МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ РЕСПУБЛИКИ БЕЛАРУСЬ

УЧРЕЖДЕНИЕ ОБРАЗОВАНИЯ
«ГОМЕЛЬСКИЙ ГОСУДАРСТВЕННЫЙ МЕДИЦИНСКИЙ УНИВЕРСИТЕТ»

Кафедра общей гигиены, экологии и радиационной медицины

В. Н. БОРТНОВСКИЙ, А. А. ЛАБУДА

РАДИАЦИОННАЯ МЕДИЦИНА

Учебно-методическое пособие
для студентов 2 курса факультета по подготовке специалистов
для зарубежных стран медицинских вузов

RADIATION MEDICINE

The educational methodical text-book
for 2nd year English medium medical students
of the Faculty of preparation of experts for foreign countries
of medical higher educational institutions

Гомель
ГомГМУ
2014

УДК 614.876 (072)=111
ББК 53.6 (2Англ) я 73
Б 83

Рецензенты:
доктор медицинских наук, доцент,
директор Республиканского научно-практического центра
радиационной медицины и экологии человека
А. В. Рожко;
доктор медицинских наук, профессор
заведующий кафедрой общей гигиены
Витебского государственного ордена Дружбы народов
медицинского университета
И. И. Бурак

Бортновский, В. Н.
Б 83 Радиационная медицина: учеб.-метод. пособие для студентов 2 курса факультета по подготовке специалистов для зарубежных стран = Radiation medicine: the educational methodical text-book for 2nd year overseas students of the Faculty of preparation of experts for foreign countries of medical higher educational institutions / В. Н. Бортновский, А. А. Лабуда. — Гомель: ГомГМУ, 2014. — 112 с.
ISBN 978-985-506-677-5

Предназначено для проведения практических занятий по дисциплине «Радиационная и экологическая медицина», разделу «Радиационная медицина» в высших медицинских учреждениях образования Республики Беларусь. Представлен основной учебный материал по радиационной медицине в соответствии с типовой учебной программой, а также практические задания и тестовые вопросы.

Предназначено для студентов 2 курса факультета по подготовке специалистов для зарубежных стран медицинских вузов.

Утверждено и рекомендовано к изданию научно-методическим советом учреждения образования «Гомельский государственный медицинский университет» 26 июня 2014 г., протокол № 6.

УДК 614.876 (072)=111
ББК 53.6 (2Англ) я 73

ISBN 978-985-506-677-5

CONTENT

LIST OF ABBREVIATIONS

AED — Annual effective dose
ARS — Acute Radiation Syndrome
Bq — Becquerel
BR — Background radiating;
ChNPS — Chernobyl Nuclear Power Station
Ci — Curie
CNS — central nervous system
CV — Cardiovascular
DNA — deoxyribonucleic acid
DL — dose limit
EMF — electromagnetic field
EPA — Environmental Protection Agency
FE — fuel element
GAC — granular activated carbon
Gy — Gray
HF — high frequency
ICRP — International Commission on Radiological Protection
IR — ionizing radiation
LD50 — lethal dose
LAR — limit of annual receipt
LET — linear energy transfer
mcR — microroentgen
MWF — a microwave frequency
NCRP — national commission of radiation protection
NFC — nuclear fuel cycle
PED — power exhibition dose
RAL — the Republican admissible levels
RB — the Republic of Belarus
RBE — relative biological effectiveness
RCF — radiochemical factories
R — roentgen
SI — International System of Units
SIR — source of ionizing radiation
SRS — Sharp radiation sickness
Sv — Sievert
Teff — the effective period
TLD — termo luminescent dosimeter
TPS — thermal power-station
UHF — ultra high frequency
UV — ultraviolet
WB — whole body
$\mathbf{W_R}$ — radiation weighting factor
YED — yearly effective dose

THE FOREWORD

The present stage of the development of the society, building of the enterprises of a nuclear fuel cycle, application of new technologies (including those in medicine) are bound to increasing scales of the application of ionizing radiation sources. This tendency enlarges risk of irradiation of the personnel and the population on different scales.

