Lesson 1

INTRODUCTION

Radiation Medicine and its place among medical disciplines

There is uncertainty in the use of term *radiation medicine*. In world English-language literature and medical practice this term is used rarely and as a synonym of radiation therapy in all its varieties (in particular, radiotherapy with opened radionuclides), and it is absent in the most important English-language terminology dictionaries. In Germany a few known specialized radiological clinics (in the cities of Aachen, Monchengladbach, Munich) in which treatment with radionuclides is performed are named the *clinics of radiation medicine*.

In the first time the term *of radiation medicine* was used in 1955 in the USSR for denotation of scientific and practical problems of prophylaxis, pathogenesis, diagnostics and treatment of radiation damages (in particular radiation disease): that year guidance was given out for doctors and students of collective of authors under the general release of the known radiobiologist, academician A. Lebedinski with the name of «Radiation Medicine». The questions of physiopathology, clinic and therapy of radiation illness opened up at the book. After the radiation accidents, especially after Chernobyl NPP accident (1986), that had consequences for hundreds thousands of men and to the study and liquidations of which were attracted large contingents of doctors and researchers, term *radiation medicine* in the states of the CIS began to live status of current concept, to which they began to include all of problems, tangent prophylaxis, clinical radiobiology (to pathogenic), clinic and treatment of all of types of radiation damages of man. Sometimes as a synonym is used term *atomic medicine*.

Institutes and centers of radiation medicine are opened in Russia, Byelorussia, Ukraine and other states of the CIS. But practical profession (specialty) with such name in the official register of medical specialties in Ukraine is absent.

As a chronic irradiation of low-level the workers of different categories (personnel) are undergone in the process of work with radiation sources, question of influence of such irradiation professionally of possible level behave to the problems more general discipline *medicine of labor*. A personnel which is professionally related to work in the field of action of radiation can also test the irradiation of more considerable level in the case of origin of technological radiation incidents the medical consequences of which as radiation damages of different degree of weight and prevalence also logically behave to jurisdiction of medicine of labour. Thus, radiation medicine can be examined as a section of medicine of labour by analogy to confessedly, for example, aviation medicine, medicine of sea transport, space medicine, etc. Common biological bases of pathogenesis of radiation damages are examined in *radiobiology*, and pathogenesis of such damages of man – a*t the clinical radiobiology* to jurisdiction of which the questions of theoretical bases of radiation treatment of oncologic and non-oncologic diseases of man belong also. In addition, as ionizing radiations have property to cause violation of chromosomes of cellular nuclei with various genetic consequences (teratogenesis, congenital diseases, cancerogenesis), radiation medicine examines the proper questions *of clinical genetics* also. In a that or other degree radiation medicine must touch also problems of prophylaxis of radiation pathology, which is examined in *a radiation hygiene*.

Although the etiologic factor of radiation pathology is ionizing radiation, it has actions after mechanisms, obviously, it is brightly expressed specific features and, as a result, specific nosotropic lines, treatment of it is fully possible facilities which are utilized in the different sections of internal medicine, namely haematology, endocrinology, cardiology, neurology, etc.

Thus, radiation medicine is *clinical integrative discipline*, in which questions general with clinical radiobiology, clinical genetics and radiation hygiene are considered, and the performing of Medicare is possible within different branches of traditional internal medicine, and in certain cases by surgery.

Tragic history of acquaintance of humanity with a radiation as pathogenic factor it is possible to divide into two periods: first from 1896 to 40th of 20th century – period of the human personal dramas and tragedies among the pioneers of radiology, the second (next 50 years) the period of population dramas and tragedies as a result of radiation accidents, catastrophes and military application of nuclear weapon.

On the 4th of April, 1936 on territory of hospital of St. George (Gamburg-Eppendorf, Germany), one of prominent pioneers of world radiotherapy Albers-Schonberg worked in which, that perished from a radiation cancer, opening of monument, devoted lost by then in the entire countries of the world from the action of radiation in connection with their professional work took place (fig. 1). The memorial has a type of limestone stele, set in the center of circle from the blocks of limestone and crowned by a stone laurel wreath. On the front surface of stele inscription is: «The monument is devoted to the roentgenologists and radiologists of all countries, to the physicians, physicists, chemists, technicians, laboratory workers and nurses who gave their lives in the struggle against the diseases of their close. They heroically made the way to effective and safe application of x-rays and radium in medicine». «THEIR GLORY IS IMMORTAL». «FROM GERMAN X-RAY SOCIETY». On other surfaces the names of 169 persons died in the heavy sufferings from radiation damages got by them during work with x-rays and radium carved. In the next 1937 H. Meyer published «Book of Honor» with short biographies of those, whose names were carved on the stele. But this was far not complete martyrologue of the pioneers of radiology. In future behind and aside from the stele additional stones were set with the again opened names of the lost explorers-radiologists, and in 1959 new edition of «Book of honour» was published already with 360 names.

Fig. 1, Monument in honor of the pioneers of radiology tragically lost from radiation damages, set on April, 4, 1936 on territory of hospital of St. George (Gamburg-Eppendorf, Germany) from German x-ray society.

From those, who was among the first, practically nobody could avoid an own bitter acquaintance with an insidious threat for a health and life from invisible and imperceptible, but such multireliable and that encouraging energy, named by a radiation. Henry Becquerel, Nobel laureate – author opening of radiation of salts of uranium of invisible rays, similar to the x-rays, just now described by W. Roentgen, got the radiation burn of skin with an ulcer from an ampoule with radium, which he some time carried in the waistcoat pocket. Maria Sklodowska-Curie, twice Nobel laureate, died of leukemia in the small hospital of township of Sansellemoz in French Alps. Doctor Tobe did an official record about it: «Madam Curie died in Sansellemozi on July, 4, 1934. Sickness is acute malignant anaemia.

Bone marrow did not give the reaction, possibly, as a result of transformation from the long accumulation of radioactive radiations». Irene Jolio-Curie, daughter of Maria Curie and also Nobel laureate for opening of artificial radioactivity, died in Paris on March, 17, 1956 from acute leukemia. Doctor-roentgenologist S.P. Grigoriev, founder of the x-ray Academy in Kharkiv, presently Institute of Medical Radiology of NAMS of Ukraine named after S.P. Grigoriev, had a radiation cancer of skin of hand and chronic radiation sickness. Death from an infectious disease was drawn through the defeat of immunity. For the radiologists of the USA in a period between 1929 and by 1957 years leukemias were registered in 4 %, that in 10 times exceeded frequency of this disease among non-radiologists (0,4 %).

Only Wilhelm K. Roentgen, who put beginning to the history of radiology, passed 7 weeks of seclusion in the physical laboratory one on one with the Crooks tube, which radiated a mysterious ray (x-radiation), and executing an experiment after an experiment with this rays, had no signs of worsening of health, and even his luxurious beard and head of hear remained unchanged. Explanation to it can be only in that this talented person, probably, foresaw possible harm to living tissues from those mysterious rays, and he avoided an irradiation by them, closed before including of the tube in a leaden closet, in which held the supply of photographic plates, necessary for research of X-rays.

From American data, life-span of roentgenologists in a period 1938–1942 was on the average on 5.2 years less, than doctors of other specialties, being 60.5 and 65.7 years, accordingly. Roentgenologists accumulated dose up to 10 Gy for 30–35 years of practical work. More short duration of their life was predefined by higher frequency of origin of tumors, in particular haemoblastoses, by more frequent early development of degenerative changes and infectious complications. In radiologists of the USA in a period between 1929 and 1957 years leukemias were registered in 4%, that in 10 times more frequent than among non-radiologists (0.4%).

An international commission on radiation protection (ICRP), created in 1928, in 1934 offered the first limit of professional irradiation («tolerant dose») in 200 mR/d. The possible dose of professional irradiation was repeatedly looked over in the future. In 1957 these possible levels were substantially revised, and in next years morbidity of radiologists on leukemias did not differ from morbidity among other layers of population.

BASIC OF IONIZING RADIATION PHYSICS

RADIATION MEASUREMENTS. SOURCES OF IONIZING RADIATION

1. Types and properties of ionizing radiation

Ionizing radiation (IR) is radiation, interacting of which with media causes, in the end, ionization of atoms and molecules. To IR belong: electromagnetic radiations of high energy (gamma- and X-rays beams) and atomic particles (alpha- and beta-particles, electrons, positrons, protons, neutrons and other charged and neutral elementary particles).

Energy of ionizing radiation is measured in *electron-volts* (eV).

Photons are discrete portions (quanta) of electromagnetic energy, which can behave as waves or particles and does not have mass of rest and electric charge. Photons with energy approximately up to 2 keV (2×10^3 eV) are the photons of optical range of electromagnetic radiation (light), and at greater energy they are able to ionize the atoms of environment, consequently they belong to ionizing radiation. If energy of photons makes at least 10 MeV (10^6 eV), their interacting with the nucleus of atom results in destruction of the last with emission of neutron, proton or alpha-particle from it. This process carries the name of photodisintegration (fig. 2).

