Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

It is approved
on meeting of department of
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Methodical instructions

for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	2. Bases of medical physics
Theme of lecture:	**Radioactivity. Ionizing radiation use in a medicine. A dosimetry of an ionizing radiation**
Year	1
Faculty	Medical, Stomatological
Speciality	Medicine, Stomatology

Poltava - 2020

The topic significance:

Radioactivity is common appearance of outer word, as natural radiation is present in form cosmic rays and Earth irradiation. But it gains in importance at XX century with use of artificial sources of ionizing radiation. In modern life it present both as technological radiation, and as medical diagnostical and treatment methods. Sometimes any doctor can face with a problem of radiation-exposed patient.

Specific targets:

To have general knowledge of the topic studied;
To understand, to remember and to use the knowledge received;
To form the professional experience by reviewing, training and authorizing it;
To be able to carry out laboratory and experimental work.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Disciplines	Obtainable skills
Previous (providing disciplines): physics, biology	To know concepts: ionizing radiation, radioactivity, radiactive decay, isotopes.
The subsequent disciplines: Normal physiology, patological physiology	To know concepts and describe ideas: types of decay, radiolysis of water, photoeffect, incoherent scattering, annihilation, To know the Bouguer law. To describe basic symptom-complexes of infringement of functions of an organism by ionizing irradiation

Materials for the before-class self-preparation work:

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
Half-life period	The half-life period of the substance is the time during which the amount of radioactive atoms decreases two-fold.
Ionization braking	It happens when α- and β^{-}-particles electrically interact with the electron shells of the atoms and lose their energy on ionizing atoms.
Annihilation reaction	The reaction of interaction of positrons and electrons with formation of 2 γ-quantums.
Penetrability of radiation	The capability of radiation to penetrate through the matter is known as their penetrating capacity (penetrating power).
Radiolysis of water	Formation of ions and radicals from water.
Radiotoxins	Unsaturated fatty acids, amino acids and phenolums oxidazed during irradiation forme lipid and quinones radiotoxins**,** which depress synthesis of nucleic acids, react on DNA molecule as chemical mutagen, vary activity of enzymes, and react with lipid-albuminous endocellular membranes.
Maximum permissible dose	The maximum permissible dose is the maximum value of an individual annual equivalent dose, which, at uniform exposure during 50 years, shall have no detrimental effect on man's health.
Maximum permissible dose for professional exposure\	The maximum permissible annual equivalent dose for professional exposure is equal to 5 rem.
Ionizing radiation detector	Ionizing radiation detectors are intended for registering radiation and measuring some of their characteristics (e.g., energy and velocity of particles, the ratio of their charge to mass, and others).
Dosimeter	Dosimeters are devices for measuring doses of ionizing radiation, or values related to doses.

Theoretical questions to class:

1. What is spontaneous decay?
2. Describe types of spontaneous decay.
3. What substances can be radioactive?
4. Describe and explain the law of radioactive decay.
5. Mechanism of ionizing irradiation interaction with substances.
6. Photoeffect, incoherent scattering (Compton effect) and formation of electron-positron pairs.
7. Characterize penetrability of radiation. The Bouguer law.
8. Describe radiolysis of water.
9. What are radiotoxins?
10. Infringement of vital activity of cells by ionizing irradiation.
11. Basic symptom-complexes of infringement of functions of an organism by ionizing irradiation.
12. Radiation sickness.
13. Absorbed dose, Equivalent dose, Effective equivalent dose, Collective effective equivalent dose, Complete collective effective equivalent dose.
14. Units of dosimetry: Gray, rad, coulomb per kilogram, roentgen, grey per second.

15. Relative biological effectiveness.
16. Units of dosimetry: rem , sievert, person-rem.
17. Maximum permissible dose.
18. Effective equivalent dose.
19. Collective effective equivalent dose.
20. Expected collective effective equivalent dose.
21. Dose rate.
22. Detectors of ionizing radiation: track detectors (Wilson chamber, the bubble chamber, spark chamber, thick-layer photo plates), counters (proportional counter, the Geiger counter) and integral devices.
23. Dosimeters: ionization, luminescent, semiconductor and photo dosimeters.

Practice work executed at class.

Dosimetry

1. To familiarize with a structure of a dosimeter of ionizing radiation.
2. To familiarize with a manual of the dosimeter.
3. To choose place for measurement of background radiation in a class room.
4. To switch on the dosimeter and to measure ionizing radiation level.
5. To repeate measurements some times.
6. To calculate average value of the background radiation.
7. To draw conclusion.

Contens of the topic.

