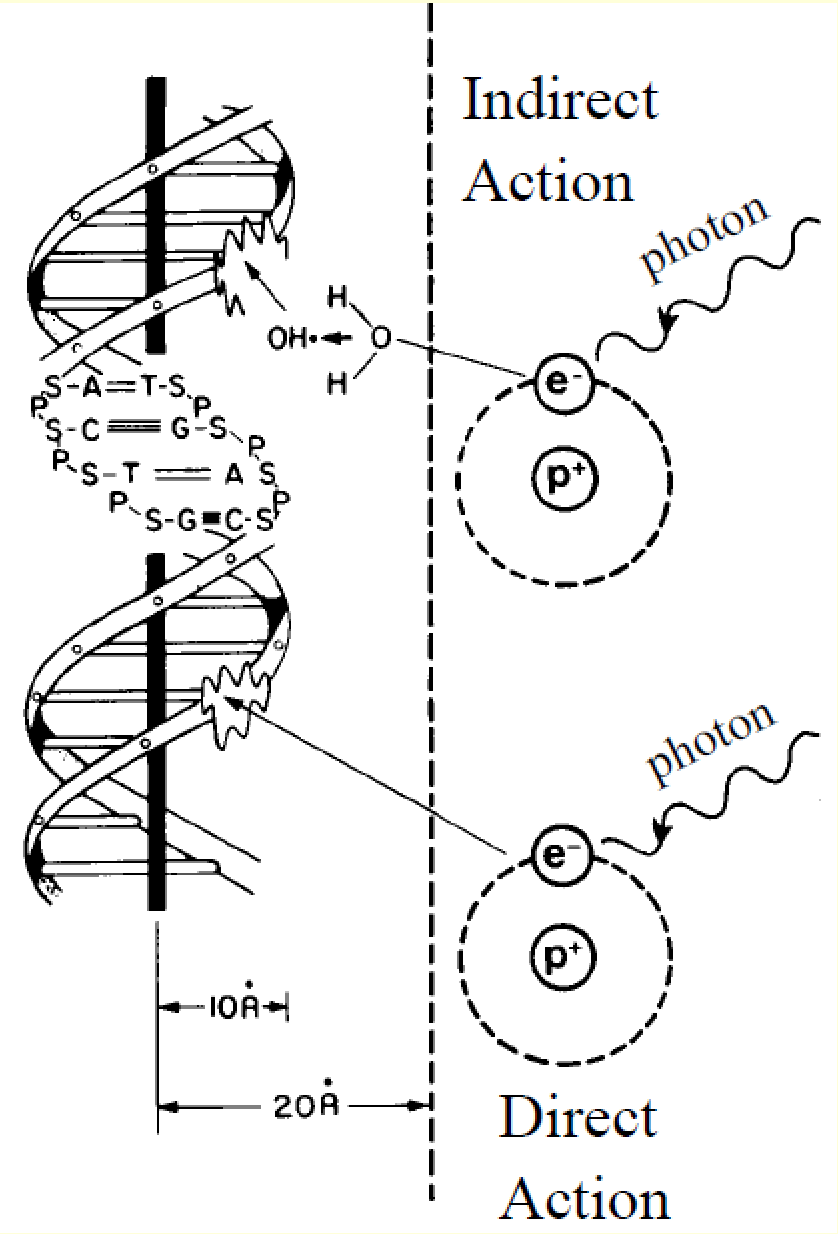
- The nature and severity of **these symptoms** and the time at which they appear depend on

Radiation interaction with cell

- The **cell** is the microscopical building block of all living creature.



- The radiation biological effects can be the consequence of the damage produced in **any molecule** in the cell, mainly in the **DNA** molecule.



The absorption of energy from ionizing radiation produces damage to molecules by **direct** and **indirect**

actions.

