Ionizing radiation

Ionizing radiation is a collective name for radiation whose quanta have the energy to directly or indirectly tear off (i.e. ionize) electrons from the electron shell of atoms along their path. Through this process, a positive ion is created from the given atom, while the freed electron reacts with another atom and gives a negative ion - an **ion pair** is created .

Ion radiation is therefore the **transfer of energy** , which can be either in the form of material particles or in the form of waves of electromagnetic radiation. However, from the point of view of Einstein's principle of duality, it is possible to attribute a wavelength to each particle (with microparticles we find both particle and wave behavior), so the name ionizing radiation includes both entities.

Ionizing radiation traditionally includes:

- X-rays (photons, in English-speaking countries *X-radiation* or *X-ray*),
- α radiation (current of helium nuclei $_{2}^{4}He$),
- β radiation (current of electrons or positrons),
- γ radiation (photons),
- neutron radiation .

Division

According to charge

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  - **electroneutral** - *photons (X-rays, gamma radiation), neutrons* , ionize secondarily (electrons are the mediator)
  - **polar** – *electrons, positrons, protons, fission products of primary ionization*

According to the particles

- **electromagnetic, photon** – X-ray, gamma radiation
- **corpuscular** – electrons, positrons, neutrons, nuclear fission products

Only charged particles can directly ionize , i.e. alpha (helium nuclei) or **beta particles** (which are electrons or positrons of nuclear origin), as well as electrons and positrons of non-nuclear origin (perhaps from an accelerator), also with energy sufficient for ionization.

They indirectly ionize uncharged particles, i.e. **neutrons , photons and gamma radiation** (i.e. photons of nuclear origin). When interacting with atoms or their nuclei, uncharged particles directly release ionizing particles or cause nuclear transformations accompanied by the emission of such particles.

Ionizing particles are emitted by a **radiation source** - for example, a radionuclide and the radioactive transformations taking place in it. The main source of this radiation in peaceful conditions is the natural **background** , as well as nuclear energy and the disposal of nuclear waste. The source of ionizing radiation can also be technically accelerated particles - electrons and ions of atoms originating from accelerators, X-ray machines and neutron generators.

The same doses of different types of ionizing radiation will produce **different biological effects**. The reason is the different amount of energy transferred to the tissue per unit path (one micrometer) of the particle. X-rays, gamma rays, and beta particles ionize about 100 ion pairs per micrometer of tissue they pass through. Fast neutrons, protons and alpha particles create about 2000 ion pairs per one micrometer of tissue and are therefore 20 times more biologically effective. We say that X-rays, gamma rays , and beta rays have low linear energy transfer , and neutrons, protons, and alpha rays have high linear energy transfer.

Characteristics of radionuclides

Radionuclide sources can be characterized by four quantities – absorbed dose, dose rate, dose equivalent and activity.

Dose is the average energy transferred by ionizing radiation to a substance of a certain mass. It is given in joules per kilogram ($J.kg^{-1}$) , the corresponding unit is **gray (Gy)** . The increase in dose over a certain time interval is called the dose rate. **Dose equivalent** also refers to how much a substance absorbs. It is only a correction of the absorbed dose by the quality factor Q. The quality factor Q expresses the different biological effectiveness of different types of radiation. Unlike the becquerel unit, which indicates the value of the activity of a radioactive substance, it does not express the physical intensity of radiation, but its consequences on the organism.

A quantity called **activity** tells us how many radionuclides undergo radioactive transformations per unit of time**. It is the frequency of events expressed in reciprocal seconds and the Becquerel unit (Bq = s^{-1}) is introduced for it** . The becquerel unit is also used in units of activity related to a unit of mass, volume, areal content, or time and area (eg volumetric activity, areal activity).

The effective dose equivalent (referring to the stochastic effects of radiation) is expressed in Sieverts [Sv] . 1 Sievert is the absorbed dose that produces the same biological effect with any type of ionizing radiation.

Mechanism of action of ionizing radiation

The effect of ionizing radiation at the cellular level is manifested clinically only when the DNA macromolecule is damaged. Although damage to proteins and enzymes can alter some cellular functions, it rarely has serious effects on the macroorganism, as the cell, with intact genetic information in the DNA, usually quickly restores the damaged function, e.g. by synthesizing new proteins. Damage to DNA by ionizing radiation occurs both directly – through ionization and excitation of the atoms of these macromolecules, which leads to cleavage of bonds and even breakage of DNA, and indirectly – through the radiolysis of water to form reactive radicals , which are highly active and thus transform a number of organic substances.