Nuclear decay

Radioactivity most often is result of a spontaneous decay of unstable nuclei followed by emission of other nuclei or elementary particles. It is main source of corpuscular ionizing radiation. Corpuscular radiations are gained artificial with the help of particles accelerators. Nucleuses of atoms of the same element always contain the same number of protons, but the number of neutrons in them can be varied. The atoms having nucleus with identical number of protons, but with different quantity of neutrons, are termed as isotopes of the given element. Neutrons are electrically neutral particles with mass, the close to 1 u (nuclear unity or atomic mass unit).

For their discrimination to an element sign there are assigned the number peer to the total of all particles in a nucleus of the given isotope. So, uranium-238 (U^{238}) contains 92 protons and 146 neutrons; in uranium-235 (U^{235}) too 92 protons, but 143 neutrons. Some isotopes (nuclides) are stable, i.e. in absence of exterior action never undergo any transmutations.

The majority of nuclides are unstable; they are capable to be transmuted spontaneously into other nuclides, undergoing a nuclear decay. The moment of such decay is determined by stochastic laws.

γ-Quantums are emitted by excited nuclear nucleus during nuclear reactions. A nucleus as well as the atom, represents a quantum-mechanical system with a discrete set of energy levels. At transition of a nucleus from one energy state into another γ-quantum is emitted; its energy is peer to a difference of energy levels of a nucleus before and after transmutation.

Most often, α-decay and β-decay of nuclei are observed. At α-decay, α-particle is emitted. α-Particle is a helium atom nucleus ^{2}He with mass 4,003 and charge equal 2 units. Atom formed in result of α-decay has the mass number (A) of which is four units less than that of the mother nucleus, the atomic number (Z) being two times less than that of the mother nucleus.

β-Particle is name of fast moving electrons and positrons emitted as result of intrinsic nuclear conversions. Three types of *β-decay* are distinguished: *electron decay* (β^--decay), *positron decay* (β^+-decay) and the so-called *e-capture.* At β-decay of a nuclear nucleus the electron (or a positron) and antineutrino (or, accordingly, neutrino) is emitted. Thus the atom is transmuted into an isotope of a previous element when the positron is emitted, and in an isotope of the following in periodic system of elements, when an electron is emitted.

During e-capture the atom nucleus captures one of the inner electrons of this atom. In so doing, a new nucleus is formed, with an atomic number a unit less than that of the mother nucleus. The previous mass number is retained and a neutrino is emitted.

At all kinds of β-decay there may occur X-radiation or γ-radiation.

Protons (hydrogen nuclei with mass ≈1), deuterons (deuterium nuclei with mass ≈2) can be emitted from nuclei in time of some nuclear reaction, for example, at alpha-particle bombardment of some heavy nuclei.

The properties of elementary particles which are most relevant for their interactions with matter are the type of particle and its kinetic energy. Energy *E* of any kind particles of corpuscular radiation is determined by their rate of a movement:

$\boldsymbol{E} = \frac{\boldsymbol{mv}^2}{2}$, where *m* — particle mass; v — its velocity.

The proton has a rest mass of 1.008 atomic mass units (au). One electronic charge unit (*e*) equals 1.602 x 10^{-19} coulombs (C). The electron-volt (eV) unit of energy is used extensively in radiation science: 1 eV = 1.602 x 10^{-19} joules (J).

Law of radioactive decay. Radioactive substance activity

During radioactive decay of a substance, the number of its atoms decreases with time. The dependence of the number (***N***) of non-decayed atoms on time (***t***) during radioactive decay is known as the *law **of radioactive decay.*** This dependence has the form:

$\boldsymbol{N = N_0 \cdot e^{-\lambda t}}$, where $\boldsymbol{N_0}$ is the initial (at t=0) number of the atoms of the radioactive substance; it is a ***decay constant*** for the given substance. In some cases the radioactive decay law is written as follows:

$$\boldsymbol{N} = \boldsymbol{N}_0 \bullet 2^{-\frac{\boldsymbol{t}}{\boldsymbol{T}}} ,$$

where T is the ***half-life period*** of the substance. The half-life period is the time during which the amount of radioactive atoms decreases two-fold. It can be shown that

$\boldsymbol{T = \ln 2/\lambda \approx 0,7/\lambda}$.

The intensity of ionizing radiation formed during radioactive decay is in direct proportion to the number of atoms disintegrating per unit time. To characterize the rate of decay of a radioactive substance the ***activity*** (A) is used. The activity of a substance is equal to $\boldsymbol{A = -dN/dt}$.

From the law of radioactive decay it follows that the activity of a substance changes with time by the relation: $\boldsymbol{A = \lambda N = \lambda N_0 e^{-\lambda t}}$

The unit of the radioactive substance activity is ***Becquerel*** (Bq). Activity of material equals one Bq, if one atom of substance decays per a second. In practice, Also ***curie*** (Ci) and ***rutherford*** (Rd) are used as off-system units.