Chernobyl disaster in its sizes and environmental contamination consequences was the largest in nuclear power history. Radioactive substances got to the environment with the average activity nearby 10 eBq. Their greatest quantity (about 70 %) fell out on territory of Belarus. The injury caused to Belarus by Chernobyl disaster, turned the republic territory to a zone of ecological disaster. The appreciable collective dose generated on inhabitants of Belarus because of irradiation by various radionuclides, results in numerous medical consequences of the accident bound to the growth of the case rate and, in particular, to oncologic pathology of a thyroid gland at children and adults, to augmentation of somatic case rate, etc.

Hence, integral part of the preparation process for the medical faculty is detailed treating of mechanisms of ionizing radiation effects on a human body, including a child body, and also coping with the consequences of such influence.

The radiative medicine is in a close connection with biochemistry, molecular biology, pathophysiology, clinical disciplines, physical health and other disciplines. One of the main objectives of radiative medicine is to induce students to understand the interrelation between primary damaging mechanisms of ionizing radiation effects and formation of effects in the shape of the nearest and remote consequences, as well as to understand the ways of prevention and levelling of such effects. A doctor should understand the main principles of comprehensible risk of the influence of such powerful physical factor as the ionizing radiation.

TOPIC 1.
BASES OF IONIZING RADIATION EFFECTS. METHODS OF REGISTRATION IONIZING RADIATION

The motivational characteristic of the theme

The knowledge of the basic characteristics of ionizing radiation, features of radiation interaction with substances of various kinds is necessary for understanding the mechanisms and laws of beam damages formation of a human body and a choice of a protection method against ionizing radiation influence.

The general time of employment: 4 hours

The employment purpose

To learn the characteristics of principal ways of ionizing radiation and basic terminology, features of beam damages formation of a person and dosimetry principles.

Employment problems:

1) to consider the value of radiating medicine in activity of the doctor in connection with radiating conditions which have developed in Belarus;

2) to fix knowledge on bases of nuclear physics;

3) to learn methods of registration of an ionizing radiation;

4) to acquire knowledge about features of interaction of an ionizing radiation with biological structures;

5) to acquire knowledge about main principles of dosimetry and radiometry;

6) to receive practical skills of calculation of quantity predicted at various times after radiating radionuclide failure and estimations of the received results.

Requirements to initial level of knowledge

For full development of theme of bases of physics knowledge employment and general chemistry, adequate representation of planetary model of atom structure, concepts of «ionizing radiation», «nucleon», «atom», «isotope», «radionuclide» and their basic characteristics are necessary.

Control questions on the employment theme:

1. The subject maintenance «radiation medicine». The purposes, problems, methods of the radiation medicine.

2. Value of the radiation medicine in the course of formation of medical shots for needs of preventive public health services of republic.

3. Radio-activity: a concept, phenomenon essence, system and traditional units of radio-activity, their parity. The law of radioactive disintegration decay,

its practical use for substantiation of actions for population protection against failures on nuclear-physical installations.

4. Types of radioactive transformations of nucleuskernels: alpha-beta-gamma transformations of nucleuskernels. Examples of the elements undergoing corresponding types of radioactive transformations.

5. The characteristic of corpuscular kinds of radiation (an alpha-beta particles); their interaction with substance. Concept of linear transmission of energy.

6. Features of interaction of neutrons different energy with substance. The phenomenon of the induced radio-activity.

7. The characteristic of electromagnetic kinds of ionizing radiation (x-ray and gamma radiations), their interaction with substance.

8. Stages of formation of a radiation injury. Direct and indirect effect of ionizing radiation.

9. Types of cells reaction on irradiation. Modern representations about mechanisms interphase and mitotic cell destructions. Sequence of the reactions conducting to lysis cells.

10. The general and individual dosimetry. Doses: exposition, absorbed, equivalent, effective; system and stand-alone (traditional) units of doses, parity between them. Collective doses.