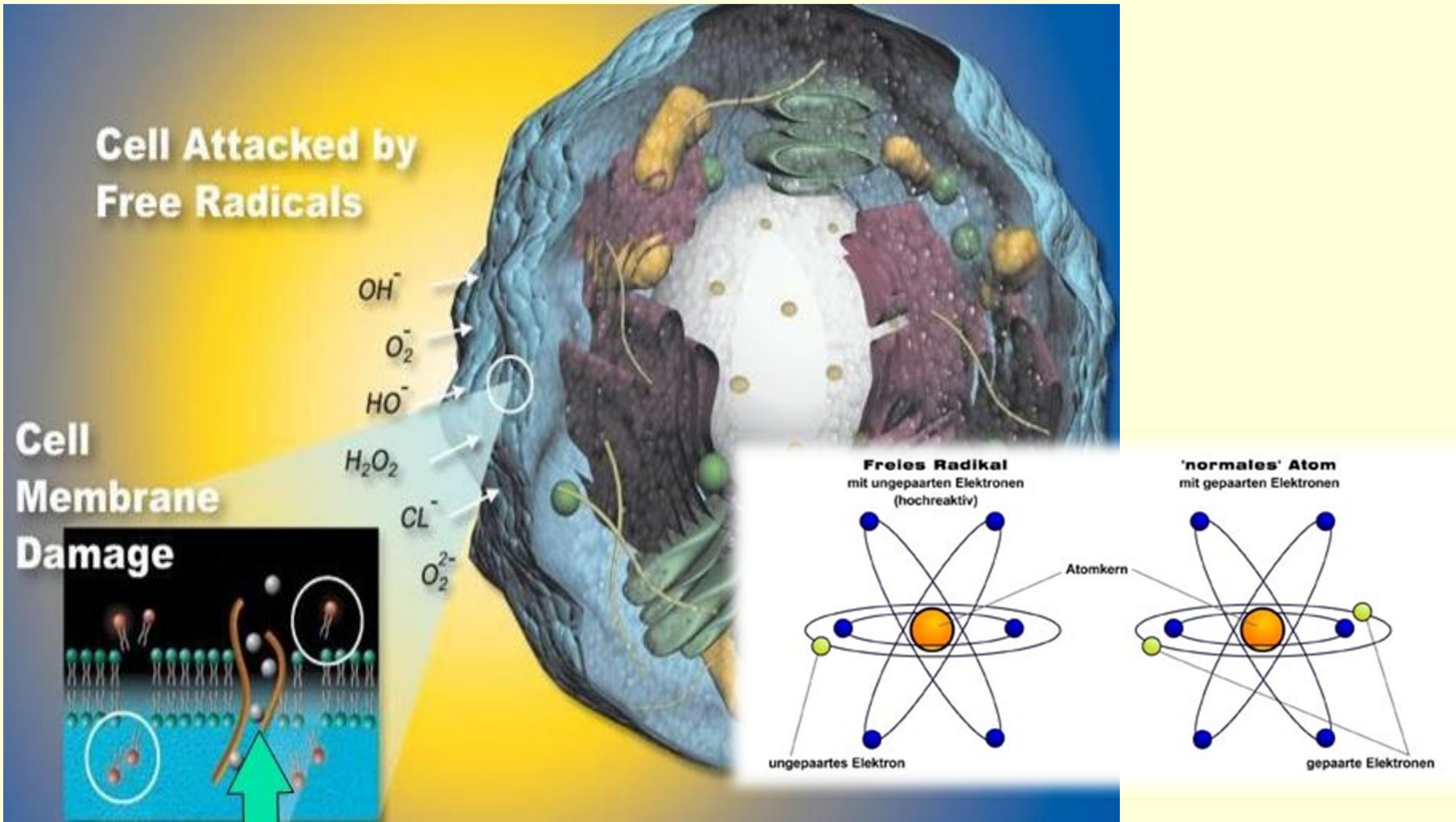
For **direct action**, damage occurs as a result of ionization of atoms on key molecules in the biologic system. This causes inactivation or functional alteration of the molecule.

Indirect action involves the production of reactive free radicals whose toxic damage on the key

molecule results in a biologic effect.

A **free radical** is an electrically neutral atom with an unshared electron in the orbital position.

The radical is highly reactive.



Radiolysis of Water

$$H\text{-}O\text{-}H \rightarrow H^{+} + OH^{-}$$

ionization

$$H\text{-}O\text{-}H \rightarrow H^{0} + OH^{0}$$

free radicals

Free radicals readily turn into **neutral molecules**

However, when many exist, as in high radiation fluence, orbital neutrality **can be achieved** by:

- Hydrogen radical dimerization (**H_2**)
- The formation of toxic *hydrogen peroxide* (**H_2O_2**).
- The free radical can also be transferred to an organic molecule in the cell.

The presence of dissolved oxygen can modify the reaction by enabling the creation of other free radical species with greater stability and lifetimes (**HO_2^0** -*hydroperoxy free radical*, **RO_2^0** - *organic peroxy free radical*)

The Lifetimes of Free Radicals

- The lifetimes of simple free radicals (H^0 or OH^0) are **very short**, on the order of 10^{-10} sec. They do not exist long enough to migrate from the site of formation **to the cell nucleus**.

- However, the **oxygen** derived species such as *hydroperoxy free radical* does not readily recombine into neutral forms. These more stable forms have a lifetime long enough to migrate **to the nucleus** where serious **damage** can occur.