1 Ci = 3.7·10^{10} Bq; 1 Rd =1 MBq.

Interaction of ionizing radiation with a material

The ionizing radiation produces excitation and ionization of atoms, i.e. transmitting of electrons of atom on higher energy levels.

Excitation of atom descends, if it absorbs energy no more than 10 eV, which is equaled about binding energies of an electron with a nucleus. The electron thus remains in borders of atom. At reverse transition of electrons from excited levels on basic the earlier absorbed energy is radiated as quantums of visual, ultraviolet or X-ray radiation. Besides excited atoms can to enter chemical interaction.

If the atom absorbs energy of more binding energy of an electron with a nucleus the electron leaves borders of atom (molecule) – there is ionization. Atoms and the molecules which have lost electrons, become positively ionized atoms. Released electrons, being associated to neutral atoms and molecules, form negatively ionized atoms. Besides electrons, breaking out from atoms, can have major energy, and then they are capable to ionize atoms and molecules and to originate secondary electrons.

The mechanisms of ionization are different for different kinds of ionizing radiation.

Ionization braking is the basic ionizing mechanism for α- and β^{-}-radiation. These charge particles electrically interact with the electron shells of the atoms and lose their energy on ionizing atoms.

The β^{+}-particles (positron) interact with the electrons of atoms. The reaction of interaction of positrons and electrons is known as the ***annihilation reaction.*** During the annihilation reaction the positron and electron disappear to be replaced with several (usually two) γ-photons. Due to this reaction the atom is modified to an ion.

During ionization deceleration the β^{-}-particles can emit X-ray radiation. It can also ionize atoms of substance.

There are three basic mechanisms of γ-radiation interaction with a substance: ***photoeffect, incoherent scattering (Compton effect)*** and ***formation of electron-positron pairs.*** The first two mechanisms are considered early. Formation of electron-positron pairs is observed only at sufficiently high energies of γ-quanta (more than 1,2 MeV). In this case the γ-photon disappears to be replaced by an electron and positron. These charge particles can ionize neutral atoms.

More often than other mechanisms, photoeffect is observed at relatively small energies of γ-quanta; incoherent scattering prevails at medium energies, and formation of electron-positron pairs occurs at high energies of γ-photons.

In addition to the primary mechanisms considered above, interaction of γ-radiation with a substance displays secondary ionization mechanisms (as there are displayed at interaction with other kinds of ionizing radiation too).

At photoeffect the dislodged electron can attach to another atom to form a negative ion. The vacancy lower level can be occupied by an upper-level electron to form an X-radiation photon, which also produces ionization.

At incoherent scattering the Compton electrons can ionize a substance due to the ionization braking mechanism or at abrupt braking they can generate X-radiation.

When electron-positron pairs are formed, the emerging electrons can have a sufficiently high energy and ionize a substance due to the same mechanisms that Compton electrons.

Photonuclear reactions are radioactive transformations of atom nuclei after they have absorbed γ-photons. Neutrons by themselves do not cause ionization of a substance, but in interacting with the nuclei of atoms they generate ionized radiation. Interaction of neutrons with nuclei causes either scattering of neutrons or their capture by the nuclei.

Neutrons by themselves do not cause substance ionization, but in interacting with the nuclei of atoms they generate ionized radiation. Interaction of neutrons with nuclei causes either scattering of neutrons or their capture by the nuclei.

During scattering part of the neutron's kinetic energy is transferred to the nucleus. Light nuclei receive a high velocity with sufficient kinetic energy for ionizing. They are termed Compton nuclei. When capturing a neutron the nucleus goes to an excited state, which is often an unstable one. In this case it can be observed nuclear fission, though reactions with emission of protons or α-particles can also occur.

Penetrability of radiation

In passing through a material, the γ-radiation flux can attenuate. The ***Bouguer law*** describes the attenuation of the flux of a monochromatic γ-radiation (similar to X-rays): $\Phi = \Phi_0 e^{-\mu t}$,

where μ can be presented as $\mu = \mu_{ph} + \mu_c + \mu_p$,

where μph, μc and μp are the components of the total absorption coefficient due to photoeffect, the Compton effect and formation of electron-positron pairs respectively.

Passage through the substance a charged particle flow is characterized by ***linear ionization density, linear braking capacity,*** and **mean free *path.***

Linear ionization density (***i***) is the ratio of the number of ions of one sign (***n***), formed by the particle in travelling over path l, to the length of this path. Therefore, linear braking capacity (***S***) is the ratio of energy (***E***), lost by the particle in travelling over path l, to the length of this path

$$i = \frac{dn}{dl}.$$

Linear braking capacity (***S***) is the ratio of energy (***E***), lost by the particle in travelling over path l, to the length of this path

$$S = \frac{dR}{dl}.$$

The *mean free path* is the mean distance passed by the particle in a substance until its velocity decreases to the particle's thermal velocity.

