Content

Abbreviation

Bq – becquerel
Rem (roentgen equivalent man) – biological equivalent of X-ray
ESD – entrance surface dose
ARS – acute radiation sickness (syndrom)
Gy – Gray
DNA – deoxyribonucleic acid
Sv – sievert
IR – ionizing radiation
IDC – individual dosimetric control
CHD – coronary heart disease
Ci – curie
LD – lethal dose
MeV – a mega electron volt
mSv / year – millisievert per year
IAEA – International Atomic Energy Agency
LRI – local radiation injuries
RSSU-97 – Radiation Safety Standards of Ukraine (1997)
BSRRSU – Basic Sanitary Rules for Radiation Safety of Ukraine
EDR – exposure dose rate
R – Roentgen
R/h – Roentgen per hour
R/sec – Roentgen per second
R/min – Roentgen per minute
TFD – total focal dose
CRS – chronic radiation sickness/syndrome

"Radiation is a flame of stars,
let's treat it with reverence,
so that it warms people,
and does not incinerate"
M. I. Pylypenko

PREFACE

Today, humanity is living in a period of rapid development of nuclear energy, large-scale use of radionuclides and other sources of ionizing radiation in industry, agriculture and other sectors of the economy, including medicine.

However, along with the positive aspects of the use of nuclear energy, there are also negative ones. First of all, it is the deterioration of environmental conditions due to the increase of anthropogenic radiation background, pollution of the environment by nuclear waste. It is in connection with the use of nuclear technology in industry, which consistently maintains the risk of emergencies, that the question of the danger of ionizing radiation and the effectiveness of existing means of protection becomes especially relevant. In Ukraine, the problem of biological action of ionizing radiation, especially in low doses, and protection against it continues to be one of the fundamental problems in the complex of medical and biological sciences.

Today, this problem is extremely relevant in connection with the Chernobyl disaster, which is recognized as the largest man-made disaster in the world. A lot of people, including those involved in the liquidation of the Chernobyl accident, received various doses of ionizing radiation, which adversely affected the body, especially the nervous, endocrine, immune systems and genetic apparatus.

Therefore, mastering the basics of radiation medicine is extremely necessary not only for physicians, biologists, but also for other professions.

Radiation medicine is a science that studies the features of the effects of ionizing radiation on the human body, the principles of treatment of radiation injuries and prevention of possible effects of radiation on the population. Radiation medicine covers a wide range of issues and is closely related to sciences such as nuclear physics, biology and other fields of science.

The textbook is compiled in accordance with the program of the discipline “Radiation Medicine” for the training specialists of the second (Master's Degree) level of higher education according to the requirements for textbooks for students of higher medical education of Ukraine III–IV levels of accreditation. It may be useful for interns, clinical residents and university students in the study of disciplines of general biological and ecological profiles.

The authors, in addition to personal experience, used many years of experience in the field of radiation medicine of leading specialists of Ukraine, as well as the latest literature, instructions and regulations and do not claim authorship of these provisions and facts, as most of them are taken from the bibliographic index

Chapter I: GENERAL ISSUES OF NUCLEAR PHYSICS

Theories of the structure of the atomic nucleus

1. The planetary model of the structure of the Rutherford-Bohr atom. The Rutherford model of the atom looks like this:

1) all the positive charge of the atom and almost all of its mass are concentrated in the atomic nucleus – a region that occupies a very small volume compared to the entire volume of the atom (the linear size of the nucleus is approximately $10^{-15} – 10^{-14}$ *м*, and the linear size of the atom is 10^{-10} *м*). It was later established that the nucleus of an atom always contains an integer number of positive elementary charges. In other words, the charge of the nucleus is expressed by the formula q = Ze, where e – the elementary charge; Z – number of the chemical element in the periodic table / periodic table of elements;

2) electrons move around the nucleus at high speed in circular orbits like planets around the Sun. The radius of the circular orbit of the electron furthest from the nucleus is the radius of the atom;

3) the total negative charge of electrons is equal to the positive charge of the nucleus – the atom is generally neutral;

4) the electron is held in orbit by the Coulomb force of attraction to the nucleus, which gives the electron centripetal acceleration.