Effects of ionizing radiation

The harmfulness of ionizing radiation depends on which organ is irradiated. Accordingly, we distinguish between **radiosensitive** (i.e. sensitive to radiation damage) and **radioresistant** tissues . In general, it could be said that rapidly dividing cells are far more sensitive to ionizing radiation than cells that have a longer cell cycle. Radiosensitive are:

- bone marrow,
- intestinal epithelium,
- embryo.

The stochastic effect represents the late, random effect of the radiation. It is an effect without threshold; with increasing dose, the severity of the damage does not increase, but the probability of its occurrence. The cellular basis of stochastic effects are mutations and malignant transformation of one or several cells. Stochastic effects do not have a characteristic clinical picture.

For more detailed information, see Stochastic Effects of Ionizing Radiation .

Deterministic (non-stochastic) effects, in contrast, are non-random and have a threshold value (1–3 Gy); above the threshold dose, the severity of damage increases approximately linearly. They cause a characteristic clinical picture – e.g. acute radiation sickness , acute local damage, non-neoplastic late damage and damage to the fetus in the womb.

For more detailed information, see Deterministic Effects of Ionizing Radiation .

Basic principles of radiation protection

The goal of protection is to eliminate the possibility of endangering workers and the population by deterministic effects and to reduce the risk of stochastic effects to an acceptable level by means of organizational and technical measures.

The acceptability of human exposure must be demonstrated by fulfilling the three principles of the dose **limitation system :**

1. No activity leading to the irradiation of people may be carried out unless there is a sufficient benefit to the irradiated individuals or to society to compensate for the health damage caused by the radiation (**principle of justification**).

2. Within a certain activity, the amount of individual doses, the number of exposed persons and the probability of exposure (if it is not certain that they will occur) must be kept as low as can reasonably be achieved taking into account economic and social considerations (principle of optimization) .
3. The exposure of individuals must be subject to dose limits, representing an unexceeded ceiling of controllable exposure (**principle of not exceeding limits).**

Fulfillment of the requirements for the protection of workers is verified by a monitoring system , which includes, using primarily radiometric and dosimetric procedures, both monitoring of the working environment and monitoring of the workers themselves. The **personal monitoring system** is used to determine the individual external and internal exposure of individual persons.

More detailed information can be found on the Protection against ionizing radiation page .

Typical doses of ionizing radiation

Comparison of typical effective doses of individual diagnostic and intervention procedures.

Examination	Effective dose [mSv]
Skiagraphy of the heart + lungs	0,02–0,10
Skiagraphy of the lumbar spine anteroposterior image	0,8
Skiagraphy of the lumbar spine, side view	1,5
Skiagraphy of the abdomen or pelvis	0,3–0,4
Intravenous excretory urography	1,6
Mamography	0,3
Skiagraphy of the knee joint	0,005
Intraoral skiagraphy	0,005
CT scan of the brain	1–2
CT chest	5–6
CT abdominal	10
CT pelvis	7–8
CT dental	6
CT-angiography of the coronary arteries	8–15
CT determination of coronary calcium score	1–2
Interventional angiography of the head or neck	5
Interventional coronary angiography	5–12
Interventional performance of PTCA	15
Interventional performance of radiofrequency ablation	15
Interventional abdominal angiography	12
Interventional aortography	12
Interventional performance of transjugular porto-hepatic stent placement	70
Interventional embolization in the pelvis	60

Links

related articles

- Electromagnetic ionizing radiation
- Alpha radiation
- Beta radiation
- Gamma radiation
- A radionuclide
- Protection against ionizing radiation
- Non-ionizing radiation

Source

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- State Office for Nuclear Safety. *ACTOR campaign* [online]. ©2019. [feeling. 2020-04-15]. < https://www.sujb.cz/radiacni-ochrana/lekarske-ozareni/herca-kampan/ >.

External sources

- ULLMANN, Vojtěch. Nuclear physics, radiation physics, radioisotopes: Ionizing radiation (http://astronuklfyzika.cz/JadRadFyzika6.htm)
- Ionizující záření (na serveru Fyzika v moderním lékařství) (http://cz7asm.wz.cz/fyz/index.php?page=iozar)