The capability of radiation to penetrate through the matter is known as their ***penetrating capacity (penetrability, penetrating power)***. Neutron, γ- and X-radiation possess a high penetrating capacity. Charged particles possess a significantly less penetrating capacity. Usually the greater the penetrating capacity of the radiation the less is its ionizing capacity, and conversely.

α-Radiation has low penetrating ability, being impeded, for example, a leaf of a paper, and practically is not capable to penetrate through the external skin layer forming by mortified cells. Therefore it does not represent danger until the radioactive materials which are emitting α-particles, it will not get inside of an organism through an unclosed wound, with nutrition or with inhaled air; then they become extremely dangerous.

β-Radiation transits in a tissue of an organism on depth of 1–2 centimeter. Penetrability of γ-radiations is very great: only thick lead or concrete plate can detain it.

Biophysical bases of interaction of an ionizing radiation with biological tissues.
Direct action of radiation

At activity of the ionizing radiation in organisms *initial physicochemical processes* which consist in formation of chemically high-active compounds – excited molecules, ions, radicals, and peroxides proceed.

Being absorbed by a macromolecule, energy of ionizing radiation can migrate on a molecule, being implemented in most weak spots. Results are ionization, excitation, a disruptive of the least strong bonds, a separation of the radicals termed as free.

Initial target can become high-molecular compounds (proteins, lipids, enzymes, nucleic acids, molecules of the composite proteins – nucleoprotein complexes, lipoproteins). If DNA molecule appears the target the genetic code can be broken.

As the alive organism contains a plenty of water (60-90 %) the greatest value in development of a radiation injury has a ***radiolysis of water***, i.e. formation of ions and radicals from water. Main products of a radiolysis are: H_2O^*, $OH^\bullet$, $H^\bullet$, H_3O^+, e^-, H_2O^-, OH^- .

At the presence of oxygen it is probable formation of hydroperoxide and peroxide of hydrogen $HO_2^\bullet$, H_2O_2, and also atomic oxygen O.

Energy of radiation can be absorbed directly by molecules of organic compounds. Thus there are excited molecules, ions, radicals and peroxides: RH^*, RH^+, ${}^\bullet R$, ${}^\bullet RO_2$.

Further intercept of energy of free radicals by other materials (most active reductants) is carried out.

Chemically high-activity compounds formed at this stage enter reactions with other biochemical compounds of an alive organism that gives in infringements of biochemical processes and structures of cells, hence, and to infringements of functions at a level of a complete organism.

Indirect action of radiation

The chemical one after another chemical and biochemical reactions can promptly grow, getting character *of the chain branched reactions*. The activity of an ionizing radiation caused ***by products of a radiolysis of water*** is termed ***as indirect activity of radiation***.

The proof of the important role of products of a water radiolysis in formation of consequences of an irradiation is higher radiostability of dry and powdered enzymes in comparison with their water solutions.

Free radicals and peroxides are capable to vary chemical composition of DNA. Unsaturated fatty acids, amino acids and phenolums are exposed to an oxidizing, therefore are formed lipid (lipid peroxides, aldehydes, ketones) and quinones ***radiotoxins***. Radiotoxins depress synthesis of nucleic acids, react on DNA molecule as chemical mutagen, vary activity of enzymes, and react with lipid-albuminous endocellular membranes.

Thus, initial radiochemical reactions consist in direct and indirect (through products of water radiolysis and radiotoxins) damage of the major biochemical components of a cell – nucleic acids, proteins, enzymes. Further enzymatic reactions roughly vary – strengthens enzymic decay of proteins and nucleic acids, synthesis of DNA is reduced; the biosynthesis of proteins and enzymes is broken.

Infringement of vital activity of cells

All organoids of a cell are damaged owing to the described changes. Lesions of a nucleus – aberration chromosomes (breakages, rearrangements, a fragmentation), chromosomal and genovariations (genetic mutation) break inheritable properties of a cell. Division of a cell is inhibited or proceeds abnormally. At the moment of division, and also in an interphase the cell can be lost.

Endocellular membranes – membranes of a nucleus, mitochondrions, lysosomes, endoplasmic reticulum – are damaged. From the defective lysosomes enzymes which damage nucleic acids, cytoplasmic and nuclear proteins are released. Infringement of energy metabolism of a cell is one of the causes of a stopping of nucleic acids and nuclear proteins synthesis, as inhibitions of mitosis.