Sequence of Effects

- **Physical:** less than seconds
- **Chemical:** seconds
- **Biological:** seconds to many years
  - Reactions with molecules and cells
  - Tissue changes
  - Cancer, leukemia

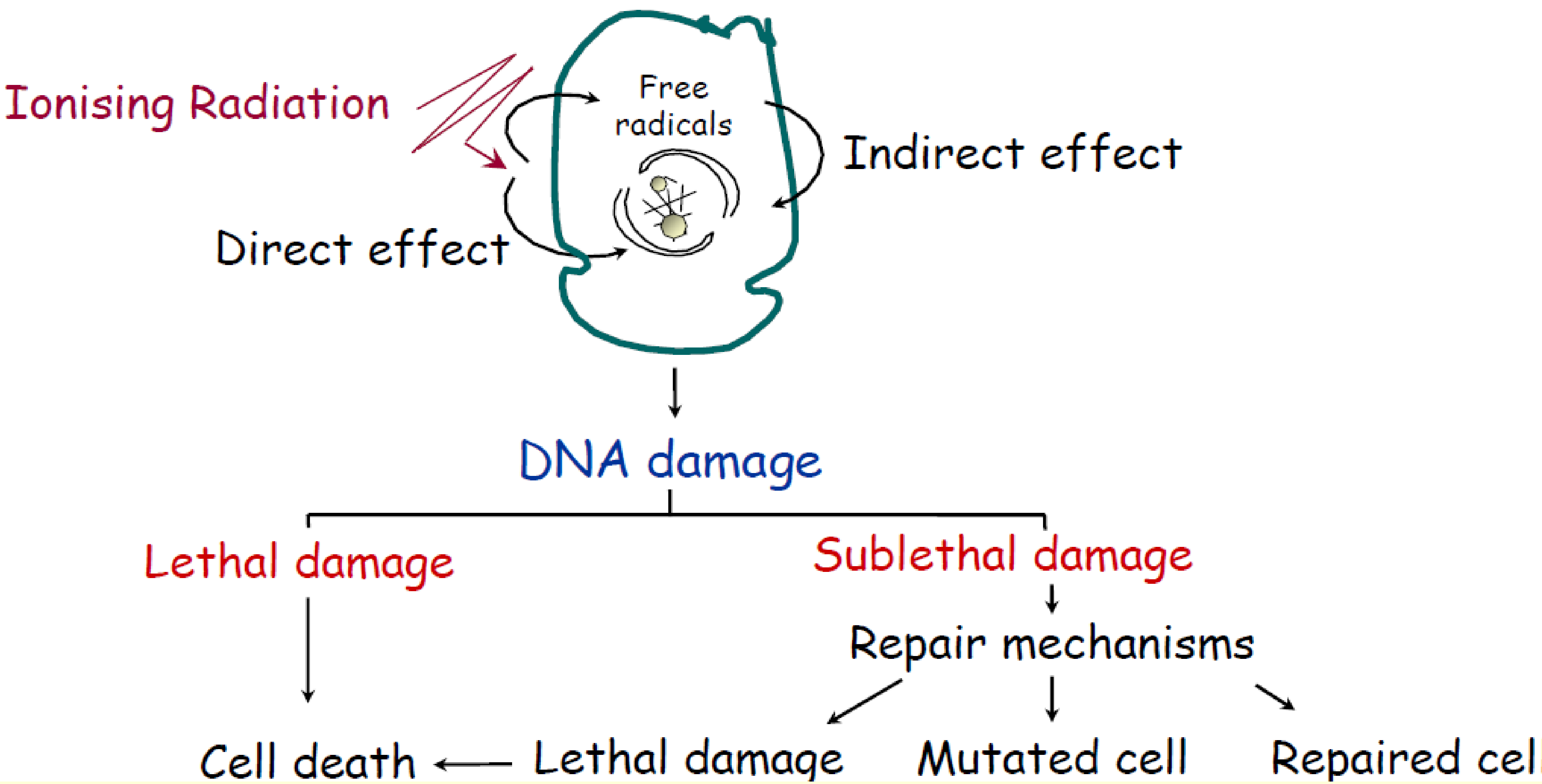
Physical phase

- Interactions of radiation with matter
- Direct ionization of atoms by charged particles
- Indirect ionization by neutral particles