2. Drip model. The nucleus is like a droplet, in which the function of intermolecular adhesion forces is performed by nuclear forces. As the number of protons increases, the binding energy of the parts in the nucleus weakens due to the strengthening of the Coulomb forces. According to the drip model, in order to have the nucleus stable, the ratio between the number of protons and the atomic weight must be strictly defined and equal to:

$$N = \frac{A}{1{,}98 + 0{,}015 \times A^{2/3}},$$

where N – number of protons, A – atomic weight.

When the ratio between neutrons and protons changes, the nucleus becomes unstable either due to an increase in the number of neutrons or due to its decrease. As in a drop, the surface of the nucleus can oscillate, and as the amplitude of oscillations increases, the nucleus can be divided with the yield of parts, which is similar to the evaporation of molecules.

3. Shell model. It was observed that excited atoms, like nuclei, emit electromagnetic radiation in the form of gamma quanta. In addition, it was determined that similarly to chemical stability with increasing atomic mass, the increased stability of nuclei is periodically repeated. Particularly stable and common in nature atoms, where protons 2, 8, 20, 50, 82 and neutrons 2, 8, 20, 50, 82, 126. These are He, O, Ca, Pb.

According to the shell model:

1. Nucleons are located at energy levels, where there can be no more than one proton and one neutron;
2. Groups of close levels form a shell;
3. Shells are filled according to the principle of minimum energy;
4. When the nucleus is excited, the nucleons can move to a higher energy level, their return to the previous level is accompanied by the release of energy in the form of a gamma quantum. When the quantum transition is difficult, the nucleus can remain excited for more or less a long time (metastable isomer).

Types of radiation: electromagnetic and corpuscular.

Radiation properties:

1. Permeable property;
2. Ionizing;
3. Photochemical action;
4. Light-exciting effect;
5. The ability to change the electrical conductivity of semiconductors;
6. Biological action.

Radioactivity is a property of involuntary transformation of nuclei of one element into nuclei of another with radiation of energy in the form of rays, including ionizing ones. There are natural and artificial radioactivity. The nucleus is stable (according to drip theory) because neutrons and protons are held together by nuclear forces.

Properties of nuclear forces:

1. These are the strongest, known in nature, because nothing can break a stable nucleus;
2. They are charge independent (unite protons and neutrons);
3. They act only at very short distances, because the nature of these forces is quantum and is connected with the exchange of nucleons by $\pi\pm$ mesons, which form a thin cloud around protons and neutrons. The exchange of $\pi\pm$ mesons is possible only at a distance of no more than 10^{-15} m, so they act only in the nucleus.

4. Nuclear forces can be saturated, because each nucleon can interact only with a limited number of nucleons closest to it.

The decay of nuclei is accompanied by the emission of energy in the form of alpha, beta, gamma radiation and others. There are three radioactive families: $^{238}_{92}\mathrm{U}$ uranium, $^{238}_{90}\mathrm{Th}$ thorium, $^{235}_{92}\mathrm{Ua}$ uranium actinium, $^{222}_{89}\mathrm{Ac}$ actinium. They all decompose into different isotopes of lead.

Types of decays:

1. Alpha decay $^{a}_{z}X \rightarrow {}^{4}_{2}\alpha + {}^{a-4}_{z-2}y + Y$ – with an excess of protons and neutrons;

2. Beta decay $^{a}_{z}X \rightarrow {}^{0}_{-1}e + {}_{z+1}^{a}y + Y$ – with an excess of neutrons it is converted into a proton, accompanied by electron radiation;

3 Positron decay $^{a}_{z}X \rightarrow {}^{0}_{+1}e + {}_{z-1}^{a}y + \nu$ – few neutrons, the proton is converted into a neutron, emitting a positron;

4. Electronic capture of $^{a}_{z}X + {}^{0}_{+1}e \rightarrow {}_{z-1}^{a}y + Y$ – few neutrons.

During beta and alpha decay, the formed new nucleus is in an excited state, which is accompanied (according to the shell model) by Y-ray radiation, this usually happens instantly, but sometimes the excited level lives even more than an hour – it is a metastable state of the nucleus. Such nuclei emit only Y-quanta. This phenomenon is used in generators, which are used to label various compounds for radioisotope diagnostics.

$$^{113}_{50}Sn + {}^{0}_{1}B \rightarrow {}^{133m}_{49}In \rightarrow hv \rightarrow {}^{113}_{49}In,\ T_{1/2} = 100 \text{ min.}$$

$$^{99}_{42}Mo + {}^{0}_{-1}B \rightarrow {}^{99m}_{43}Tc \rightarrow hv \rightarrow {}^{99}_{43}Tc,\ T_{1/2} = 6 \text{ hours.}$$

These are examples of an isomeric transition. After the decay of the nucleus, a nucleon in it passes to a higher energy level. Going back, it emits a gamma ray. If it knocks out an electron along the way, it is an example of another type of decay called internal conversion.