The nucleus of a cell has especially high radiosensitiveness in comparison with cytoplasm.

Therefore cells of tissues, in which processes of division are most intensive and constant, perish at an irradiating even in small doses. They are, first of all, thymus gland, sexual glands, hemopoietic and adenoid tissue.

The epithelial tissue (in particular a glandular epithelium of alimentary and sexual glands, an integumentary epithelium of a skin, then an endothelium of vessels) is following on radiosensitiveness.

Cartilaginous, osteal, muscular and nervous tissues are radioresistant.

Nervous cells have no ability to division and consequently perish only at activity on them radiation in major doses (interphasic destruction). Mature lymphocytes, which perish even at an irradiating in a dose 0,01 Gy, are exception of this rule.

The basic symptom-complexes **of infringement of functions of an organism**.

At an irradiating of lethal and superlethal doses interphasic destruction of cells prevails; the death comes the nearest minutes or hours after an irradiating. At an irradiating medial doses life is possible, but in all without exception the functional systems pathological changes move. Their intensity is in dependence on a relative radiosensitiveness of tissues.

Infringement of a hemopoiesis and blood system is most typical. The quantity of all blood cells decreases, cells become functionally incomplete. At the first hours after an irradiating the lymphopenia, later – a disadvantage of granulocytes, thrombocytes and even later – erythrocytes is noted. Exhausting of a bone marrow is possible.

The immune reactivity is reduced. Immunodefence is depressed, therefore an infection is the earliest and serious complication of an irradiating. The infection develops in an intestine; there is an adsorption of toxins and bacteria into a blood. Infringement of function of a digestive tract gives in an attrition of an organism.

The hemorrhagic syndrome is the typical attribute of **radiation sickness**. The quantity of thrombocytes is reduced, as well as their ability to coagglutination, the molecular structure of fibrinogenum variates, in a blood there are anticoagulants, mechanisms of protection of a vascular wall are broken. All this promotes to hemorrhages.

Circulations in capillaries it is disturbed due to a developing stasis that enhances a lesion of tissues.

In **nervous system** rasping structural changes and destruction of nervous cells come at rather high exposure doses. Therefore the functional changes are evident in the beginning, since in some seconds after irradiating nervous receptors are exposed to an irritation by products of radiolysis and disintegration of tissues. Nervous-reflex activity is broken before appearance of other typical signs of a radiation sickness.

The lens is the most vulnerable for radiation a part of an eye. The lost cells become opaque, and growth of the turbid fields brings at first to a cataract, and then to the complete blindness. The greater dose, the more loss of sight. The grown turbid fields can be formed at exposure doses 2 Gy and less. More serious form of a lesion of an eye – a progressing cataract – is observed at doses about 5 Gy. The professional irradiating harmful for an eye: doses from 0,5 up to 2 Gy, received during 10–20 years, give in augmentation of density and a phacoscotasmus [lenticular opacity, opacity of lens cataract].

In organs **of endocrine system** primary attributes of activity rising are replaced by depression of endocrine glands function. Single exposition of spermaries at a dose only in 0,1 Gy gives in a time sterility of men, and doses from above 2 Gy can give in a permanent sterility.

Owing to chromosomal damages somatic cells can undergo **to a malignant degeneration**, and aberration chromosomes in sex cells give in development **of hereditary diseases**. A cancer is most serious of all consequences of an irradiating of the human at small doses.

Children are extremely sensitive to activity of radiation. The age of the child less, the bones grows is more strongly depressed. A cooperative dose about 10 Gy, received within several weeks at a daily irradiating, it happens enough to cause some anomalies of a skeletogeny.

Dosimetry. Doses of the ionizing irradiation

Dosimetry is an essential part of radiation science.

Exposure doses

Absorbed dose – the energy of an ionizing radiation absorbed by the irradiated body (substance or tissues of an organism), in recalculation on a mass unit.

Equivalent dose – an absorbed dose increased on coefficient, reflecting ability of the given kind of radiation to damage a tissue of an organism.

Effective equivalent dose the equivalent dose increased on coefficient, taking into account different sensitivity of various tissues to an irradiation.

Collective effective equivalent dose – the effective equivalent dose received by group of people from any radiant of radiation.

Complete collective effective equivalent dose – a collective effective equivalent dose which will be received with generations of people from any radiant for all time of its further existence.

Absorbed dose

The radiobiological effect of ionizing radiation is the greater the greater the radiation energy absorbed by the substance. The amount of absorbed radiation is determined by a dose, i.e. quantity of an absorbed energy. Influence of the radiation on objects can be characterized by the ratio of radiation energy (***E***) absorbed by the object's material, to the mass (***m***) of this material, irrespectively of its source. This characteristic is known as the radiation dose or absorbed dose (***D***):

$D=E/m$.