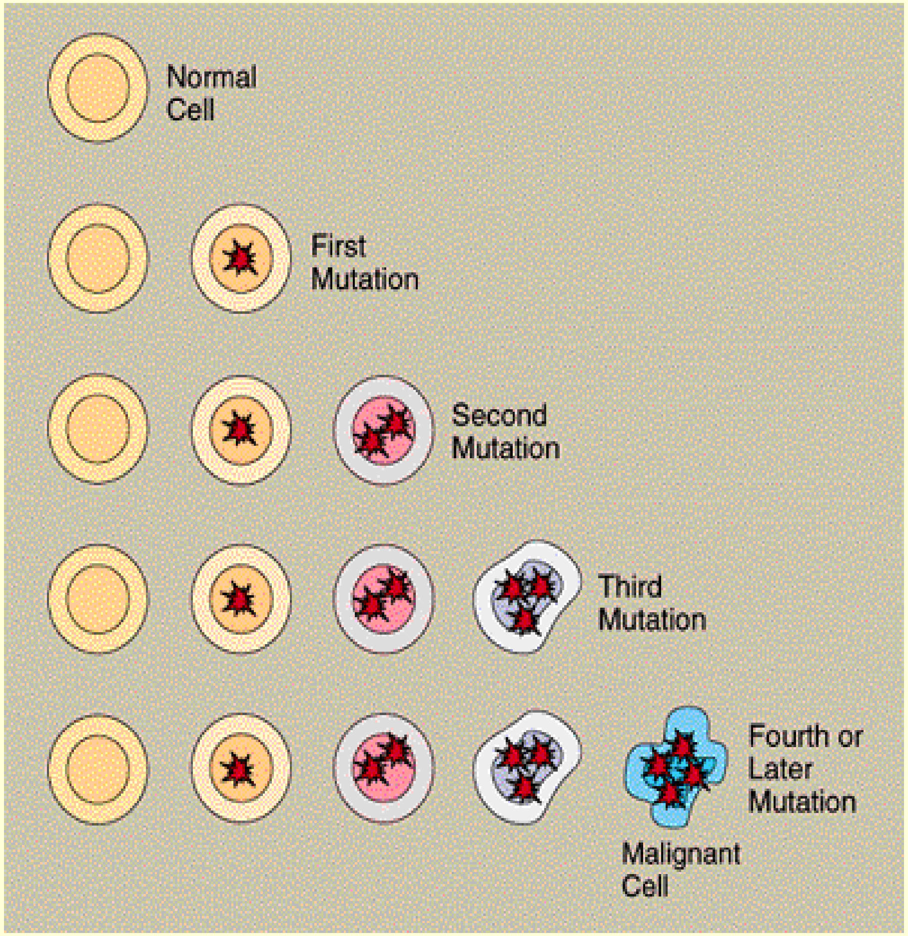
Chemical phase

- Chemical changes of biological molecules

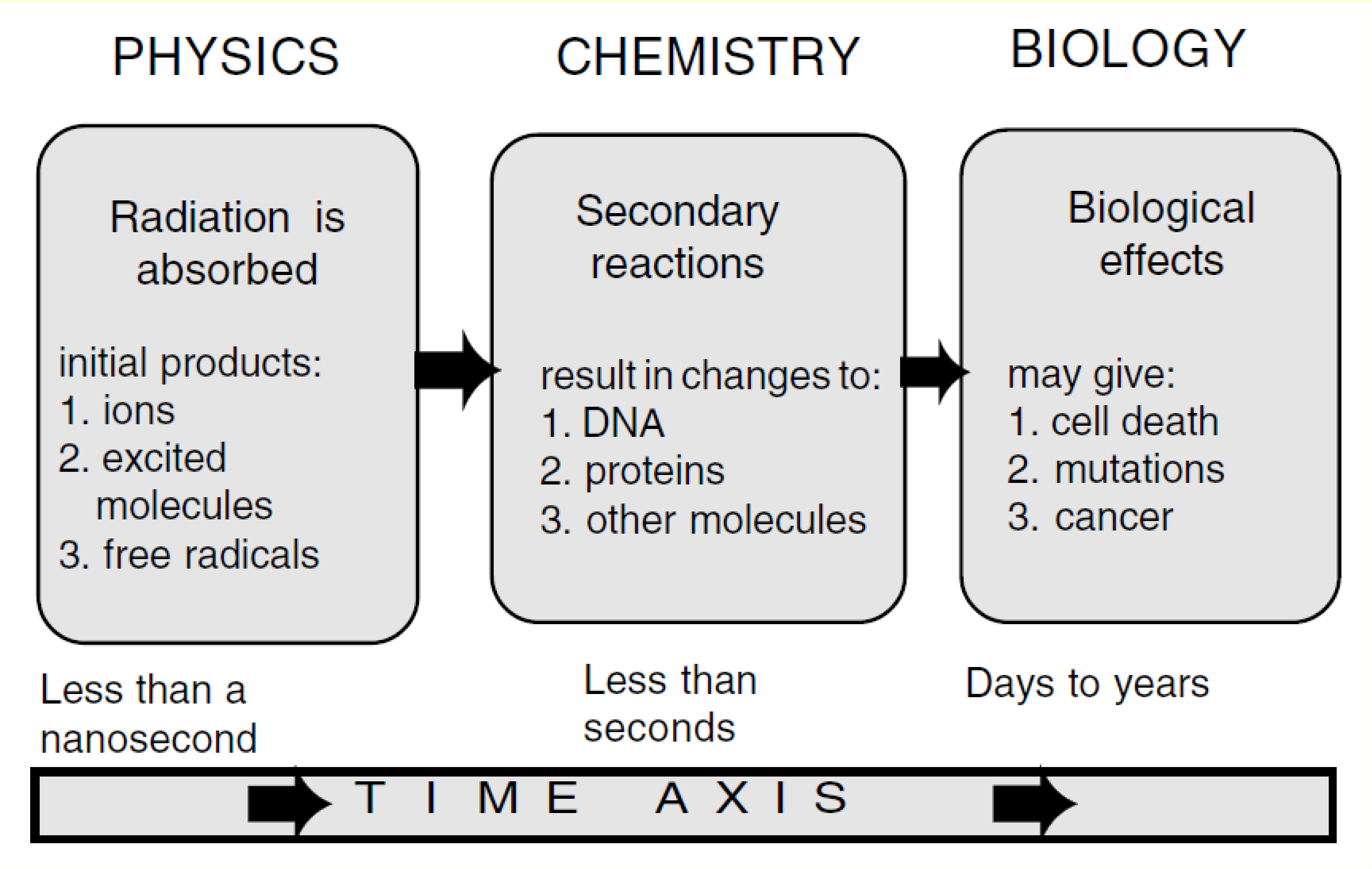
- **The rates of chemical effects are comparable with the rates of chemical reactions**.