11. Biological dosimetry. Reconstruction of the doses received by the person.

The additional information on the topic

Radiative medicine — a science studying features of influence of ionizing radiation on a human body, principles of treatment of radial damages and preventive maintenance of possible consequences of the population irradiation.

Radiative medicine studies a wide range of questions and is closely connected with bioradiology, nuclear physics and biophysics, bioorganic and biological chemistry, clinical disciplines, epidemiology. The big section of radiative medicine — physics health which is allocated as an independent hygienic science.

Ionizing radiation is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from their orbits, causing the atom to become charged or ionized.

Here we are concerned with only one type of radiation, *ionizing radiation*, which occurs in two shapes — waves or particles.

Heat waves, radiowaves, infrared light, visible light, ultraviolet light, X rays and gamma rays are all forms of electromagnetic radiation. They differ only in frequency and wave length.

Longer length waves, lower frequency waves (heat and radio) have less energy than shorter length waves, higher frequency waves (X and gamma rays). Not all electromagnetic (EM) radiation is ionizing. Only the high frequency portion of the electromagnetic spectrum (shown above), which includes ***X rays*** and ***gamma rays*** is ionizing.

Most of the more familiar types of electromagnetic radiation (e.g. visible light, radio waves) exhibit «wave-like» behaviour in their interaction with matter (e.g. diffraction patterns, transmission and detection of radio signals). The best way to think of electromagnetic radiation is a wave packet called a **photon**. Photons are chargeless bundles of energy that travel in a vacuum at the velocity of light, which is 300 000 km/sec.

Specific forms of ionizing radiation:

Particulate radiation, consisting of atomic or subatomic particles (electrons, protons, etc.) which carry energy in the shape of kinetic energy or mass in motion.

Electromagnetic radiation, in which energy is carried by oscillating electrical and magnetic fields traveling through space at the speed of light.

More particular, directly ionizing radiation consists of alpha particles and beta particles. They are considered directly ionizing because they carry a charge and can, therefore, interact directly with atomic electrons through coulombic forces (i.e. like charges repel each other; opposite charges attract each other).

The neutron (shown in the middle) is an indirectly ionizing particle. It is indirectly ionizing because it does not carry an electrical charge. Ionization is caused by charged particles, which are produced during collisions with atomic nuclei.

The third type on the right includes gamma and X rays, which are electromagnetic, indirectly ionizing radiation. These are indirectly ionizing because they are electrically neutral (as are all electromagnetic radiations) and do not interact with atomic electrons through coulombic forces.

What is the relationship between atom structure and radiation production?

To understand the principle of radioactive decay it is necessary to consider the structure of the atom (figure 1.1).

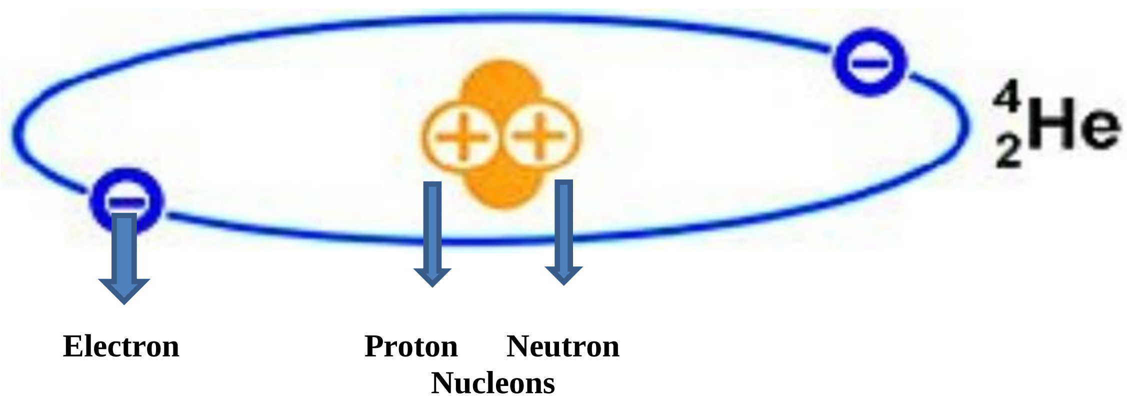


Figure 1.1 — The structure of a helium atom

Atomic Structure

The simplest structural unit of any element that can exist while still retaining its chemical and physical characteristics is an atom. An atom is composed of a central nucleus containing most of its mass and electrons orbiting in shells around the nucleus. The structure of a helium atom is shown.