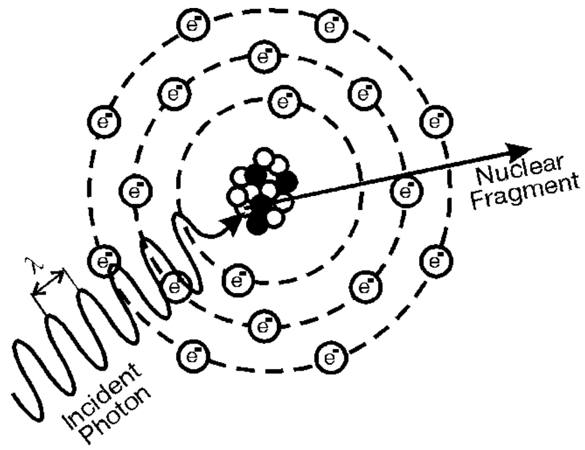

Fig. 2. Scheme of interaction of photons of super-high energy with the nucleus of atom with photodisintegration of the last

The beams of photons depending on an origin are named *x-* or *gamma-rays*.

X-rays arise up at interacting of electrons beam with the atoms of any matter. In the field of atoms electrons are decelerated, and their energy emanates as quanta, that in such cases carry the name of *bremsstrahlung* (from *bremsen* ‘to brake’ and *Strahlung* ‘radiation’, i.e. ‘braking radiation’ or ‘deceleration radiation’). Energy of quanta of such radiation makes the continuum (continuity) of values in a range from minimum (on verge of ultraviolet rays) to maximal, proper to complete kinetic energy of decelerated electrons. Consequently deceleration x-rays has a *continuous energy spectrum*. In addition, part of falling electrons remove orbital electrons outside atoms. Into exempted on the internal electronic shell of atom place an electron passes from an external shell, emitting part of the energy as a photon of x-rays. For every element such photons have the characteristic values of energy, that is why spectrum of their energy is *linear*, and they are named *characteristic x-rays*.

Gamma-radiation (γ) are photons of nuclear origin, which arise up at the radioactive decay of nuclei of unstable nuclides of chemical elements. Usually, photons a gamma-radiation have enough high energy from dozens of keV and higher.

Electron (e^-) is an elementary particle of shells of atom with a charge –1 and mass of rest of 511 keV (mass of rest of particles has a certain equivalent of energy and, accordingly, can be determined in units of energy). Electrons can also be of nuclear origin. Such appear in the process of radioactive decay of unstable nuclei by disintegration of one of neutrons of nucleus on a proton and electron. The electrons of such origin are named beta-particles (β^-). Them kinetic energy has characteristic for this nuclide value.

Positron (e^+) is an elementary particle of antimatter with a charge +1 and mass of rest 511 keV. Actually it is a mirror particle to the electron which appears in a pair with an electron at decelerating of photon with energy not less than 1.022 MeV, as mass each of these particles equals 511 keV. In addition, there are positrons of nuclear origin. The nuclei of some unstable nuclides are disintegrated with the radiation of positron (so-called positron beta-decay) which appears in the nucleus as a result of disintegration of proton on a neutron and positron. In such case a neutron remains in the nucleus, and a positron emits outside its limits.

Positrons, being the particles of antimatter, in the surrounded matter exist only afoot. When their kinetic energy is closed in the fields of atoms of matter, they meet with the nearest electron, and the masses of both particles disappear, making birth of two photons with energy of 511keV each. This process carries the name of annihilation. Annihilation photons fly away in opposite directions under the angle of 180° (fig. 3). On the basis of the phenomenon of annihilation it is designed nuclear medicine diagnostic method under the name of positron emission tomography (PET), by which they get medical molecular images.

Proton (p) is a nuclear particle (nucleon) with a charge +1 and mass of rest 938 MeV.

Neutron (n) is nuclear particle (nucleon) with a zero charge and mass of rest 940 MeV.

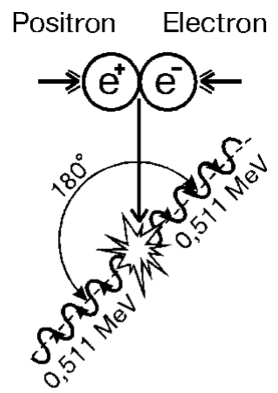

Fig. 3. Scheme of process of annihilation of electron-positron pair

Alpha-particle (α) is a composite particle which consists of 2 neutrons and 2 protons that equivalent to the nucleus of helium, it has a charge +2 and mass 3.8 GeV ($3{,}8x10^{12}$ eV or 4 atomic mass units).

Passing through an environment IR *excite*s (cause the transition of electrons from internal orbits on more high) or *ionizes* (knock out outside an atom one or a few orbital electrons) its atoms. Excitation or ionization of atom does it chemically more active.

With ability of IR to cause ionization of atoms of environment their derivative properties are linked:

- to cause luminescence of some materials
- to do photochemical action (to expose a film)
- to initiate chemical reactions
- to do a biological action.

2. Attenuaton and absorption of beam of IR. Types of interaction of IR with matter

Intensity of beam of IR falls proportionally to the square of increase of distance from its source (law of inverse squares). For example, the increase of distance from a source twice diminishes beam intensity in four times (fig. 4).

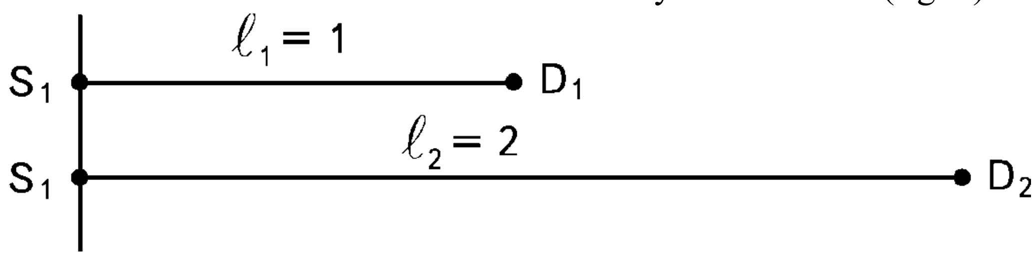

Fig. 4. The change of intensity of stream of radiation is inversely proportional to the square of distance from its source. D_1 and D_2 is intensities of the beam in the distance l_1 and l_2 from a source consequently. $l_2 = 2l_1$, $D_2 = ¼D_1$

Mathematically this conformity is expressed by equation:

$$D_2 = D_1 \times l_1^2 / l_2^2$$

where D_1 is intensity of radiation beam in the distance from the source of l_1, D_2 is intensity of radiation beam in the distance from the source of l_2.

Conformity of change of intensity of beam with increase of distance is used, usually, as one of important factors of radiological defense.

On its way in the matter IR gradually loses energy, passing it to the atoms in the process of their ionization and excitation. The collision of radiation with atoms carries stochastic (statistical) character, that is why intensity of beam in a matter decreases after *exponential law*: on every unit of thickness of homogeneous matter (absorber) the same part of radiation is absorbed. If in the first unit of thickness of layer of matter 1% from 100 units of intensity of radiation is absorbed, there will be 99 units on a next layer, from what 1% will be absorbed in this layer. Continuation of such calculation will show that after passing of stream through 10 units of thickness of this matter 90.45 units of intensity of stream will remain (fig. 5).

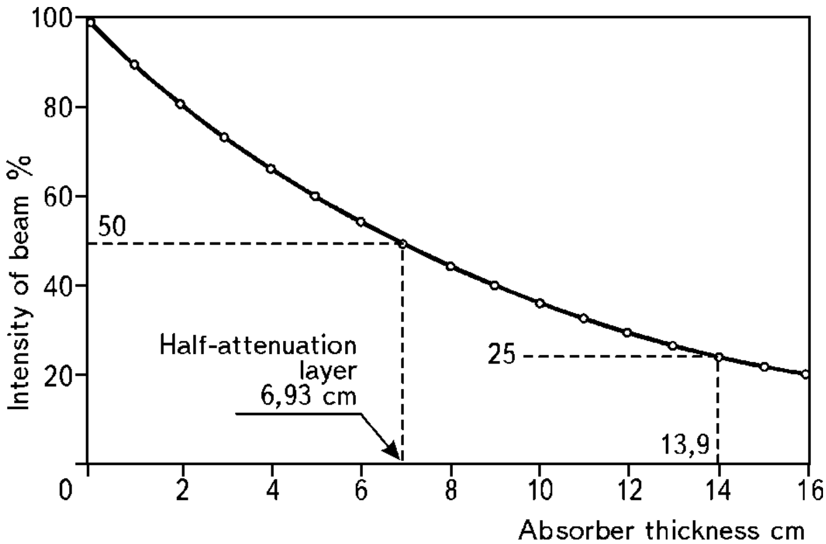

Fig. 5. Conformity to law of falling of radiation beam intensity in a matter

Fully clearly, that with the increase of specific density of matter probability of collisions of radiation with atoms grows, i.e. ability of matter to attenuate the beam of radiation depends on its specific density. Otherwise talking, a matter with high specific gravity will attenuate the beam of radiation more intensive than with low one. For this reason for protecting from a radiation they use such materials as concrete, in particular barite-concrete (here is ta concrete with content of insoluble compound of barium — barium sulfate), lead, impoverished uranium and others like that. For quantitative description of attenuation ability of materials they usually use two indexes: *linear coefficient of attenuation* and *half-value layer (HVL)*.