Decay of nuclei of radioactive elements.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{90}_{36}Kr + {}^{141}_{56}Ba + 5\,{}^{1}_{0}n$$

$$^{90}_{36}Kr \rightarrow {}^{90}_{37}Rb \rightarrow {}^{90}_{38}Sr \rightarrow {}^{90}_{39}I \rightarrow {}^{90}_{40}Zr$$

Nuclear synthesis:

$$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + E \ (\sim 17 \text{ MeV})$$

$$^{6}_{3}Li + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + {}^{4}_{0}He + E \ (26 \text{ MeV})$$

Artificial radioactivity. In 1934, Irene Joliot Curie and Frederic Joliot Curie first received a radioactive element.

$${}_{2}^{4}He + {}_{13}^{27}Al \rightarrow {}_{0}^{1}n + {}_{15}^{30}P \rightarrow 0 + 1p + {}_{14}^{30}Si + Y, \; T_{1/2} = 2.5 \text{ min}$$

At the same time, they discovered positron decay, but could not recognize the neutron. It was discovered by the English physicist Chadwick, and the Italian physicist Fermi used neutrons to create artificial radioactive elements:

1. With fast neutrons (20–0,5 MeV). ${}_{Z}^{A}X$ /n. a / = ${}_{Z-2}^{A-3}Y$;
2. With intermediate neutrons (500–0,5 KeV). ${}_{Z}^{A}X$ /n. p / = ${}_{Z-1}^{A}Y$;
3. With slow neutrons (up to 0,5 eV). ${}_{Z}^{A}X$ /n/ = ${}_{Z}^{A+1}X$.

Law of radioactive decay: for the same period of time the same parts of unstable atoms decay:

$$A = A_0 \, e^{Л t},$$

where e – the basis of the natural logarithm.

Л – decay constant, which is determined by the number of atoms decaying per unit time

t – decay time.

$$Л = \frac{0{,}693}{T_{1/2}},$$

where $T_{1/2}$ – the time during which half of the initial number of atoms decays.

$T_{1/2}$ and $T_б$ determine $T_{еф}$ (effective) – effective half-life.

$$T_{еф} = \frac{T_б \times T_{1/2}}{T_б + T_{1/2}},$$

where $T_б$ – biological half-life.

Activity – a measure, the number of decays per unit time. It is measured in Bq and Ci. 1 Bq = 1 decay in 1 sec.

1 (Ci) = 3.7×10^{10} decays of one gram of radium in 1 sec.

Chapter II: DOSE. DOSIMETRY OF IONIZING RADIATION

The dose is the energy transmitted by ionizing radiation to the elementary volume or mass of the substance being irradiated. For the quantitative characterization of quantum radiation, a quantity called the exposure dose, the X-dose absorbed in the air, is introduced. In International System of Units (SI) it is measured in coulomb/kg. 1 coulomb/kg is equal to the exposure dose of X-ray or gamma radiation, at which the combined corpuscular emission in 1 kg of dry atmospheric air produces ions that carry an electric charge of each sign, equal to 1 class. Extrasystem unit – 1 X-ray – is equal to the radiation dose at which combined with X-ray or gamma radiation body emission forms ions per 0.001293 g (1 cm^3) of air, which carry a charge in one electrostatic unit of quantity electricity of each sign:

$$D = f\ x,$$

where the coefficient of proportionality for X-ray f = 0.873,

D – is the absorption dose, x is the exposure dose.