The current unit of **absorbed dose** in a SI is the ***gray*** (Gy). Represents quantity of energy of the ionizing radiation absorbed by a mass unit of any physical body, for example tissues of an organism.

1 Gy = 100 rad = 1 J/kg. It's mean that 1 kg of material absorbs 1 J of energy of ionizing radiation.

The ***rad*** was the original unit of absorbed dose. It is an off-system unit for the radiation dose.

1 rad=10^{-2} Gy=10^{2} erg/g; 1 Gy=100 rad. 1 erg = 10^{-7} J.

One rad corresponds to the absorption of 6.242 x 10^{13} eV by one gram of substance for any type of ionizing radiation. Although the basic concept of the rad is unambiguous, it is often difficult to calculate the absorbed dose in a given system. Absorbed dose is an average quantity for a macroscopic material. The local dose in different regions of the absorber may vary owing to the production of secondary ionizing particles or electromagnetic radiation (EMR) which contribute to the dose in other regions of the material.

Exposure dose of photonic radiation (X- or γ-radiation) is measured by value equal to ratio of sum of electric charges of all same charge (one-sign) ions (***Q***) which are produced by electrons under the affect of X-radiation or γ-radiation to the mass of this air (***m***):

$X=Q/m$.

In the SI the unit of exposure dose is ***coulomb per kilogram*** (C/kg).

In practice, a widely used off-system unit of the exposure dose is ***roentgen*** (R). It is one of the first unities of X-ray and γ-radiations dose. One roentgen is the dose of X-radiation or γ-radiation, under the affect of which, at total ionization in 1 cm^3 of air under normal conditions (temperature 0°C and pressure 760 mm Hg), $2.08 \cdot 10^9$ pairs of ions of each sign are formed. 1 R=$2{,}58 \bullet 10^{-4}$ C/kg.

1 roentgen (1 R) – such X-ray or γ radiations dose at which 1 g of air absorbs 84 erg of energy at 0°C temperature and 760 mm hg atmospheric pressure.

Unity is applied to dosage measurement of any ionizing radiation exposure doses – a *physical roentgen-equivalent* (***rep***). It is a dose of any ionizing radiation at which 1 g of materials absorbs 84 erg – as much, how many as 1 g of air absorbs at 1 R electromagnetic radiation.

This unit is difficult to measure and not often used today.

Ratio of the radiation dose to the time of exposure is known as the **dose rate** or **exposure rate** (***Ď***). $\check{D}=D/t$.

It unit is *grey per second* (Gy/s) or *rad per second* (rad/s). In practice, it is difficult to measure the dose rate. Hence, the radiation dose absorbed by a body is estimated by measuring the degree of ionization of air ambient to the body.

Fluence (F) [integrated flux density] is a unit of exposure dose defined as the number of particles or amount of energy incident per unit area.

Fluence rate is the fluence per unit time. "Flux" is often used in neutron physics in lieu of fluence rate. This usage is confusing because radiant flux is a power unit in optical physics with the units of watts.

Equivalent dose

Other units of absorbed dose have been employed to express the biological effectiveness of a given radiation.

The biological effect of radiation depends on an ionic density which is measured by number of ions pairs formed on 1 micron of a particle trajectory.

The ionic density is proportional to a quadrate of a charge and in inverse proportion to particle velocity. As at peer energies velocity of a particle is inversely proportional to particle mass that the ionic density will be directly proportional to mass of a particle. Therefore at identical energies the greatest ionic density is given with the α-particles having the greatest charge and the greatest mass. The least ionic density is given with electrons, X-ray and γ-ray. Protons, neutrons and deuterons occupy the intermediate standing between the first and second groups of radiation.

The ***rem*** (*roentgen-equivalent-man*) [biological equivalent of roentgen] is the dose in ***rad*** multiplied by a ***relative biological effectiveness*** (RBE) factor. For unity the relative biological effectiveness is accepted efficiency of X-ray with energy 200 keV. The RBE is taken as unity for "hard" X-rays and γ-rays and may be much higher for other types of radiation, for example, the RBE is about 20 for fast neutrons.

$D_{rem} = D_{rep} \cdot RBE,$

where D — radiation absorbed dose,

or in standard signs: $H = D \cdot q,$

where H – equivalent dose, D — radiation absorbed dose, q – quality coefficient (***RBE factor***, table 15.4). H is measured in rem or ***sievert***, D – in rep or coulomb per kilogram correspondingly.

Unit of aggregate exposure dose of particular group of people is ***person-rem***.