Linear coefficient of attenuation is index of degree of the relative attenuation of beam of radiation of the layer of matter 1 cm in thickness.

HVL is absolute value of thickness of layer of matter which provides attenuation of the beam twice.

Fully clearly, that a value of these indexes will be different not only for different materials but also for the same material depending on a kind and energy of radiation.

For determination of attenuation ability of protective device from any material they use an index which carries the name *leaden equivalent* (in *millimeters of thickness of lead*). Leaden equivalent is thickness of layer of lead, which attenuates beam of photonic radiation in the same measure, as well as the given layer of material.

The charged particles are ionize the atoms of matter mainly *directly* at incidents with them. Such mechanism of ionization carries the name of *direct ionization*. At passing of particles without a charge (neutrons) or photons through a matter ionization of atoms takes place mainly under the action of the secondary particles (orbital electrons or nuclear particles) which are beaten out from an atom at the first interaction of uncharged IR, and that is why such type of ionization is named *indirect ionization*.

There are 5 types of interaction of photons with the atoms of matter:

1. coherent (Thomson's, classic) scattering,
2. Compton's scattering (Compton effect)
3. photoelectric effect
4. formation of pair (or triplet) and
5. photodisintegration.

Coherent scattering consists in that a falling photon in the field of atom changes direction of motion (scattered), not losing kinetic energy (fig. 6).

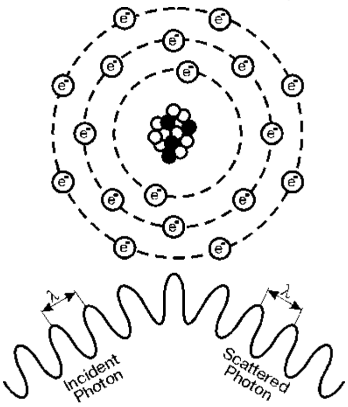

Fig.6. Scheme of coherent (classic) scattering of photons of x-rays on the atom of matter

The change of motion trajectory of photon can take place under any corner, up to reverse direction (*reverse scattering*). In radiological defense this circumstance is taken into account at arranging of workplaces of personnel: after the back of operator (for example, radiologist) in the distance less than 2 meters it must not be wall or any massive objects which the reverse scattering will go from.

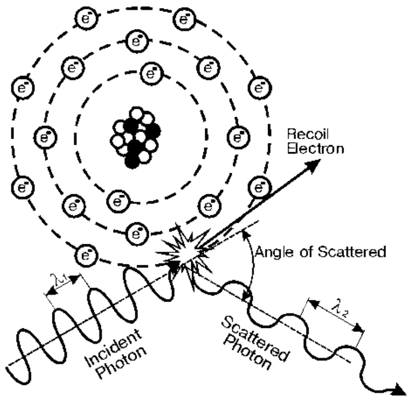

Fig. 7. Scheme of Compton scattering of photons in a matter

Compton scattering is change of direction of motion of photon with the simultaneous loss of part of its energy as a result of direct collision with the electron of atom (fig. 7). As a result of such event an electron acquires an acceleration and leave an atom, becoming the «shell» of the second (indirect) ionization of surrounding atoms. Angle of rebound of electron to direction of motion of photon at small energies varies in enough wide limits (wide scattering), diminishing at the increase of energy of falling photon. At energies of photon over 1 MeV the secondary electrons practically all move along the trajectory of beam of photons, increasing the delivered energy in depth of the exposed matter. As a result absorbed energy in the superficial layers of matter can be less than this one on some depth, depending on initial energy of photons. The level of most absorbed energy in the matter at such situation is named peak of dose. In addition, with the increase of energy of photons probability of reverse scattering of radiation diminishes.

Photoelectric effect is a photon at a collision with electron of atom passes all energy to it (absorbed by an electron), and electron gets sufficient energy to abandon an atom. Such electron carries the name photoelectron (fig. 8). Its vacant place is occupied by other electron from an outer electronic shell, radiating here a quantum of characteristic X-ray.

Formation of pair is process at which a high-energy photon ($E \geq 1.022$ MeV) is transformed in the pair of particles: electron and positron, that is converting of energy into a matter is happened (fig. 9).

Such event takes place only in the field of atom, which has the role of «catalyzer» in this process.

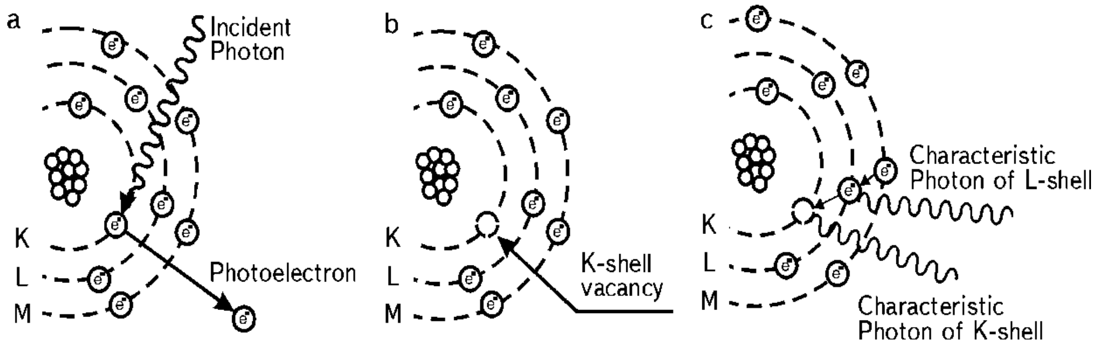

Fig. 8. Scheme of the successive stages of photoelectric effect. a) — collision of falling photon with the electron of K-shell and outbreak of the latter outside an atom; b) — a vacancy on K-shell оболонці; c) — filling of vacancy of K-shell by an electron from L-shell and radiation photon of characteristic X-rays of K-shell by it, and farther filling of formed vacancy of L-shell by an electron from M-shell with the radiation of characteristic X-ray photon of L-shell

About *photodesintegration* of atom nucleus by high-energy photon we already mentioned above. It is needed to add that consequence of photodesintegration is become origin of unstable (usually short-life) atom. At treatment of oncologic patients by megavoltage radiation of linear accelerator (E = 18–23 MeV) in exposed tissues a trifle of such unstable ultrashort-life atoms which almost fully are disintegrated during ten minutes after completion of exposure to ionizing radiation.

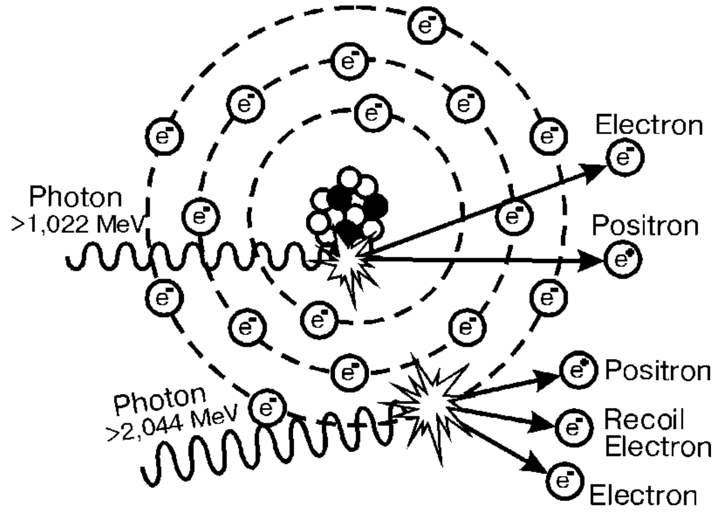

Fig. 9. Formation of pair of particles in the field of atom from high-energy photon — electron and positron. If such event takes place on an orbital electron, a triplet appears, as the knocked electron joins to the pair of particles

Frequency of collisions of photon beam with the atoms of media depends on their mass, charge and energy. Obviously, particles with greater mass and electric charge have chances on more frequent acts of interaction with atoms, and that is why on their trajectory there will be a lot of the ionized atoms on *unit of run-length* in a media (fig. 10).