Ionising Radiation
Free radicals
Indirect effect
Direct effect
DNA damage
Lethal damage
Sublethal damage
Repair mechanisms
Cell death
Lethal damage
Mutated cell
Repaired cell

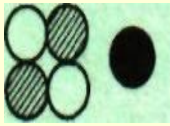
Biological phase



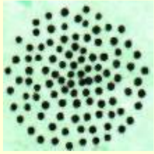
- A damaged cell may **die**.
- A damaged cell may be **mutated**.


PHYSICS
CHEMISTRY
BIOLOGY
Radiation is absorbed
initial products:
1. ions
2. excited molecules
3. free radicals
Secondary reactions
result in changes to:
1. DNA
2. proteins
3. other molecules
Biological effects
may give:
1. cell death
2. mutations
3. cancer
Less than a nanosecond
Less than seconds
Days to years
T I M E A X I S

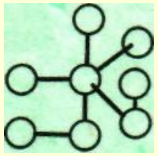
- The transfer of the free radical to a biologic molecule can be sufficiently damaging to cause **bond breakage** or inactivation of **key functions.**



- The *organic peroxy free radical* can transfer the radical form molecule to molecule causing damage at each encounter. Thus a **cumulative effect** can occur, greater than a single ionization or broken bond.

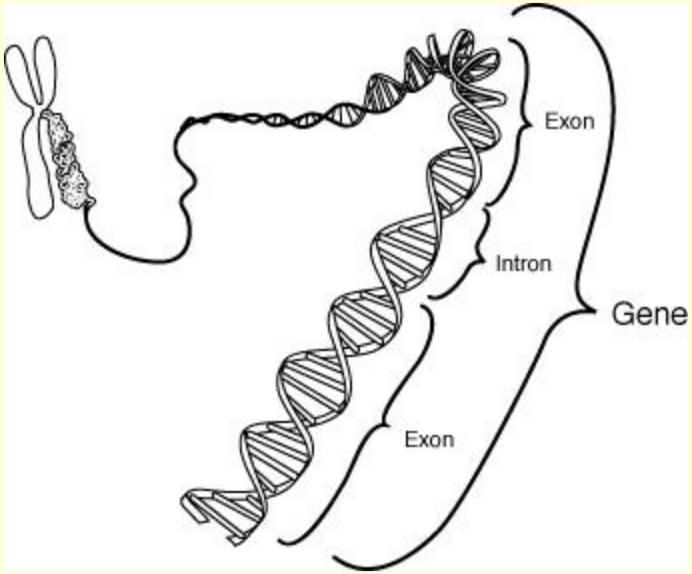


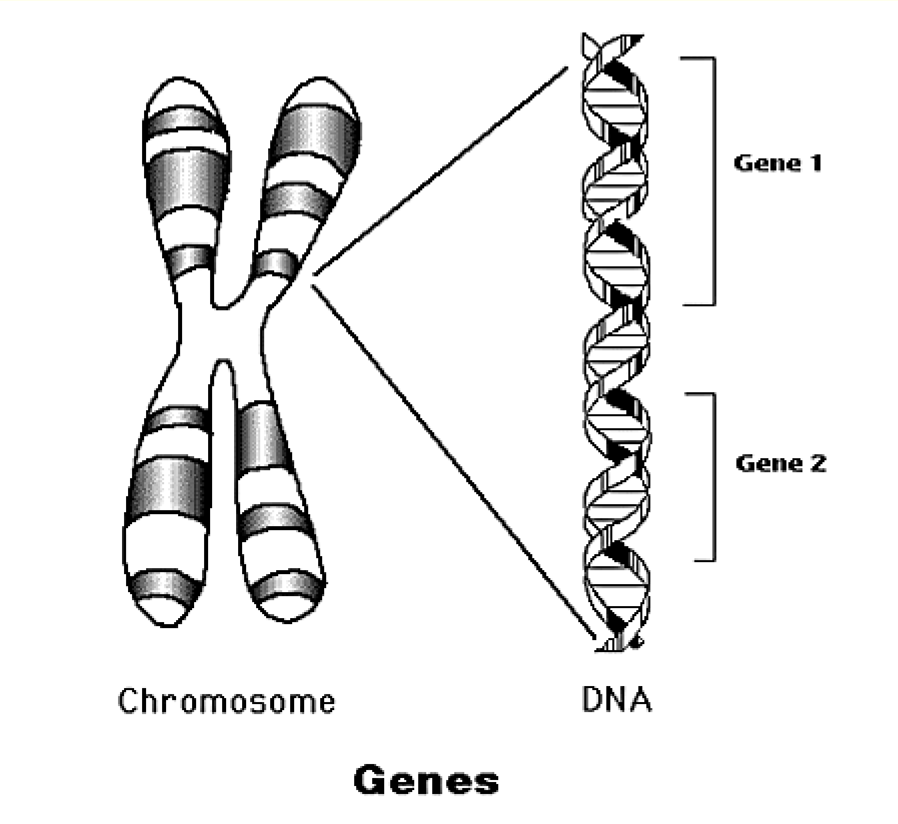
- DNA is the **primary target** for cell damage from ionizing radiation.
- Toxic effects at low doses to moderate doses (cell killing, mutagenesis, and malignant transformation) appear to result from damage to **cellular DNA**.