The atomic nucleus is composed of two types of elementary particles called protons and neutrons, which are collectively known as nucleons.

1. ***The proton*** is a particle with a positive charge, equal in magnitude and opposite in sign to that of the electron. A proton is about 1837 times heavier than an electron.

2. ***The neutron*** is an uncharged particle with a mass slightly greater than that of the proton, approximately equal to the sum of the masses of a proton an electron.

3. ***Electrons*** are negatively charged particles.

Atoms in their normal state are electrically neutral because the total negative charge of electrons outside the nucleus equals the total positive charge of the nucleus.

The mass of a proton is less than one billionth of a gram. To make it more convenient to work with, a relative mass scale was developed where an «atomic mass unit» is equal to one-twelfth of the mass of a single carbon atom of the type that contains 12 nucleons in its nucleus.

Any grouping of nucleons capable of more than a fleeting existence is called a ***nuclide***.

Atoms with the same number of protons and different number of neutrons are called ***isotopes***. An isotope may be defined as one or two or more forms of the same element having the same atomic number (Z), differing mass numbers (A), and the same chemical properties. These different forms of an element may be stable or unstable (radioactive). However, since they are forms of the same element, they possess identical chemical properties.

The simplest atom is the *hydrogen atom*. It has one electron orbiting a nucleus on one proton. Any atom which has one proton in the nucleus is a hydrogen atom, like both of the ones shown here. Hydrogen-3 is called tritium. While their chemical properties are identical their nuclear properties are quite different. Hydrogen-3 is radioactive and hydrogen-1 is stable (figure 1.2).

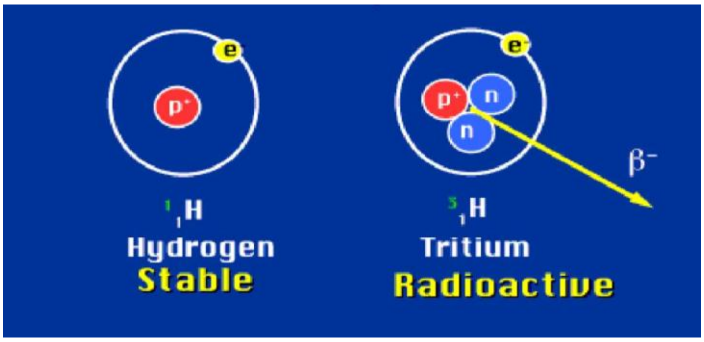


Figure 1.2 — The structure of a hydrogen-1 and hydrogen-3

Why are some nuclides radioactive?

The stable isotopes of elements have very definite ratios of neutrons to protons in their nuclei. As the atomic mass number increases, the ratio of neutrons to protons increases according to a definite pattern. If isotopes vary from this pattern, they are relatively unstable.

The most stable state of a nucleus is called the **‘*ground*’** state. In an unstable nucleus the nucleons are in an **‘*exited*’** state and must release energy to reach the ground state. In the transformation of an unstable nucleus to a more stable nucleus, energy is emitted in the form of particles such as alpha and beta particles, and in some cases photons (gamma rays). This is the process of ***radioactive decay***.

When the atom rearranges itself we call the event decay or disintegration. The number of atoms decaying during a given time is dependent on the total number present and the stability of the atom. The time it takes for half of the material to decay is called the «HALF-LIFE» of the material.