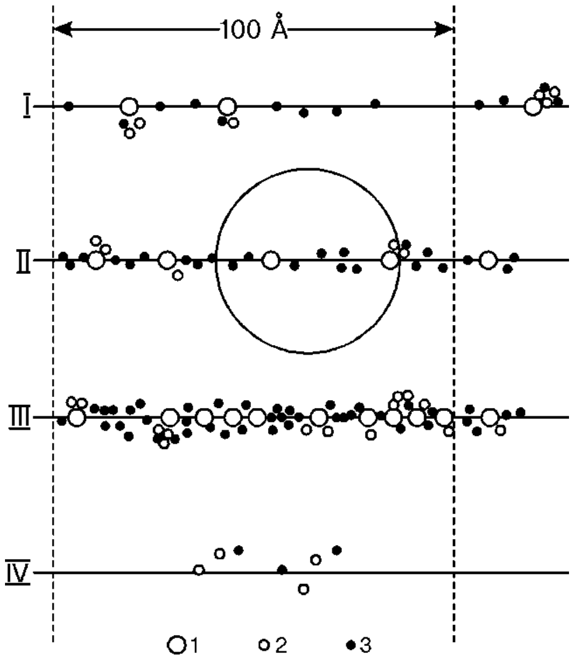

Fig. 10. Scheme of distances of trajectories of different types of IR with distribution on them of acts of interaction with a substance. 1 — primary ionization; 2 — secondary ionization; 3 — excitation; I — photon with energy of 40 keV, II — beta-particle with energy of 90 keV; III — alpha-particle with energy of 4 MeV; IV — gamma-quantum with energy of 1.25 MeV.

In such cases say about *high density of ionization*, and, accordingly, radiations are named high-dense (protons, neutrons, alpha-particles).

In a counterbalance to them, radiation with a small charge and small mass (electrons, positrons) and especially without a charge and mass of rest (quanta of gamma- and x-radiation) cause ionization of media *of low density* and that is why are named low-dense.

There is a feed-back dependence between energy of IR and density of ionization of media by it: with growth of energy ionizing ability of IR diminishes.

It is important to mark, that with the density of ionization the physical, chemical and biological consequences of interaction of IR with the exposed media are linked — the higher density of ionization, the more considerable consequences, that from the point of view of problems of radiation medicine means that *high-dense IR make a considerably anymore threat*.

Run-length of IR in a media is average general way which elementary particle or photon can pass in it. It depends on mass, charge and energy of IR and density of the media. Fully clearly, that high mass and charge of IR accompanied with a short run-length. Also clearly, that in the medias of specific high-density run-length of IR is also shortened due to rapid absorption of their energy by media.

3. Dosimetry

Dosimetry is branch of physics from the problems of determining the amount and distributing of absorbed energy of IR in different medias. Fundamental in dosimetry is a concept *of dose*. Much time passed — a few decades — from the moment of opening of x-rays to formulation of concept of dose by scientists in a that kind which is accepted presently. In something the simplified kind it is determined so: *a dose* is energy which is transferred to the *unit of mass* of matter by the beam of radiation.

It follows to pay a regard to that a dose is not quantitative description directly of the beam of radiation (other measures are used for this purpose, for example, density of beam). It quantitatively characterizes a factor which draws certain effects in the exposed media and amount of which aught proportional to the level of these effects. Such factor is energy which is absorbed in a media from the beam of radiation.

Other important aspect of the accepted definition of concept of dose is that for a dose is accepted not whole energy absorbed by matter, but its amount in the unit of mass.

It would seem that in biology and medicine is useful to take into account the general amount of energy, absorbed in a living matter, as a level of biological effects in relation to an integral individual obviously depends exactly on this magnitude. In fact a priori is clear, that *local exposure* to ionizing radiation of animal or man will have less fatal consequences, than *total exposure* to ionizing radiation on condition that in both cases there is on the average identical energy on unit of mass of the radiation-exposed tissues, that, otherwise speaking, doses will be identical in both cases, and biological effects of exposure to ionizing radiation are different. And this circumstance seems paradoxical, taking into account that we need such measure of action of radiation which would do possible the foresight of level of consequences of irradiation, that consequences must be a function from the accepted measure of action.

The concept *of integral dose*, which was determined as a *general amount of energy, absorbed in all of the radiation-exposed tissue*, was entered at one time. But presently this concept for many reasons has a historical value only, main from which is a problem of determination of size of integral dose and dependence of consequences of irradiation of biological object from numerous other factors of physical or biological nature, part of which even and until now remains uncertain.

Direct determination of absorbed energy from the beam of radiation in living tissue is the undecided task, because living tissue from the point of view of physics is the system with well-organized streams of energies, the levels of which in physiology terms on a few orders are exceeded the level of that energy which is taken in tissues even at a lethal exposure to ionizing radiation. It is known the phenomenon which is marked as a paradox of biological action of radiation is one of factors of doing of the direct measuring of energy, added by the stream of radiation in living tissue impossible.

Taking into account it, the direct measuring of dose is carried out in certain physical or chemical medium which is name *dosimetric model medium*. As such media are used gases, solids and liquids. In accordance with it *detectors* of devices, intended for measuring of dose is *dosimeters* are distributed on *gas, solid and liquid.*

On figure 11 the principle scheme of structure of radiation dosimeter is shown.

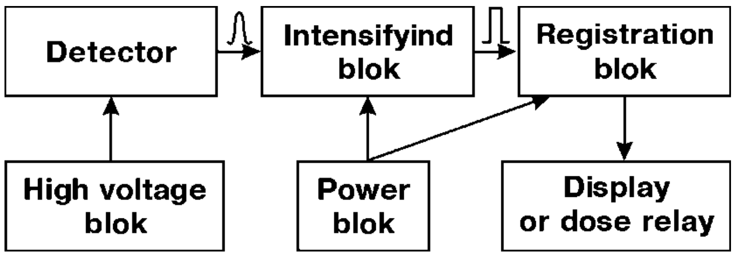

Fig. 11. Principle scheme of structure of radiation dosimeter

It follows to pay attention, that material of detector, a signal, proper a by value measureable radiation dose, is formed in which, and is a model medium.

Determination of radiation dose, that energy, passed to the medium, is carried out on the basis of measuring of amount of certain effects which take a place in a model medium at interaction of IR with the atoms of this medium. On the type of such effects radiation detectors and methods of dosimetry are distributed on:

- *ionizing,*
- *scintillation,*
- *thermoluminescent (TL),*
- *film (photo),*
- *thermal and*
- *chemical.*

An *ionization chamber* with two electrodes (fig. 12), filled air, serves as a detector at an ionization dosimeter. The sizes of chamber, that a volume of air in it varies from 1 см^3 up to 1000 см^3, that is determined by necessary sensitivity of dosimeter: (greater volume provides a greater sensitivity) and space accuracy of the measurement (small volume provides space accuracy). Photons and particles which are entered in chamber transfer energy to atoms of air as a result of what the last are ionized. Free ions move to the electrodes of chamber creating a current in an external electric circle. The size of current is measured by certain device and after it is possible to calculate the amount of energy which is absorbed from the beam of photons by air in a chamber, i.e. *dose in air of chamber*.

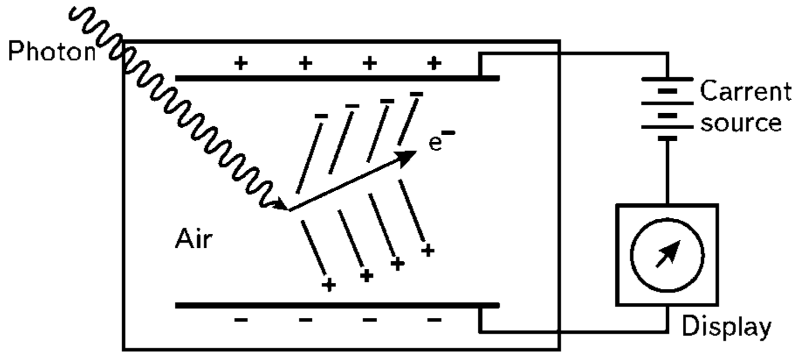

Fig. 12. Principal scheme of design and action of ionizing dosimeter

Ionizing dosimeters due to the row of important reasons are most common in dosimetry which serves to the necessities of medical practice.

Luminescent dosimeter as detector has scintillator (single-crystal of NaI, special plastics, scintillation liquids) to which photoelectric multiplier densely adjoins (PEM). Energy of radiation in scintillator transforms into light photons, which in PEM excite electric impulses which are registered by the external blocks of dosimeter. The amount of impulses is proportional to absorbed energy in scintillator, i.e. to the dose.

Near on principle to scintillation dosimetry there is *thermoluminescent dosimetry* (TLD), discovered and developed during 70^{th}. The method presently is widely used for the estimation of level of exposure to ionizing radiation of personnel, calibration of radiation output of therapeutic sources, measuring exposure to ionizing radiation of patient's body at x-ray procedures, etc. For this dosimetry a little pill or column (3–10 mm in diameter) of LiF or other material (for example, AlO_2, CaF_2) serves as a detector the atoms of which are able to accumulate absorbed energy in electronic shells on long time and then to give it as a light flash at heating. Such dosimeters allow to measure doses in a large range even 8 orders.