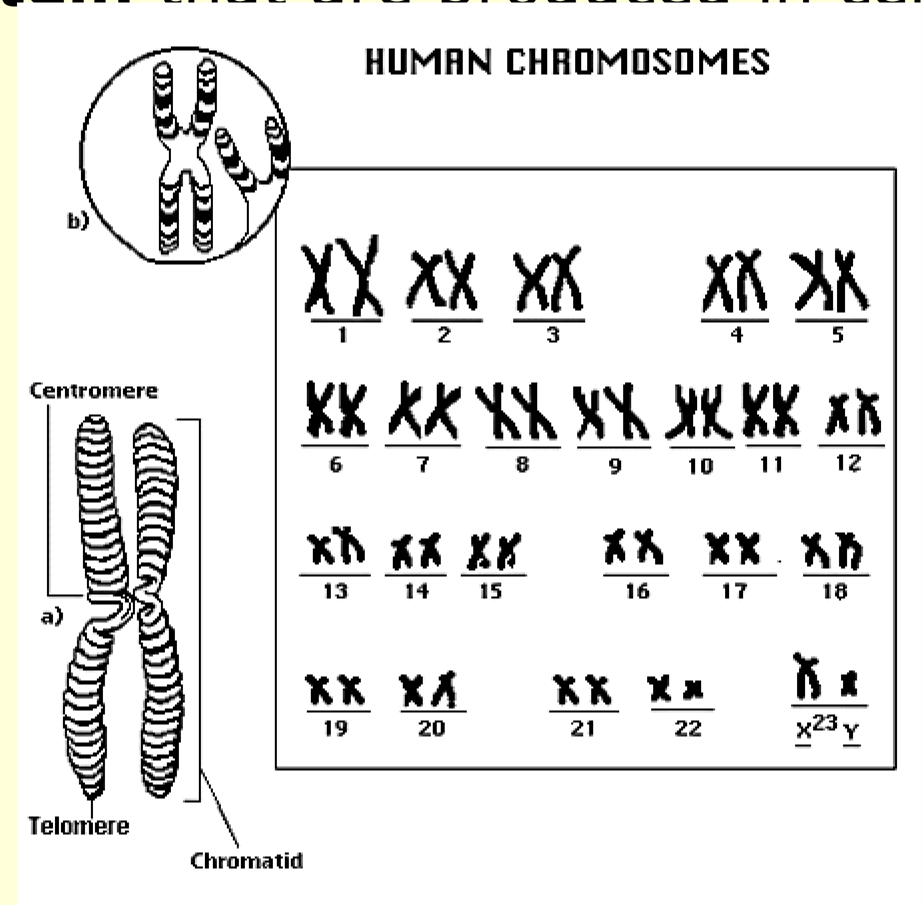


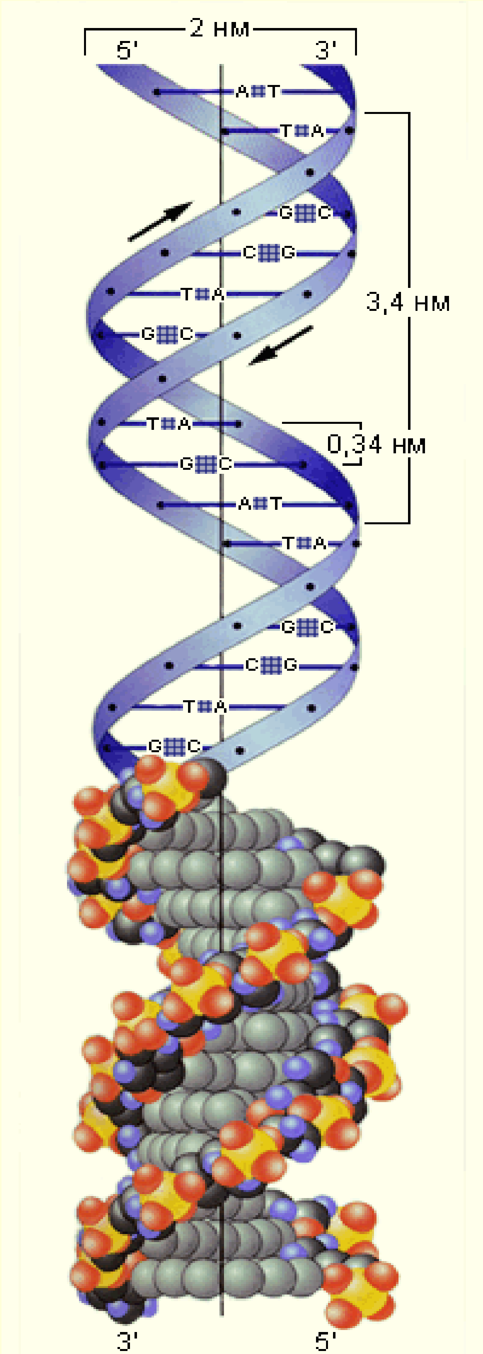
- Thus, ionizing radiation is a classical **genotoxic** agent.