An alternative unit of the equivalent dose in a SI-system is the ***sievert*** (Sv) which equals 100 rem. 1Sv=100 rem. Represents unity of an absorbed dose multiplied on coefficient, taking into account unequal radiative danger to an organism of different kinds of an ionizing radiation. 1 sievert corresponds to an absorbed dose in 1 J/kg for X-ray, γ- and β-radiations.

Because the rem is a relatively large unit, typical equivalent dose is measured in millirem (mrem), 10–3 rem, or in microsievert (μSv), 10–6 Sv. 1 mrem = 10 μSv.

Thus, the dose in Sv and Gy are the same for RBE = 1. The maximum permissible lifetime radiation exposure is 5 mSv in the U.S. for the general population, which is equivalent to 0.5 rad of X-rays and gamma-rays. This is 0,1% of the expected lethal dose for a whole body exposure.

Natural sources of ionizing radiation create a certain radiation level that continuously affects all the organisms on Earth. This level is known as the “*background*”. The annual equivalent dose related to the natural background is usually equal to 125 to 300 mrem (1,25–3 mSv) for most of people.

In medicine the ***maximum permissible dose*** is used. The maximum permissible dose is the maximum value of an individual annual equivalent dose, which, at uniform exposure during 50 years, shall have no detrimental effect on man's health. The maximum permissible annual equivalent dose for professional exposure is equal to 5 rem.

Relative biological effectiveness value for different kinds of radiation

Kind of radiation	**RBE**
X-rays and γ-rays	1
β-particles and electrons	1
α-particles and protons	10
Slow neutrons (energy less 1 keV)	3
Fast neutrons (energy more 100 keV, before 20 MeV)	10
Multicharged ions (polyvalent ions) and recoil nuclei	20

Different organs and tissues have different sensitivity: for example, at an identical equivalent exposure dose originating of a cancer in lungs is more probable, than in a thyroid gland, and an irradiation of sexual glands especially dangerously because of hazard of genetic damages. Still in 1906 I. Bergonje and L. Tribondo have formulated a rule: sensitivity of cells to an irradiation is directly proportional to them proliferative activity and inversely proportional degrees of their differentiation. After multiplying of the equivalent doses on the corresponding coefficients (see table below) and summation on all organs and tissues, we shall receive ***the effective equivalent dose*** reflecting a cooperative effect of an irradiation for an organism; it also is measured in *sievert*.

The weight coefficient accounting for the contribution of the tissue (organ) to the body's total radiosensitivity

Tissue or organ	W
Gonads	0,2
Red bone marrow	0,12
Large intestine	0,12
Lungs	0,12
Stomach	0,12
Urinary bladder	0,05
Mammary gland	0,05
Liver	0,05
Esophagus	0,05
Thyroid gland	0,05
Skin	0,01
Periosteum	0,01

After summation of the individual effective equivalent doses received by group of people, we shall come to **a collective effective equivalent dose** which is measured in person-sievert (person-Sv).

As many radioactive materials decay very slowly also will be the active in the long-term future too, that collective effective dose which will be received with many generations of people from any radioactive source for all time of its further existence, term **as an expected (complete) collective effective equivalent dose.**

Dose rate

Dose rate is dose of irradiation in a unit of time. Dose rates can be calculated for all before-mentioned dosimetric characteristics. They can use, for example, if it is necessary to calculate influence of some permanent active source of radiation: native or professional sources. They ca calculate in day, in year and so on.

For evaluation of population radiation risk it is used such unit as mSv/year.

Dosimetry

Instruments used for detecting ionizing radiation, determining their characteristics, and measuring radiation doses can be divided into two groups: *detectors of ionizing radiation* and *dosimeters.*

Detectors of ionizing radiation. Ionizing radiation detectors are intended for registering radiation and measuring some of their characteristics (e.g., energy and velocity of particles, the ratio of their charge to mass, and others). Detectors can be referred to three groups: track detectors, counters and integral devices.

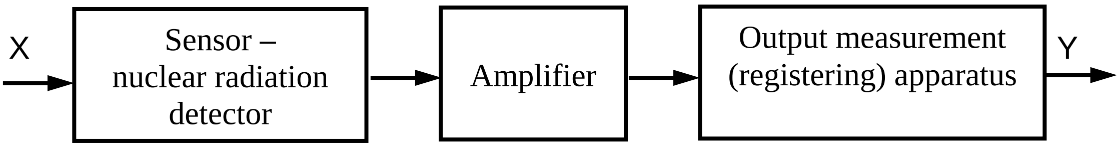

Fig.1. The general scheme of all dosimeters.

Track detectors allow to observe particle path, counters register particle appearance in device chamber, integral devices give information about ionizing radiant flux.

Track detectors include the Wilson chamber, the bubble chamber, spark chamber, thick-layer photo plates. Counters are proportional counter, the Geiger counter and others.