Absorbed dose. The effect of ionizing radiation on a substance is manifested in the excitation and ionization of molecules that are part of it. An indicator of this effect is the “absorbed dose”. Absorbed dose – the amount of energy absorbed per unit mass of the irradiated substance. In SI units, it is measured in grays, 1 Gy = 1 J/kg, ie equal to the dose of ionizing radiation at which a substance of mass 1 kg transmits energy in 1 J. In off-system units – radiation (Radiation Absorbed Dose). 1 rad = 100 erg/g and is equal to the dose when the mass of 1 kg is transferred to 0.01 J of energy. The dose rate Gy/s – for the absorbed dose, and A/kg – for exposure.

Equivalent dose. Different types of ionizing radiation affect tissues differently, because damage to tissue by ionizing radiation is associated not only with the amount of energy absorbed, but also with the spatial distribution of the dose. The latter is characterized by a linear ionization density. It was found that the higher this density is, the higher is the degree of biological damage. To account for this factor, the concept of “equivalent dose” was introduced.

An equivalent radiation dose is an absorbed dose of any radiation that, when irradiated, produces the same biological effect as 1 Gy of the absorbed dose of X-ray or gamma radiation. The equivalent dose is determined by equality

$$H = D \times G,$$

where D – absorbed dose, G – dimensionless quality factor, intended only for use in the field of radiation protection, which characterizes the biological efficiency of ionizing radiation of this type.

The quality factor shows how many times this type of irradiation has a stronger bioactivity than quantum, with the same absorbed dose of energy in units of mass of the substance. Measured in the SI system in sieverts (Sv):

$$1\ \text{Sv} = \frac{1\ \text{Gy}}{\text{K}} = \frac{1\ \text{J/kg}}{\text{K}}$$

in non-system units – in rem

$$1\ \text{rem} = \frac{1\ \text{rad}}{\text{K}} = \frac{0{,}01\ \text{J/kg}}{\text{K}}$$

Relative biological efficiency (RBE) of different types of ionizing radiation

RBE	Type of radiation
1	X-ray and bremsstrahlung
1	Gamma radiation
1	Beta particles, electrons
10	Alpha particles
3	Slow neutrons
10	Fast neutrons
10	Heavy ions, recoil nuclei

Due to the fact that the irradiation of the human body is uneven, in the interests of radiation safety it is necessary to assess the possible harm to human health from irradiation of various organs. To this end, the concept of “effective equivalent dose” (H_E) is introduced, the value of which is defined as:

$$H_E = \Sigma_m\ \omega_m\ H_{m},$$

where H_m – the average value of the equivalent dose in the organ or tissue;

ω_m – a coefficient that reflects the ratio of the damage to the irradiation of the organ or tissue “m” to the damage from the irradiation of the whole body at the same equivalent doses.

The effective equivalent dose is the dose evenly absorbed by the whole body, which creates the same risk of harm from individual stochastic effects as the actual doses absorbed in individual organs or tissues. At transition from actually absorbed doses in bodies and fabrics to an effective dose special coefficients which weigh are used.

Significance of tissue weight factors for various human organs and tissues (MP Mashchenko, 1999)

Organs and tissues	ω_m
Gonads (reproductive glands)	0.20
Mammary gland	0.05
Red bone marrow	0.12
Lungs	0.12
Thyroid gland	0.05
Bones (surface)	0.01
Colon	0.12
Stomach	0.12
Bladder	0.05
Liver	0.05
Esophagus	0.05
Skin	0.01
Other organs (tissues)	0.025

Mandatory condition for compliance with radiation safety rules is the registration and accurate quantitative accounting of values that characterize the interaction of ionizing radiation with the substance, including biological.

Dosimetry is a determination of the quantity and quality of ionizing radiation. With the help of dosimetry two fundamental issues are solved:

- search for a radiation source, determining its type, quantity and energy;
- determining the degree of influence of radiation on the irradiated object.

The basis of any method of registration is a quantitative assessment of the processes occurring in the irradiated substance. The first device to record radiation was Wilson's chamber, which he filled with air or water vapor. If alpha rays of radioactive substance are passed through such a chamber, the alpha particles will knock electrons out of the outer shells of the gas atoms, converting the gas molecules into ions. If you cool the gas contained in the chamber and reduce the pressure, the vapor will condense and the path of the alpha particles will look like thin strips of fog that can be photographed.