Half-life

The rate of decay of an unstable atom is predictable and specific to the given radionuclide. If we start with 100 atoms, after a given period of time, seen in the above graph as «1» on the horizontal axis, 50 % of the unstable atoms will have undergone radioactive decay. This time period is called a ***half-life***; it is the time necessary for a radionuclide to decay to half its activity. Half-life values range from fractions of a millionth of a second to billions of years.

Decay is a random process which follows an exponential curve. The number of radioactive nuclei remaining after time (t) is given by:

$$\mathbf{N_{(t)} = N_0\, e^{-0.693t/T}}$$

N_0 = Original number of atoms
$N_{(t)}$ = Number remaining at time (t)
t: decay time
T: half-life

Activity

Activity — is the number of decaying nuclei per unit of time.

The Systéme International (SI) unit of radioactivity is the ***Becquerel (Bq).***

The activity of a radionuclide is simply a measure of how many atoms undergo radioactive decay per a unit of time.

The old unit for this is the ***Curie (Ci),*** in honour of *Marie Curie* who discovered radioactivity while working with radium-226. The curie is based on the activity of 1 gram of radium-226, or 3.7×10^{10} radioactive disintegrations per second.

The SI unit for measuring the rate of nuclear transformations is the becquerel (Bq). The becquerel is defined as 1 radioactive disintegration per second.

One Bq = 1 disintegration per second
Non-SI unit of radioactivity is the **Curie (Ci)**
One Ci = $3, 7 \times 10^{10}$ transformations per second
One milicurie (mCi) = $3, 7 \times 10^{7}$ s^{-1}
One microcurie (μCi) = 3.7×10^{4} s^{-1}
1 Bq = 2.7×10^{-11} Ci

Dosimetry — a measurement of the dose or it power (i.e., the dose in unit of time). Currently distinguish the following doses:

Quantity	Definition	New Units	Old Units
Exposure	Charge per unit mass of air 1 R = 2.58 x 10^{-4} C/kg	---	Roentgen (R)
Absorbed dose to tissue T from radiation of type R $D_{T,R}$	Energy of radiation R absorbed per unit mass of tissue T 1 rad = 100 ergs/g 1 Gy = 1 joule/kg 1 Gy = 100 rads	Gray (Gy)	Radiation absorbed dose (rad)
Equivalent dose to tissue T H_T	Sum of contributions of dose to T from different radiation types, each multiplied by the radiation weighting factor (w_R) $H_T = \Sigma_R w_R D_{T,R}$	Sievert (Sv)	Roentgen equivalent man (rem)
Effective Dose E	Sum of equivalent doses to organs and tissues exposed, each multiplied by the appropriate tissue weighting factor (w_T) $E = \Sigma_T w_T H_T$	Sievert (Sv)	rem

Radiation exposure

Radiation exposure is a measure of the intensity of the radiation field. For X and gamma rays, exposure is precisely defined in terms of the amount of ionization produced in air by the radiation source. It is measured in units of coulombs per kilogram (C/kg) of air at NTP, and is directly related to the radiation fluence.

The old unit for exposure is the roentgen (R). The roentgen (R) was originally defined as the amount of X radiation that produced 1 electrostatic unit (esu) of charge as a result of interactions in 1cc of dry air at NTP. 1R = 2.58×10^{-4}C/kg.

Some radiation passes through a volume of medium without interacting and, therefore, does no damage. Thus, only the radiation that interacts with the medium is measured. The SI unit for exposure is the coulomb per kilogram, or unit of charge generated per unit mass (figure 1.3).

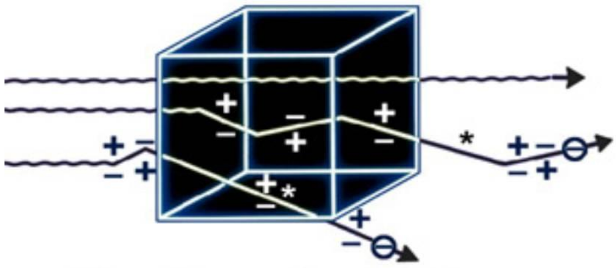


Figure 1.3 — Radiation exposure

Traditional unit: ***Roentgen (R)*** *= 2.58×10^{-4} coulomb/kg = 1esu/cm^{3}*

Absorbed dose (D)

Energy imparted to matter from any type of radiation:

$$D = E/m,$$

where: D — an absorbed dose.
E — energy absorbed by material of mass 'm'.