In the *Wilson chamber (cloud chamber, expansion chamber, fog chamber or diffusion chamber)* there are saturated pairs of any fluid, which are made supersaturated by sharp magnification of volume of the chamber.

The chamber is in a magnetic field. Ionizing particles flying in this moment through the chamber leave tracks as fluid droplets condensed on the ions formed by particles. Tracks are photographed. The shape and volume of a track depends on a charge of a particle, its mass and energy.

In *bubble chamber (bubble cell)* there is a superheated fluid, and the flying particle produces an ebullition (boil) and formation of pair bubbles. Registering descends as in an expansion chamber.

In thick-layer photo plates particles leave tracks on emulsion which becomes visible after development of photo plates.

In the capacity of an instance of gas devices we shall consider a Geiger-Muller counter; it will consist of coaxially located cylindrical electrodes (fig.2): 1 – the cathode (a metal evaporated on a glass tube, 3 – the anode (the thin hairline tensioned along an axis). Pressure of gas inside the counter is of 100-200 mm Hg. The voltage about several hundreds volts is created between electrodes. The ionizing particle, flying by in the chamber, ionizes atoms of gas; the formed free electrons move to the anode. Electrons near to a thread are sped up so, that begin ionize gas. In result there is a discharge and a current flows in a circuit.

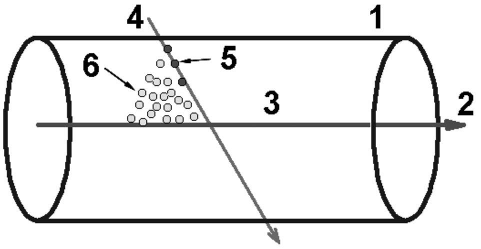

Fig.2. Scheme of Geiger counter camera. 1 – sealed tube (gas filled); 2 – to electronics; 3 – anode (wire at high voltage stretched along axis); 4 – particle track; 5 – primary electrons; 6 – electron avalanche.

It is necessary to extinguish the self-sustained discharge in a Geiger-Muller counter, differently the counter will not react to the following particle. To quenching the discharge there are applying a radio engineering method and a method based on addition of polyatomic gases in a tube (self-quenched counters).

The electrical impulses incipient in an external circuit are strengthened and filed by the special device.

Scintillation (luminescent) counter counts short-term flashouts of light – scintillations which descend in some materials under activity of an ionizing radiation. In the luminescent counter they are filed automatically with use of the photomultiplier tube.

Semiconductor counters react to change of an electrical conduction of p-n junction under action of a charged particle.

X-ray and γ radiations are filed due to ionization which is invoked by the charged particles formed at a photoeffect, the Compton effect, etc.

Counters should meet some general requirements, such, as the efficiency, resolvent time, etc. Efficiency is the relation of the registered number particles to general number of the particles which has flown by through the counter. Resolvent (or dead) time of the counter is the minimum time which should part the particles following one after another that they have not been counted as one.

Dosimeters are devices for measuring doses of ionizing radiation, or values related to doses. Depending on the physical phenomenon determining the dosimeter's principle of operation is based, the following devices are distinguished: ionization, luminescent, semiconductor and photo dosimeters.

Radiometers are the devices applied to measuring activity or concentration of radioactive isotopes.

Self-control material:

B. Test tasks

1. What is law for determination of weakening of ionizing radiation in substabce?

A) Mozli law
B) Bouguer law
C) Plank law
D) Einstein law

2. What are radiotoxins?

A) Substabces amplified toxic effect of irradiation;
B) Toxical compound formed in irradiated tissues;
C) Toxic substances, which toxic effect is amplified by irradiation.

3. What is Bouguer law?

A) $\Phi = \Phi_0 e^{-\mu t}$.
B) $I = dn/dl$.
C) $S = \frac{dR}{dl}$.
D) $N = N_0 \bullet 2^{-\frac{t}{T}}$.
E) $E = \frac{mv^2}{2}$.

4. Unity of an absorbed dose of an ionizing radiation in SI is:

A. Roentgen
B. Coulomb per kilogramme
C. Sievert
D. Grey
E. Kerma

5. Unity of an exposition dose of a photon ionizing radiation in SI is:

A. Coulomb per kilogramme
B. Grey
C. Sievert
D. Kerma
E. Roentgen

6. Unity of the equivalent dose of an ionizing radiation in SI is:

A. Roentgen B. Coulomb per kilogramme
C. Grey D. Sievert E. Kerma

7. Unity of an exposition dose of a photon ionizing radiation in SI is:

A. A coulomb per kilogramme B. Grey
C. Sievert D. Kerma E. Roentgen

Literature recommended

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