In radiation-hygienic practice and medical radiology, charged particle counters have become widely used. Depending on the principle of operation, there are ionization survey meters, semiconductor (crystal) , scintillation detectors, and Cherenkiv's counter. The operational principle of the Cherenkiv counter is scintillation, but instead of luminophore, a substance is used in which fast electrons (visible Cherenkov radiation) are knocked out under the action of radiation. Let's dwell on each of them separately.

The ionization principle of registration underlies the operation of ionization counters/ ionization survey meters. These include proportional counters and self-discharge counters – Geiger-Mueller counter. These are gas-filled end or cylindrical capacitors-counters, which register each charged particle that enters the counter.

Semiconductor (crystal) counters are also ionization meters, in which a flying particle generates conduction electrons and "holes" in the semiconductor. Small plates of cadmium sulfur (CdS), zinc sulfur (ZnS), diamond, silver chloride (AgCl), germanium, silicon and others are included in a special radio circuit. A stream of particles is directed to the plate to be measured. A particle that penetrates a semiconductor generates a large number of current carriers in it: conduction electrons and "holes". The semiconductor inhibits the conductivity, which will instantly affect the growth of electric current. The measuring device is calibrated so that it will show not the strength of the current, but the number of particles that hit the plate. According to the number of registered pulses, a conclusion is made about the number of particles that hit the plate.

Simplicity of the device and operation, the small sizes, high sensitivity, fast growth of a pulse of current are advantages of crystal counters.

Gas-discharge meters have an external cylinder and a thin metal wire stretched along the axis of the cylinder and isolated from it. The voltage of 1000–1400 V is supplied to the meter. The meter is 90 %

filled with isopentane alcohol vapor (10 %). Pressure is 50–100 mm Hg. The charged particle, trapped in the counter, forms a large number of ion pairs. Primary ions (electrons) in a strong electric field acquire such energy that they begin to ionize the gas in the meter and create a large number of secondary ions in it – a gas discharge, which gives a pulse of electric current in the electrical circuit. The number of gas discharges is proportional to the number of particles entering the meter. An important indicator of the meter is the resolution, it is the number of pulses that the meter is able to register in 1 sec. It depends on the design and operating voltage. Typically, the meters operate in a mode that is inside the "plateau" (Geiger region), when the number of pulses depends only on the number of ionizing particles or gamma quanta hit the detector, and little depends on the voltage change.

The scintillation method of registration is based on the registration of flashes of light that occur in the scintillator (luminophore) under the action of ionizing radiation. Many inorganic and organic compounds are used to make luminophores: CsI(Tl), NaI(Tl), CdS, anthracene, trans-stilbene, naphthalene, tissue-equivalent layers with the addition of zinc sulfur.

There are also liquid and gaseous scintillators, which are used to detect alpha, beta particles, as well as low-energy photon radiation using a photomultiplier tube (PMT). There, the scintillations are converted into an electric current, the magnitude and speed of which are proportional to the level of radiation. PMT is a vacuum device that has a photocathode, several dynodes placed in a glass tube at a certain angle to each other and to the anode.

The most common photocathode is the antimony-cesium plate. A certain positive voltage is applied to the photocathode K, diodes and anode A, the value of which increases with each voltage on the next pair of diodes in comparison with the voltage on the previous pair. Under the action of incident light quanta, electrons erupt from the photocathode, which are accelerated by the voltage between the photocathode and the first diode.

Thus, the flux of electrons from the diode increases and millions of times more electrons appear at the last electrode (anode) than were released from the photocathode. These electrons create a current pulse in the PMT circuit, which enters the meter. A scintillation crystal is placed in the scintillation counter directly near the PMT window. When ionizing particles pass through the crystal, scintillations occur even at weak pulses.

The luminophore and PMT are placed in a opaque casing, and the only source of light is the scintillation of the phosphor. The ionization method is based on measuring the ionization of the active volume of the detector (ionization chamber) by measuring the electric current or gas discharges that occur in the detector under the action of ionizing radiation.

The simplest ionization chamber is an air-filled flask with two electrodes, which is powered by a dc voltage source. The current is measured with a sensitive galvanometer. Ionization chambers are an integral part of many dosimeters and radiometers used to record the dose, dose rate, particle flux density.