Because the roentgen is only defined for ionization in air caused by X or gamma radiation, a term is needed to quantify the amount of energy imparted to matter from any type of radiation. To look at biological effects, we must measure how much energy is deposited per unit mass of the medium with which the radiation is interacting. This quantity is known as the absorbed dose (D) which is defined as the quotient of E/m, where E is the energy absorbed by material of mass m.

Units of absorbed dose

The international unit (SI) of measure for absorbed dose is the gray (Gy), which is defined as 1 joule of energy deposited per 1 kilogram of medium.

The old unit of measure for this is the ***rad***, which stands for «**r**adiation **a**bsorbed **d**ose». One Gray is equal to 100 rads.

Not all kinds of ionizing radiation are equally damaging. How damaging any given radiation is depends on many factors. Two of the most important factors are (1) how much energy is deposited and (2) how quickly the energy is deposited.

The SI unit: gray (Gy).
1 Gy = 1 joule/kilogram.
Old unit: rad.
1 Gy=100 rad.

Equivalent dose (H_T)

Equivalent dose is a quantity which takes into account the relative biological damage produced in tissue by different types of radiation. Even when the energy deposition is equal at a macroscopic level (that is, the absorbed dose is the same), different types and energies of radiation will produce different amounts of biological damage. The actual damage produced per Gy will depend on ***the linear energy transfer (LET)*** of the radiation, or density of ionization produced at a microscopic level by each radiation particle as it traverses through tissue. For the purpose of comparing the biological effects of different types of radiation, a ***radiation weighting factor*** $\boldsymbol{W_R}$, which takes account of the ***relative biological effectiveness (RBE)*** of each type of radiation, is introduced. The average absorbed dose in a tissue or organ T in Gy is multiplied by this factor to give the *equivalent dose*, $\mathbf{H_T}$. This is given by:

$$H_T = W_R \times D_{TR},$$

where: D_{TR} — is the absorbed dose in tissue or organ T from radiation R and W_R — is the appropriate radiation weighting factor.

When the radiation source consists of various types and energies with different values of W_R, the total equivalent dose H_T is given by:

$$H_T = \sum_R W_R \times D_{TR},$$

Accounts for biological effect per unit dose radiation weighting absorbed factor (W_R) × dose (D).

Radiation weighting factors (W_R)

To account for differences in LET when measuring the effect of radiation, each type of radiation has been assigned a radiation weighting factor (W_R). This was done by measuring how much of each radiation type it took to produce the same biological effect as 200-keV X-rays.

As shown, all photons, beta particles, and electrons do the same amount of damage. Thermal neutrons do somewhat more damage, and fast neutrons and alpha particles are extremely damaging. Indeed, of the radiation types that we deal with, alpha particles and high-energy neutrons are the most damaging (table 1.1).

Table 1.1 — Radiation weighting factors (W_R)

Radiation type and energy range	$\mathbf{W_R}$
Photons (X-rays and gamma-rays) all energies	1
Electrons, all en energies	1
Neutrons: • < 10 keV • <10–100 keV • > 100 keV to 2 MeV • 2–20 MeV • > 20 MeV	 5 10 20 10 5
Protons and the charged particles	2
Alpha-particles, fission fragments	20

Unit of equivalent dose

The unit of equivalent dose is the sievert (Sv) named after Rolf M Sievert, the Swedish physicist who laid the foundations of modern radiation physics.

The old unit of equivalent dose is the rem, which is equal to the absorbed dose, rad, multiplied by the radiation-weighting factor. Also, just as 1 Gy is 100 rads, 1 Sv is 100 rems.