Radiation dose from a *photonic radiation measured in the air of ionizing chamber* is named *exposure*. A unit of exposure is Roentgen (R) *which is* non-system unit, and coulomb per kilogram (C/kg) — system unit (SI).

An exposure per time unit (*exposure rate*) is measured in *Roentgens per second* (R/s), *Roentgens per minute* (R/min) *Roentgens per hour* (R/h).

For determination of energy, absorbed from the beam of photons in any media, including different types of tissues of organism, the concept of *absorbed dose* is used.

Absorbed dose is the amount of energy of photonic radiation absorbed in unit of mass of any media:

$$D = E/M$$

where D is absorbed dose, E is total amount of absorbed energy and M is mass of exposured medium.

Absorbed dose in this point of media is accounted by formula:

$$D = f \times X$$

where f is f-factor, X is exposure.

f-factor is coefficient of relation of exposure and absorbed dose depended upon energy of photons and density of the exposed medium. From the same stream of radiation an environment with a greater density absorbs greater energy, than environment with less density. So, bones will absorb a greater dose, than muscles, and last — than fatty tissue (f-factor for photons with energy of 50 keV in these environments is 3.60, 0.94 and 0.66, accordingly).

But magnitude of the absorbed dose does not always can be the measure of the expected biological effect. The point is that the different types of radiations, as already marked, have different character of distributing of acts of ionization of atoms of tissue in its volume, or different linear energy transfer (LET). Heavy particles with a large charge (e.g. alpha-particles) on the way in tissue ionize atoms densely and it is drawn to greater their biological activity (greater damaging action) at the identical passed energy on unit of volume of the tissue that is at equal absorbed energy. With the purpose of taking into account of this phenomenon the concept *of dose equivalent* is entered (H):

$$H = D \times QF$$

where D *is* absorbed dose, Q_F is quality factor.

Quality factor of radiation (Q_F) is quantitative description of each type of radiation depending on density of ionization of medium. Dose equivalent already is not real physical size and it is relatively an abstract index (coefficient), appointed to estimate quantitatively biological risks of action of different types of radiation.

But also introduction of concept of equivalent dose did not decide all of problems, related to the desire to have the unique universal measure of exposure to ionizing radiation man risks at different conditions. This challenge of practice of radiation defense of man resulted in introduction of concept *of effective dose*.

Effective dose (E) is the sum of productions of dose equivalents (H_T) in separate organs and tissues on *tissue weighting factors* (W_T).

$$E = SW_TH_T$$

Organ or tissue weighting factor (W_T) defines the part of risk of stochastic effect from the irradiation of this organ or tissue to the general risk at the uneven irradiation of body. Values of W_T for tissues and organs defined from experiments and from the theoretical considerations.

Effective dose is abstraction, but its practical attractiveness consists in possibility to define a probable total risk from the exposure of different areas of body at different absorbed doses in periods of time, even considerably delayed one from another. Values of effective doses are summing for one man during whole his life and this total magnitude is accepted as the index of *accumulated risk* of exposure.

The concept of *collective effective dose* (Ep) for the estimation of negative meaningfulness of the dose loading on all of population of people is defined:

$$Ep = \sum E\ .$$

Thus, presently we have such *radiation doses* in consumption:

• exposure
• absorbed dose
• dose equivalent
• effective dose
• collective effective dose.

For determination of the values of these doses next units are used:

• *coulomb per kilogram* (C/kg) and Roentgen (R) for exposure
• *rad and Gray* (Gy) for absorbed dose
• *Sievert* (Sv) for dose equivalent and effective dose
• *Sievert-man* (Sv-man) for collective dose.

The name of unit «rad» is abbreviation from «**R**adiation **A**bsorbed **D**ose». Its value equals 100 ergs of energy, absorbed in one gram of a matter. The same origin has name of the unit «rem» — «**r**oentgen **e**quivalent **m**an»

Correlation of values of units of dose:

$$1\ Gy = 100\ rad \text{ and } 1\ rad = 10\ mGy = 1\ cGy.$$

For a photonic radiation with middle and high energy for the practical necessities of radiation defense it is possible to accept:

1 R ~ 1 rem ~ 1 rad ~ 1 cGy.

4. Radioactivity

In 1896 H. Becquerel discovered the phenomenon of emission of radiation by uranium, similar to X-rays opened in the year before by W.K. Roentgen. At proposition of M. Sklodowska-Curie, who together with H. Becquerel was performing investigations, it was named *radioactivity*. Afterwards other natural *radioactive* chemical elements were discovered, and in 1934 daughter of M. Sklodowska-Curie Irene Jolio-Curie together with her husband F. Jolio-Curie discovered possibility to get radioactive elements artificially: the phenomenon which was named *artificial radioactivity*.

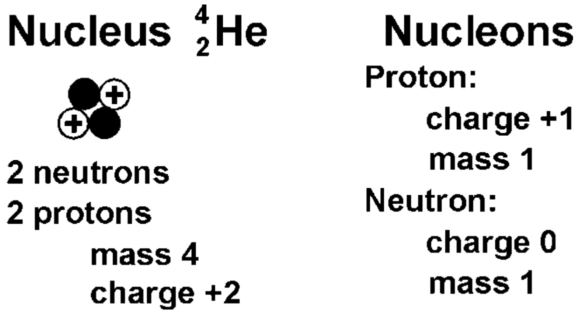

Fig. 13. Physical characteristics of nucleons: protons and neutrons.

As known, nucleus of atom consists of elementary particles with the general name of *nucleons* (fig. 13). To them positively charged *protons* (mass 1 and charge +1) and *neutrons* (mass 1 and charge 0) are referred. The amount of protons and neutrons in a nucleus makes its mass. The general amount of protons determines the total electric charge of nucleus and predetermines the physical and chemical features of element. For every element only certain amount of protons in nucleus of its atoms is characteristic. The change of their amount means in a nucleus means, that it became the nucleus of atom of other element. The change of amount of neutrons in a nucleus changes his mass only, not drawing the change of its belonging to this element. Such variants of nucleus of atom of chemical element with the different amount of neutrons got the name of its *isotopes* (taking the same place), as present the same element and that is why located in one position in the periodic table of chemical elements. The certain isotope of element is named *nuclide*, but these two terms are usually used and as synonyms.

Table 1

Isotopes of hydrogen

Symbol	Protons Z	Neutrons N	Atomic number A	Name
^{1}H	1	0	1	Protium

^{2}H	1	1	2	Deuterium
^{3}H	1	2	3	Tritium

As the example in a table 1 the isotopes of hydrogen (H) are adduced with the masses of nucleus in 1, 2 and 3 units. The first isotope has the name of *protium* (protium is *simple* (lat.)). It is the most widespread isotope of hydrogen in nature (and whole Universe), the nucleus of which consists only of 1 proton (neutrons are absent), that is why its mass is 1 and charge +1. The second isotope is *deuterium* (deuterium is the *second*) with atomic mass 2. At this isotope the nucleus consists of 1 proton and 1 neutron. Such nucleus is energetically stable, as well as in protium, that is why these two isotopes are named *stable*. Deuterium enters in the composition of molecule of *heavy water* in place of protium. The last is the third isotope (tritium is the *third*) has atomic mass 3 (in nucleus are 1 proton and 2 neutrons). The nucleus with two neutrons and one proton is energetically unstable, in course of time it disintegrates with emission of beta-particle. Such nuclides are named radioactive. All three isotopes of hydrogen have natural origin.

Unlike hydrogen, most elements have one natural isotope only, as for example, phosphorus (^{31}P). All its other isotopes (fig. 14), in particular with mass of nucleus 30 (^{30}P) and 32 (^{32}P), have artificial origin.

$${}^{A}_{Z}X \qquad {}^{30}_{15}P \qquad {}^{31}_{15}P \qquad {}^{32}_{15}P$$

Fig. 14. Isotopes of phosphorus: isotope with atomic mass 31 (^{31}P) — natural, two other ^{30}P and ^{32}P — artificial. Form of writing of isotopes: X — symbol of element, A — atomic mass, Z — charge of nucleus (a number of element in the periodic table of elements).

Presently we know more than 2000 radioactive isotopes (radionuclides) from them approximately only 300 are of natural origin.

The most widespread natural radionuclides which bring in the most contribution to the non-anthropogenic exposure of people is carbon-14, potassium-40, radon-222, radium-226, uranium-235, uranium-238 and thorium-232 (fig.15).

Carbon-14 is constantly synthesized in atmosphere under action of ultraviolet rays from stable nuclide ^{16}C and enters in plants in the process of exchange of matters, and farther with a vegetable meal enters to organism of man. This nuclide brings in up to 15% tot natural internal exposure. In biological objects, while the exchange of matters is supported in them, these two isotopes of carbon are in equal correlation. After dying of organisms radiocarbon-14 disintegrates without addition, and correlation is gradually violated more and anymore, that enables, measuring the degree of this violation, to set time of death of plants and animals or antiquity of materials of vegetable and animal origin from archaeological finds.