The electrodes can be the walls of the chamber and the rod mounted on the insulator. Ionization chambers are flat, spherical, cylindrical and face. The walls of the chamber are made of air-equivalent materials, ie 1 g of such material should absorb as much energy as 1 g of air. Under normal conditions, the gas between the electrodes is a dielectric and does not conduct electricity. If the charged part passes between the electrodes, the gas is ionized, free electrons and positive ions are created. Under the action of an electric field, ions move between the electrodes and an ionizing current occurs in the circuit. Its value is proportional to the amount of ionizing radiation entering the ionization chamber. The voltage value should be such that it includes the possibility of ion recombination (saturation current). The current is measured by a sensitive galvanometer.

Ionization chambers are an integral part of many dosimeters used to record doses, dose rates. Radioluminescent (photoluminescent and thermoluminescent) method of measuring ionizing radiation is the absorption and accumulation of energy of ionizing radiation by special fluorescent detectors with its subsequent conversion into luminescent. The intensity of luminescent radiation is proportional to the dose of ionizing radiation and can be registered during thermal stimulation (heating) or photostimulation (ultraviolet irradiation) with a special recording device. This property of the luminophore is associated with a shift in the structural lattice of the luminophore crystal.

Thermoluminophores include LiF, CaF_2, Al_2O_3, $Mg_2B_4O_7$ and others. As photoluminophore, for example, aluminophosphate glass is used. Luminophores in the form of powder, tablets, granules, etc. are used to determine the accumulated dose. For example, for individual dosimetry, a thermoluminescent detector (TLD) is inserted into a case and carried with it when in the field of ionizing radiation. After a certain time of dose accumulation, the detector is placed in a measuring device, heated to a certain temperature (200–230 °C) and the accumulated dose is determined on a board or a scale with an arrow. Detectors are calibrated in advance. Thermoluminescent detectors have a wide energy and dose range. Such detectors are reusable and, after appropriate heat treatment, are suitable for measuring doses again.

Several methods of dosimetry are defined. One of the oldest is the photochemical method based on the ability of radiation to cause photolysis of silver halide bromide (AgBr). When exposed photographic film is developed, silver is reduced to metallic silver and causes its blackening, the intensity of which is proportional to the absorbed radiation energy, i.e. to the dose. This method is used mainly to record individual doses and is quite sensitive, but requires unification of the film development and its specific grade.

The chemical method is based on measuring the yield of irreversible radiation-chemical reactions occurring under the influence of ionizing radiation in rare or solid systems that change their color as a result of radiation-chemical reactions. Such reactions include the radiochemical reaction of oxidation of divalent iron to trivalent iron. Some organic and inorganic compounds can also change their color. The color change is proportional to the energy absorbed in the detector substance. The method is used to record high levels of radiation.

Neutron activation method is related to the measurement of induced radioactivity. It is used to measure weak neutron fluxes or at short-term exposure to large neutron fluxes, also applications in emergency situations. The activation method is particularly widespread in geology when it is necessary to detect the presence of metallic inclusions at a certain depth of drilling by gamma radiation, which is the result of induced activity. When a person is exposed to neutron flux in his/her body, slow neutrons are captured by atomic nuclei of biological tissue. The tissue becomes radioactive, which can be detected by gamma counters. Sodium, potassium, phosphorus, chlorine, sulfur, carbon, calcium and other elements found in the human body are activated by neutrons. The first three play a critical role in determining neutron doses, as the others have short half-lives.

Biological dosimetry methods are based on the assessment of the reaction that occurs in some tissues when irradiated with a certain dose, such as erythema, the number of chromosomal aberrations, the mortality rate of experimental animals, the degree of leukopenia and others. These methods are not sensitive and accurate enough, so the most common are physical and chemical.