SI unit: sievert (Sv).

H_T (Sv) = $W_R \times D$ (Gy).

Old unit: rem.
(roentgen equivalent man)

H_T (rem) =(W_R) x D (rad).

1 Sv = 100 rems.

Effective dose (E)

It is now understood that different organs of the body vary in their sensitivity to absorbed doses of radiation. The ICRP(International commission by radiological protection) has introduced a quantity, the effective dose equivalent, which reflects not only specific organ doses but also the relative radiosensibility of the organs. The calculation of effective dose equivalent required knowledge of the radiation doses to individual organs. These were then multiplied by «tissue weighting factors» (W_T) to take account of the relative sensitivity of each type of tissue to radiation. This is a weighted sum of doses to individual organs where the value of the tissue weighting factors is based upon the estimates of the relative risk of stochastic effects from the irradiation of the different tissues:

$$E\ (Sv) = \Sigma_T\ W_T \times H_T,$$

where: W_T — tissue weighting factor for organ T;
H_T — equivalent dose received by organ or tissue T.

Effective dose is expressed in sieverts (Sv).

Use of this concept enables comparison between situations where the whole body is irradiated uniformly and where individual organs receive relatively higher doses (table 1.2).

Table 1.2 — Tissue and organ weighting factors

Tissue	**W_t**	**(Σ W_t)**
Red bone marrow, thick intestines, lung, stomach, mammary gland, other tissues	0,12	(0,72)
Gonads	0,08	(0,08)
Bladder, esophagus, liver, thyroid gland	0,04	(0,16)
Bone surface, skin, brain, salivary glands	0,01	(0,04)

These are multipliers used for radiation protection purposes to account for the different sensitivities of the organs and tissues to the induction of stochastic effects of radiation.

The relationship between the probability of the stochastic effect and equivalent dose varies with the tissue irradiated. Tissues which are at higher risk from radiation will have higher weighting factors (W_T)

The sum of the tissue weighting factors is equal to 1.

The basic information to be remembered:

1 Bq = 1 decay/sec.

1 Ci = 3.7×10^{10} Bq.

1 Gy = 100 rad, 1 Sv = 100 rem.

Conversion between units used in radiation protection into the table 1.3.

Table 1.3 — Conversion between units used in radiation protection

Physical quantity	SI unit	Non-SI unit	Relationship
Activity	Becquerel	Curie (Ci)	1 Bq = 2.7×10^{-11} Ci 1 Ci = 3.7×10^{10}Bq 1 mCi = 37 MBq
Exposure	Coulomb/kg	Roentgen ®	1 R=2.58×10^{-4} C/kg 1C/kg = 3876 R
Absorbed dose	Gray (= J/kg)	Rad	1 Gy = 100 rad 1 rad = 1 cGy
Equivalent dose	Sievert	Rem	1 Sv = 100 rem 1 rem = 10 mSv

Total radiation dose incurred by population:

$$S = \sum_i E_i N_i ,$$

where: E_i — average effective dose in the population subgroup i;

N_i — number of individuals in subgroup i.

Unit: man-sievert (man Sv):

accounts for the number of people exposed to a source by multiplying the average effective dose to the exposed group from the source by the number of individuals in the group.

Sources of radiation dose to general population

We all live with exposure to radiation on a daily basis. Shown here are some typical sources of radiation exposure.You can see that the largest contribution is made by natural sources (85 %). An additional 15 % of the average annual exposure is man-made, consisting of 14 % from medical examinations (10 % from diagnostic X rays and 4 % from nuclear medicine procedures) and 1 % from miscellaneous sources such as nuclear discharges, consumer goods, fallout and occupational exposure (figure 1.4).