Natural Radionuclides

$$^{232}_{90}\mathrm{Th} \quad ^{235}_{92}\mathrm{U} \quad ^{238}_{92}\mathrm{U} \quad ^{226}_{88}\mathrm{Ra} \quad ^{222}_{86}\mathrm{Rn} \quad ^{40}_{19}\mathrm{K} \quad ^{14}_{6}\mathrm{C}$$

Fig. 15. The most widespread natural radionuclides

Potassium-40 aroused up together with a matter which our planet was formed from, and saved to this day, so the middle age of its atoms makes about 1.8 billion years. The nuclide is evenly dissipated among other isotopes of potassium, in particular and in the organism of people. Contribution in the internal natural irradiation of man from it makes about 80% from all internal natural exposure. Other natural radionuclides make contribution mainly in external natural exposure (contribution so-called *natural radiation background*).

The nuclei of atoms of radioactive elements are unstable in energy, from what they are decayed with the emission of energy as gamma-quanta and emission of elementary alpha- or beta-particles (electrons or positrons). To every radioisotope certain type of decay is peculiar which takes place at the characteristic scheme.

Alpha-decay. A nucleus emits alpha-particle (2 protons and 2 neutrons, charge +2, mass 4), transforming on the nucleus of another element which is in the table of elements on 2 positions left («left shift»), as its charge is below on 2 units, than at a «maternal» nucleus. Except for the particle here gamma-quantum can be emitted additionally. Classic example of such type of radioactive decay is decay of radium-226 (fig. 16 and 17).

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$$

Рис. 16. Principal scheme of alpha-decay of ^{226}Ra. Nucleus of this radionuclide at decay emits alpha-particle (mass 4 and charge +2), in result of what nucleus of new element — ^{222}Rn is formed

Beta-decay. There are two variants of beta-decay is electron and positron. At the first variant nucleus emits either only electron, or additionally and gamma-quantum. An electron in a nucleus appears as a result of transformation of one of neutrons in a proton which remains in a nucleus and emitted electron (*electron beta-decay*) (fig. 18), in the result «daughter's» element is created with the charge of nucleus on unit greater, that is why it stands in the periodic table on a 1 cell more right («right shift»).

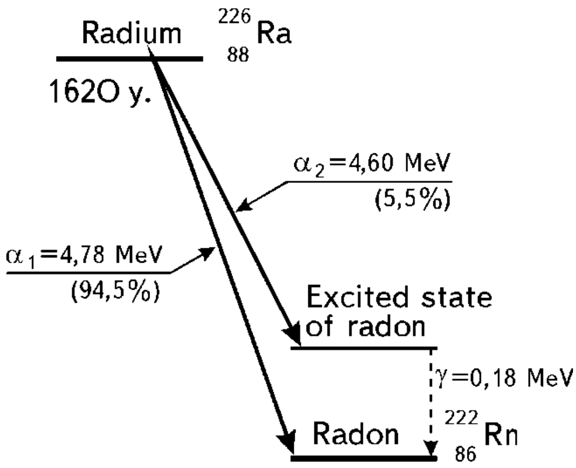

Fig. 17. Scheme of physical processes of decay of ^{226}Ra: 94,5% of this radionuclide nuclei at decay emit only alpha-particle with energy 4.78 MeV, other 5,5% of nuclei emit alpha-particle with energy 4.60 MeV and then is gamma-quantum with energy 0.18 MeV

$$^{32}_{15}P \rightarrow {}^{32}_{16}S + \beta^-$$

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta^-$$

Fig. 18. Principle scheme of electron beta-decay. Nucleus of radionuclide of phosphorus-32 emits beta-particle with a charge –1 (electron), which appears as the result of one decay of one neutrons on two charged particles: proton which remains in the nucleus and emitted electron. As the result, the charge of nucleus is increased on unit, and phosphorus transforms on sulfur

In opposition to it, in another variant of beta-decay one of protons in nucleus decays on emitted positron (*positron beta-decay*) and neutron which remains in nucleus. A nucleus loses unit of charge, and that is why «daughter's» element has position on one cell left (fig. 19).

$$^{30}_{15}P \rightarrow {}^{30}_{14}Si + \beta^+$$

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}\beta^+$$

Fig. 19. Principle scheme of positron variant of beta-decay. The nucleus of radionuclide of phosphorus-30 emits beta-particle with a charge +1 (positron), which forms as the result of transformation of one of protons in two particles: neutron which remains in nucleus and emitted positron. As result, the charge of the nucleus diminishes on unit, and phosphorus grows into silicon

In some cases of beta-decay after emission of electron or positron the nucleus of daughter radionuclide remains in energetically excited (*metastable*) condition and only after some time (sometimes this period is quite significant) comes in the stable state by emitting of excess of energy in the view of gamma-quantum. Such radioisotopes are named *metastable* (fig 20).

$$^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc + \beta^-$$

$$^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + \gamma$$

Fig. 20. Principle scheme of beta-decay with formation of intermediate radionuclide in the metastable state. Nucleus of radionuclide of molybdenum-99 emits beta-particle of with charge –1 (electron) with transformation on radionuclide of technitium-99m, nucleus of which remains in exited (with excess of energy) state during considerable time. Such state of nucleus carries the name of metastable. In future the excess of energy of nucleus emits in a kind of only gamma-quantum and metastable radionuclide of technetium grows into stable nuclide (^{99}Tc).

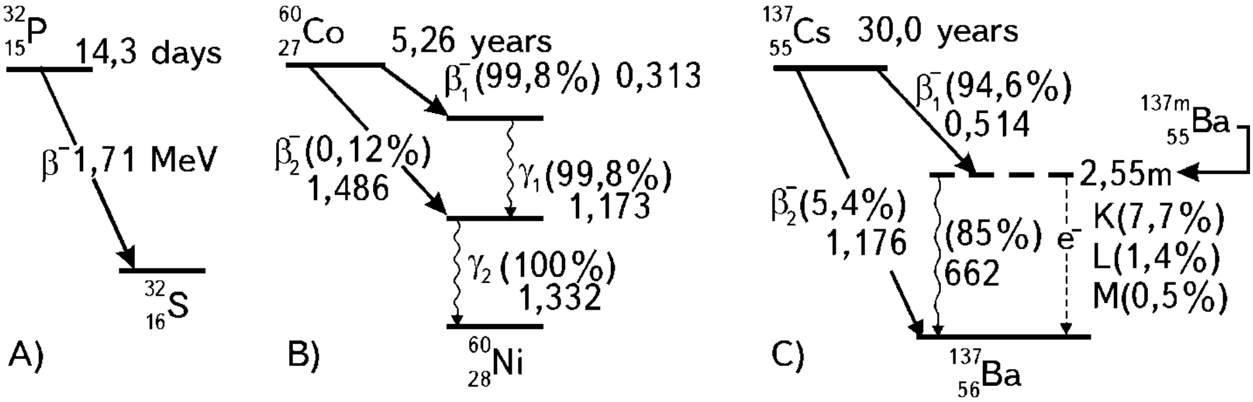

Fig. 21. Schemes of physical processes at beta-decay: **A** — nucleus of radionuclide of ^{32}P at decay emits only an electron with energy 1.71 MeV, growing at once into the stable nuclide of sulphur; **B** — 0.12% of nuclei of radionuclide of ^{60}Co at decay emits an electron with energy 1.47 MeV and gamma-quantum with energy 1.332 MeV, growing into the stable nuclide of nickel. Other 99.8% of nuclei emit electron with energy only 0.31 MeV and consistently 2 gamma-quanta with energy 1.17 MeV and 1.33 MeV; **C** — 5.4% of nuclei of radionuclide of **^{137}Cs** emit an electron with energy 1.18 MeV, growing at once into the stable nuclide of barium. Other 94.6% of nuclei emit consistently electron with energy 0.514 MeV and gamma-quantum with energy 0.662 MeV

On the fig. 21 the scheme of physical processes in nuclei are presented at different types of beta-decay.

K-capture. At this type of decay a nucleus becomes stable as a result of capture of electron from K-shell (the nearest to nucleus) by it. Captured electron conjugates with proton forming neutron. As the result the charge of nucleus diminishes on one unit and maternal radionuclide transforms in the new one with left shift at the table of elements. At such variant a nucleus does not emit energy. Place of a captured electron is taken by an electron from an external shell, what is accompanied with emission of quantum of energy is photon of *characteristic x-ray* (fig 22). So, radionuclides of such type of decay emit only photon radiation (as metastable ones) and that is why they are very interesting for using in radionuclide diagnostics because ensure low exposure of a patient.

$$^{197}_{80}Hg + \bar{e} \longrightarrow ^{197}_{79}Au + h\nu$$

Fig. 22. Scheme of radioactive decay of nucleus on type of K-capture. Nucleus of radionuclide of mercury-197 captures electron from K-shell (the nearest to nucleus). Captured by nucleus electron unites with a proton, forming neutron. As a result, the charge of nucleus diminishes on unit, and mercury grows into gold

Usually on speed of decay radioisotopes are classified on ultra short-living, short-living and long-living. For radionuclide diagnostics they use the first two types: ^{131}I, ^{125}I, ^{99m}Tc, ^{201}Tl, ^{32}P, ^{198}Au, ^{18}F. For gamma-radiotherapy usually gamma-emitted radionuclides are used ^{60}Co, ^{137}Cs, ^{192}Ir. Radionuclides cobalt-60 and caesium-137 also is used in many technological processes.