The main physical quantities used in radiation biology and their units

Physical quantity	Unit, its name, abbreviation (Ukrainian / international)		The ratio between units	
	unsystematic	SI	unsystematic and SI	SI and unsystematic
Nuclide activity in a radioactive source	Кюрі / Curie (Кі, Ci)	Бекерель / becquerel (Бк, Bq)	1 Ci = 3.7×10^{-11} Bq	1 Bq = 2.7×10^{-11} Bq
Exposure dose of radiation	Рентген / Roentgen (Р, R)	Кулон/кг / Coulomb/kg (Кл/кг, C/kg)	1 R = 2.58×10^{-4} C/kg	1 C/kg = 3876 R
Exposure dose rate of radiation	Рентген за секунду / Roentgen per second (Р/с, R/sec)	Ампер на кг / Ampere per kg (А/кг, A/kg)	1 R/c = 2.58×10^{-4} A/kg	1 A/kg = 3876 R/sec
Absorbed radiation dose	РАД /rad (рад, rad)	Гр/Gray (Гр, Gy)	1 rad = 0.01 Gy	1 Gy = 100 rad
The power of the absorbed radiation dose	Рад за секунду / rad per second (рад/сек, rad/sec)	Гр за секунду / Gy per second (Гр/сек, Gy/sec)	1 rad/s = 0.01 Gy/sec	1 Gy/ sec = 100 rad/sec
Integrated radiation dosing	Рад-грам / Rad-gram (рад-г, rad-gram)	Джоуль / joule (Дж/J)	1 rad-gram = 10^{-5} J	1 J = 10^{5} rad-gram
Equivalent radiation dose	Бер / rem (бер, rem)	зіверт / sievert (Зв, Sv)	1 rem = 0.01 Sv	1 Sv = 100 rem
The power of the equivalent radiation dose	Бер за сек/ rem per second (бер/с, rem/sec)	зіверт за секунду / sievert per second (Зв/с, Sv/sec)	1 rem/s = 0.01 Sv/sec	1 Sv/s = 100 rem/sec

The calorimetric method is based on measuring the amount of heat released in the detector when absorbing the energy of ionizing radiation, and is proportional to the energy.

The calculation (mathematical) method is used in clinical practice (for example, during radiation therapy and in other cases).

Classification of devices for measuring radiation according to their purpose:

- dosimeters;
- radiometers;
- spectrometers.

Dosimeters

Devices for measuring the dose or dose rate of ionizing radiation are called dosimeters or X-ray meters. They are used to measure the dose or dose rate, to assess the effectiveness of protective devices in control facilities or areas, to measure individual doses to personnel or the public.

Information on the dose can be obtained by:

– individual dosimetry of the body surface;

– dose measurement in a group of people who are in the same conditions (military dosimetry);

– dose measurement in air;

– calculations based on data on the length of stay of people in the area of radioactive radiation;

– biological dosimetry (for example, the number of lymphocytes on the third day after irradiation).

Radiometers

Radiometers are devices for measuring:

– total activity and specific activity of objects of external environment;

– surface contamination measurement;

– indications of radioactive contamination;

– measurement of radioactivity levels of bioobjects, body parts or the whole body – medical radiometers.

Classification of medical radiometers

Laboratory radiometers	laboratory radiometer	registration of activity of separate samples or samples of various organic and inorganic substances (impulses)
	dose calibrator	measuring the absolute radioactivity of substances when the volume is known

Clinical radiometers	medical radiometer	determining the specific activity (pulses), measuring the radioactivity of the whole body or individual organ, information about the number of pulses
	radiograph	registration of dynamics of the moved radio-nuclides in bodies, information in the form of curves on paper
	scanner	registration of the location of radionuclides in the organs or body of the patient, information in the form of a planar image, which consists of strokes on paper
	medical scanner	registration of accumulation of radionuclides in the body for suspected metastases; registration in the form of curves on paper
	scintillation gamma chamber	registration of dynamics of movement of radionuclides, location in a body and bodies; information in the form of curves and a plane image on the TV screen
	radionuclide emission tomograph, single-photon	registration of the location of radionuclides in separate layers of the body with assessment of the functional state; information in the form of images on the TV screen
	radionuclide emission tomograph (electron-positron)	registration of blood circulation in tissues, transportation of various substances, metabolism of sugars, proteins, fats, molecular transport of membrane permeability, state of receptors, distribution of medical preparations and pharmacokinetics

Spectrometers

Nuclear radiation sources usually generate monoenergetic fractions or quanta. The energy distribution of radiation is called the energy spectrum of nuclear radiation. Instruments that measure radiation spectra are called spectrometers. Spectrometers are used to determine the energy of gamma rays and, based on this, the element that the gamma ray emits. The energy spectra of different sources of gamma radiation using scintillation counters are as follows: gamma quanta interact with the materials of the