DNA is the most important material making up the chromosomes and serves as the master blueprint for the cell. It determines what **types of protein** that are produced in cell.





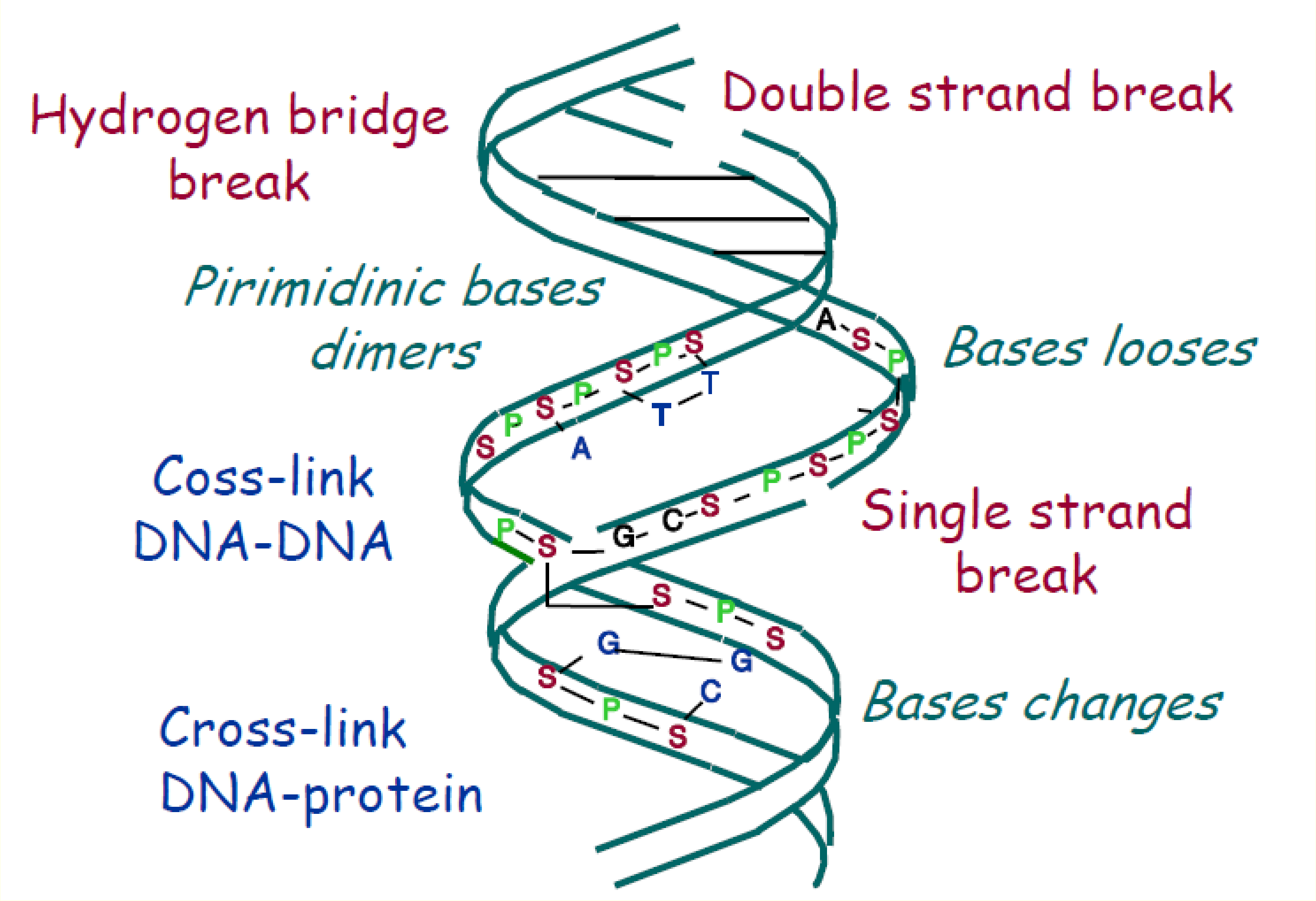




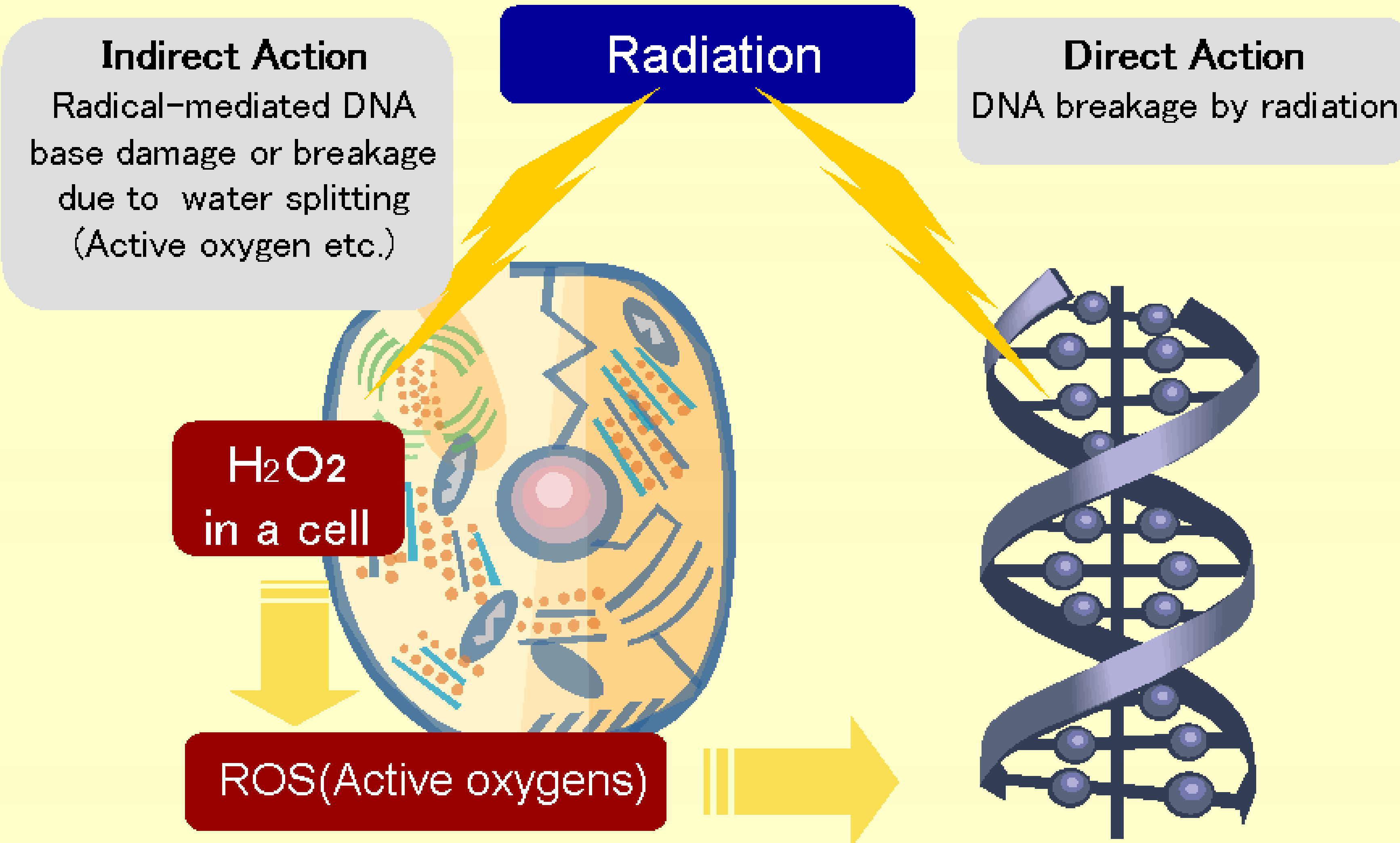
- The DNA molecule takes the form of a **double helix**.

- The sides of the chain are strands of alternating **sugar** and **phosphate groups**. Branching off from each sugar group is one of four **nitrogenous bases**: cytosine, thymine, adenine and guanine.
- This large molecule is **sensitive** to radiation damage.

Ionising radiation can induce a wide variety of DNA lesions: breaks, base changes or cross-links, among others



Action pathways of radiation on DNA



Influence of DNA damage ・・・

Irreparable Damage

- Not able to replicate genetic information
  - Stop cell growth
- Not able to transcribe genetic information
  - Stop protein synthesis

Apoptosis

- Leukocytopenia ・ infertility
- fetal anomaly
- cutaneous erythema・ acomia
- cataract

Defective Repair

- Wrong genetic information
  - Variant DNA

Mutation

Cancer・genetic effect