An act of decay of nucleus of radioisotope is the probabilistic phenomenon, that is why the amount of radioisotope in course of time evenly diminishes according to *exponential law*: equal parts of absolute amount of nuclei, which was at the beginning of such interval, disintegrate in even time domains. Otherwise speaking, the relative amount of decays of nuclei of radionuclide for time unit remains permanent, despite on decrease of amount of nuclei in course of time as a result of their decay (fig. 23). This conformity to law carries the name the *law of radioactive decay*.

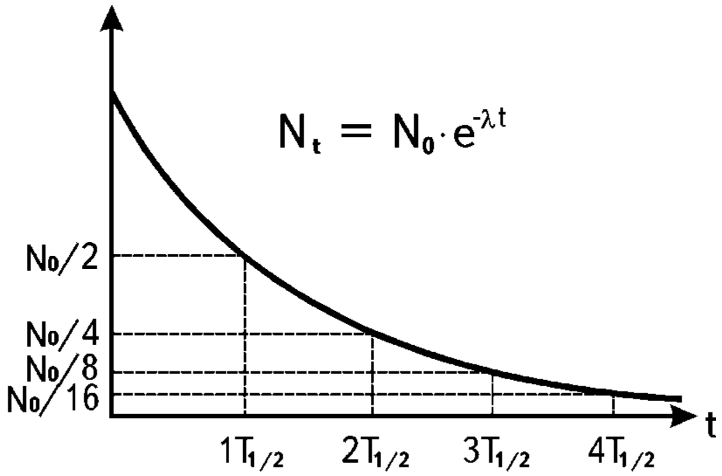

Fig. 23. Law of radioactive decay. N_0 is initial quantity of radionuclide, N_t is rest of radionuclide after interval of time **t**; $T_{1/2}$ is half-life of radionuclide, **e** is base of natural logarithm; λ is constant of decay

Every radionuclide has the characteristic speed of disintegration of nuclei, the measure of which is *half-life* ($T_{1/2}$) and *constant of decay* (**λ**).

Half-period ($T_{1/2}$) is time of decay of half of initial amount of nuclei. *Constant of decay* (λ) is relative part of nuclei of radionuclide, which decays for every time unit. Correlation of these criteria is mathematically expressed by such equations:

$$T_{1/2} = 0{,}693/\lambda, \qquad \lambda = 0{,}693/T_{1/2}$$

Furthermore such criterion sometimes is used as *mean time of life of nuclei of radionuclide* Θ, what is determined after such correlation:

$$\Theta = 1{,}44 \times T_{1/2}.$$

5. Radiometry

As absolute amount of decays of nuclei for time unit strictly proportional to presently available amount and thus in course of time diminishes proportionally to diminishing of amount of radioisotope from its continuous decay, for *measure of amount of radionuclide* is accepted value which is named *activity (*not to mix up with «radioactivity») and which is *the absolute amount of decays of nuclei in given sample for time unit.*

Units of activity are *Becquerel* — Bq and *Curie* (Ci).

1 *Becquerel* is amount of radionuclide, in which a 1 nucleus decays per second (1 decay/s).

1 *Curie* is an amount of radionuclide, in which 3.7×10^{10} of nuclei are decaying for a second ($3{,}7\times10^{10}$ decays/s).

In medical practice they use derivative units:

kBq = 10^3 Bq; *MBq* = 10^6 Bq; *mCi* = 10^{-3} Ci; *μCi* = 10^{-6} Ci.

For measuring of the amount of radionuclide they apply devices, that have generalized name *radiometers* (fig. 24). In the ideal, the task of radiometer is measuring of activity of sample of radionuclide, i.e. count of amount of decays of its nuclei in time unit. As a photon or elementary particle emits at decay of nucleus of radionuclide, their count and becomes way of count of amount of decays, i.e. determination of activity of certain sample of nuclide. Consequently as detector in radiometer there must be a device capable to create a signal on its output on the sign of hit in its volume of photon or particle. Such devices carry the name of *counters of radiation*. On their output an electric impulse, or simply impulse, is created on the sign of hit in it of photon or particle. The most wide-spread counters of radiations are *scintillation counters*.

Clearly, that counter registers only part of radiations which appear at decay of nuclei of radionuclide, as so radiations are distributed in a spherical volume in which a meter occupies only small part. This circumstance requires at measuring of activity severely to keep the maintenance of constancy of geometrical conditions of measuring of different samples of radionuclide. But also from a number of particles which got to the volume of counter, for diverse reasons (physical and statistical), only their part will be registered, magnitude of which characterizes *efficiency of counter*.

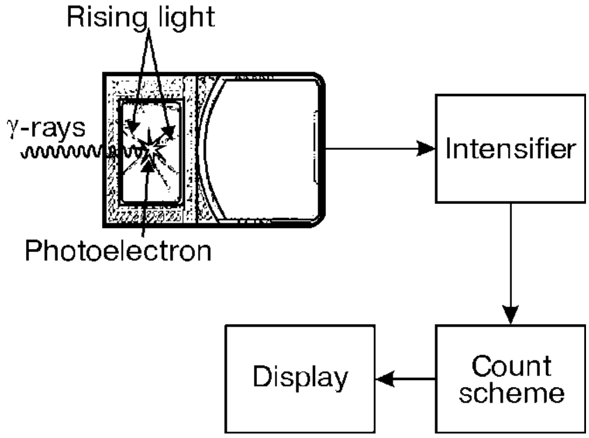

Fig. 24. Principle scheme of scintillation radiometer

But in practice all problems of nuclear medicine and radiation hygiene are solved, as a rule, by measuring of *relative activity* of radionuclide, under which they understand the relation of amount of impulses registered in the same moment of time in different parts of space (namely in different biological samples or above different sites of a body) or in different moments of time above the same anatomical part (organ) of patient's body. Also presence of contamination of media (different objects, surfaces, equipment) by radionuclides and its relative degree approximately can be estimated by the amount of the impulses registered by a radiometer in unit of time or certain interval of time.

6. Natural radiation background

During all history of becoming and existence every living creature on the Earth tests is undergone to constant exposure to ionizing radiation from the natural sources of IR: cosmic rays, radiation of the earth's crust and natural radionuclides which are contained in an organism. In common this omnipresent and pervasive beam of IR is named *natural radiation background* (NRB)*, or natural background*.

Cosmic rays are elementary charged particles with ultra-high energy (up to 10^{18} eV) from interstellar space. Protons, alpha-particles and nuclei of easy elements are included in their composition. Coming into collisions with molecules of earth's atmosphere primary cosmic rays create stream of secondary and tertiary radiations, amount of which grows in atmosphere up to the height 20–16 km, whereupon the stream weakens through absorption by atmosphere. At the sea level cosmic rays create the dose of irradiation on the average in 300 μSv per year (0.3 mSv/yr), and in mountains is in once or twice more high (at the level of high tops up to 4500 μSv/yr). For one trip between Paris and New York every passenger of airplane gets a dose in 50 μSv (flight during 7.5 hours on height of 10–11 km). The general dose of exposure of humanity, predetermined by air trips, makes a collective dose approximately in 2000 Sv-man in a year.

Radiations of the earth's crust consist of gamma-rays of radioactive elements: uranium-235, uranium-238, thorium-232 and products of their disintegration, in particular radium-226, radium-224, rubidium-87. They are sources of external exposure of man. The dose of external exposure of man from earthly radiation constitutes 300–600 μSv/yr (on the average 0.5 mSv/yr), but a 3% population of the Earth are living in regions with exposure rate of 1000 μSv/yr, and 1,5% is up to 1400 μSv/yr and even higher. In Brazil on the shore of Atlantic Ocean there is resort township of Guarapari, the population of which is about 12 thousand persons, with beaches from quartzite sand, on which approximately 30 000 persons resting annually. On the separate areas of those rich on thorium beaches radiation reaches up to 175000 μSv/yr and on streets of the city 8000–15000 μSv/yr. In India in the state Kerala on the narrow strip of coast, stretched out on a 55 km, approximately 70 thousand of population lives. Investigations showed that a middle dose on this territory made 3800 μSv/yr and separate inhabitants get the dose up to f to 17000 μSv/yr, that in 50 times exceeds a middle dose on the Earth. There are other places on Earth with a considerably increased radiation background from IR of soils.

In a concrete and brick, which are made with the use of mineral raw material (sand, cement, macadam), usually, content of radioactivity is increased (in some macadam — in dozens times), that is why in houses from such materials radiation background, clearly, increased in comparing with buildings from wood. The concentration of radon is also considerably increased in them.

The product of decay of radium-226 is radioactive gas alpha-emitter radon-222 which has a half-life 3.7 days and that is why it can drain through cracks from the depths of earthly breeds on a surface and farther to pass to the atmosphere. With air a radon-222 enters lungs of man, creating their *inhalation* exposure. In addition, at decay this nuclide transforms in RaD, hard product, which is put aside in tissues of lungs and, by-turn, slowly grows into polonium, also hard product and also alpha-emitter. Consequently, a radon-222 is the source of serious risk of origin of the radioinduced lung cancer.

Other important source of inhalation exposure is a carbon C-14, beta-emitter of atmospheric origin.

Exposure of man from internal natural sources usually is 20% from a general dose on soft tissues from a natural radiation background. The main source of natural internal exposure is radionuclide of earthly origin potassium-40 which enters an organism with foods.

After the estimations of United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR) (2001) constituents of natural radiation background, variation of doses and middle doses of Earth population exposure from them are next (**μSv/yr**):

- cosmic rays (0.3–1.0) **0.4**;
- gamma-radiation of the Earth's crust (0.3–0.6) **0.5**;
- inhalation (mainly radon) (0.2–10.0) **1.2**;
- internal irradiation (mainly K-40) (0.2–0.8) **0.3**;
- **together (1.0–10.0) 2.4.**

7. Artificial sources of IR. Factors, methods and resources of radiologic protection

IR play very important role in almost all of spheres of human activity: science, biology, veterinary, medicine, agriculture, industry, powers. Various and numerous chemical reactions take place for the action of IR at considerably lower temperatures and pressure. IR is applied for sterilization of medical wares and materials, medications, food products, etc. Action of IR is used for getting of mutations of plants for creation of their new varieties and new strains of micro-organisms.

For providing of all of the adopted necessities the large variety of artificial sources of IR, in which the radiations of different type are generated with different energies and different powers of dose, are created. The sources of IR can be vehicles and devices of energetic, industrial, scientific and medical setting (e.g. apparatus for x-ray structural analysis, electronic microscopes, x-ray therapeutic and diagnostic machines, linear and cyclic accelerators of electrons, cyclic accelerators of protons, etc.), in what IR appear due to converting of electric energy into kinetic one of the charged particles or x-rays. Such devices generate IR only at their plugging in the network of electric current. Sources of IR of other type contain different type and different amount of radionuclides, as for example, gamma-defectoscopes, gamma-therapeutic machines, isotopic sources of power supply (in particular for space vehicles) and great number of radioisotope sources of IR in a view of air-tight capsules for the most various necessities. Such sources require continuous attention from the point of view of radiation safety.

The special sources of possible exposure to ionizing radiation are the nuclear power settings — nuclear reactors of nuclear power plants, submarines and ships.

All factors of radiological protection can be generalized in three categories:

- by time,

- by distance and
- by shielding.

Protection by time factor is realized in different variants by regulation of time of presence of personnel in the sphere of action of radiation, which exclude possibility of exceeding of allowed levels of exposure to ionizing radiation.

Protection by distance is provided by optimum location of workplaces of personnel and ways of its moving on maximal possible distance from a source of radiation.

Protection by time is the most economically acceptable. However, fully clearly, that these factors could be not enough to provide adequate protection of personnel. In addition time factor can be easily violated, if additional mechanisms of its control are absent. Therefore, as a rule, protection by shielding is considered as almost main factor of radiation protection. *Protective shielding* is constructing of various stationary and movable barriers with materials capable effectively absorb ionizing radiation. Protection can be created around a source, equipment of and/or place. In the first case a protective housing surrounds a source, as for example, x-ray tube, in the second — whole apparatus, as in a case of industrial defectoscopes. Defense of workings places are built in build constructions: walls, ceiling or floor, entrance doors, windows between rooms.

Medical x-ray units. They are used for performing fluoroscopy, radiography and radiation treatment (x-therapy). Protection in medical x-ray departments is foreseen both for the personnel and patients. The allowed dose for the personnel is regulated. A modern roentgenologic apparatus provides low levels of personnel exposure structurally, that is why the allowed dose is never exceeded, unless in the cases of gross violation of rules of radiological protection in separate, too rare, cases. Except for structural decisions in relation to an apparatus, for protection of the personnel various additional protective devices and things are used, such as small and large screens from protective materials, personal aprons, gloves from lead rubber and others like that.

For patients diagnostic dose is not regulated, the only *referent diagnostic levels* for every separate examination which serve for optimization of patients exposure and simultaneously to control of quality of x-ray examinations are established. The dose of patients exposure at radiation therapy is prescribed by a doctor depending on the type of disease in limits which provide an optimum medical effect. Sure, that there are rules of decreasing of patients «non-working» exposure, main from which consists in irradiation of only area of body which is diagnosed or treated. Other parts of body, especially gonads, it is necessary to shield too by special facilities of protection (leaden rubber, tubuses).

Non-medical x- and gamma-vehicles. X- and gamma-defectoscopy detection become the generally accepted method of test of nodes and details without destruction of products, appointed to work in hard physical terms, at that providing high reliability. The industrial use of vehicles for radiation defectoscopy requires greater attention to radiological defense than medical x-ray diagnostics, because the workers of industry are weakly acquainted with the features of biological action of radiation and that is why they are willing to underestimate radiation danger, or exaggerate possible risks. In addition, above-mentioned radiation settings in industrial conditions are exploited with the considerably greater loading which increases the risk of their runaway. And finally, the controlled products on such settings are characterized by too wide varying in sizes, construction, materials and level of that creates the considerable level of physical and psychological loading of operators of such settings. Generally and shortly it is possible to assert that the best variant of providing of safety of exploitation of settings of radiation defectoscopy with prevention of radiation incidents or failures is designing of them in special procedure rooms, protected by radiation barriers, and maximal automation of technological process.

Megavolt settings of different destination and structural features. Features of radiation protection of personnel on settings of such are linked with two important circumstances: at first, at energies of radiation over 10 MeV, that cause photo-disintegration of nuclei not simple problem appears of protecting from neutrons, and, secondly, the cost of protective constructions against the radiation of such energies is high. For diminishing of tension of these problems they use maximally effective on such conditions factor of radiological protection by distance.

Open radioactive sources. Such sources, usually in form of solutions of compounds of wide spectrum of radionuclides are used in nuclear medicine for diagnostic and medical purposes, scientific researches and industry for control of some processes. Application of radioactive materials is linked with risks of not only external exposure of people but also with possibility of entering of them in the organism of a man through a skin, digestive and respiratory tracts with next internal exposure. Fully clearly, that on such conditions necessity for the specific measures of radiological protection arises up, directed not only on diminishing of probability of external exposure, but also maximal avoiding of direct contact of personnel with radioactive liquids. Special air-tight boxes for work with such sources and, on possibility, automation of works are used.

Sealed radioactive sources. Such sources of ionizing radiations of different types on used radionuclides, destination, intensity of radiation, sizes and construction and, finally, physicochemical state of encapsulated radionuclide, are almost the most widespread. It can show oneself paradoxical, but these sources more frequent become the factors of radiation incidents on industrial enterprises, in medicine and way of life. Not infrequently losses of similar sources happen through lackadaisical attitude or unsuccessful construction of device in which a radionuclide capsule is mounted. A subsequent fate of air-tight sources is unforeseeable. Each such case is detective history and, as a rule, with a tragic end. As a man has no receptors for feeling of ionizing radiation, subject, but it can be and group of teenagers, and malefactor, and persons from power structures, and workers of enterprise and anyone else, to the hands of which (what) gets heat by touch and brilliant capsule or cylinder, he can not to feel a threat which goes out from that fatal find. Another modern actual problem, linked with seal radioactive sources, is the problem of possible radiation terrorism. Exactly from all expounded reasons and circumstances sealed sources require not only radiological but also physical protection.

Sources are often «lost» during wars and revolutions, for example, after disintegration of the USSR and Yugoslavia, civil wars in Africa, wars in Korea, Vietnam, Iraq. They are revealed on frontier check-points or in large smelters on what radiation monitors are set on.

Now in all states powers of the world requirements for licensing of every source, are set by international organizations for radiation safety: UNSCEA, IAEA, ICRP, that provides possibility to trace its complete cycle from introduction in an action to the eventual burial place. Unfortunately, by such way it is possible to monitor fate of only those sources what are intended for the open practice.

On a conclusion, it should be remembered that IR can destructively influence on a medium, in particular on the biochemical and morphological structures of biological objects, causing in last case pathologic conditions with specific consequences.

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