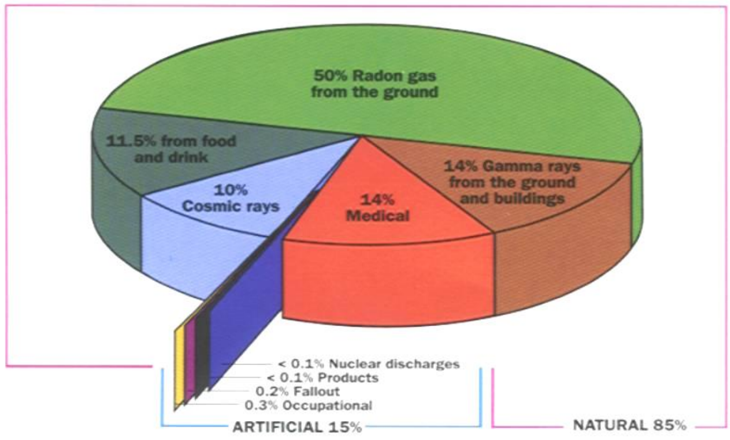


Figure 1.4 — Sources of radiation dose to general population

Nuclear binding energy

Just as there is binding energy involved with the orbiting electrons, there is also binding energy involved with the nucleus. The binding energy in the nucleus is the energy required to remove a single proton, neutron, or alpha particle from the nucleus. The existence of binding energy can be demonstrated by comparing the mass relationship of an intact helium 4 nucleus (2 protons, 2 neutrons) to the weight of 2 protons and 2 neutrons weighed separately. The intact helium 4 atom actually weighs less than the sum of its constituent parts because some of the actual mass of the helium 4 nucleus has been converted to energy (binding energy). The nuclear binding energy is the equivalent energy difference between the sum of the masses of the protons and neutrons as they would exist separately and the equivalent energy of the mass of the nucleus itself. This difference is also called ***mass defect.***

Careful experimentation and study have shown that while the mass defect is real, the law of conservation of mass has not been violated. When basic particles combine to form an atom, a certain amount of mass is lost through conversion into energy in accordance with Einstein's equation $E = mc^2$, where E is the energy, m is the mass, and c is the velocity of light in a vacuum. The converted energy is considered to be binding energy, i.e. energy necessary to hold the nucleus together.

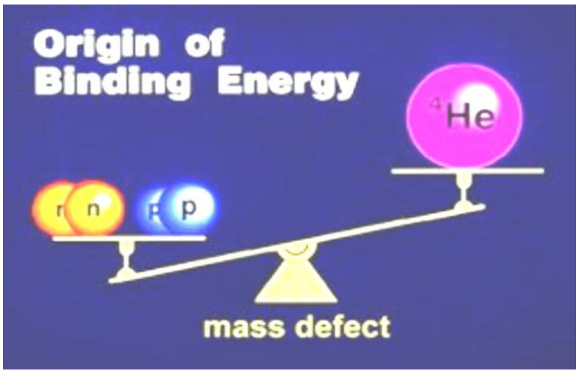


Figure 1.5 — Mass-energy relationship

Fission is a nuclear process in which a heavier unstable nucleus divides or splits into two or more lighter nuclei, with a release of substantial amounts of energy.

One of the easiest isotopes to split is uranium-235. When a thermal neutron is absorbed by a uranium-235 nucleus, it becomes uranium-236. At this point, the uranium-236 either emits a gamma ray or undergoes fission. On average, the uranium-236 nucleus will split into two smaller parts called fission fragments (FF), release two or three free neutrons, gamma rays and a tremendous amount of energy. The nuclear potential energy released in the fission process originates from the binding energy of the nucleus.

Splitting a uranium atom also releases neutrons, which act like microscopically small bullets. Neutrons are about one-fourth the size of alpha particles and have almost 2000 times the mass of an electron. If there are other fissionable atoms nearby (uranium 235 or plutonium 239, for example) these neutron projectiles may strike them, causing them to split and to release more neutrons. This is the familiar chain reaction. It takes place spontaneously when fissionable material is sufficiently concentrated, i.e. forms a critical mass. In a typical atomic bomb, the fission is very rapid. In a nuclear reactor, water, gas or the control rods function to slow down absorb neutrons and control the chain reaction (figure 1.6).

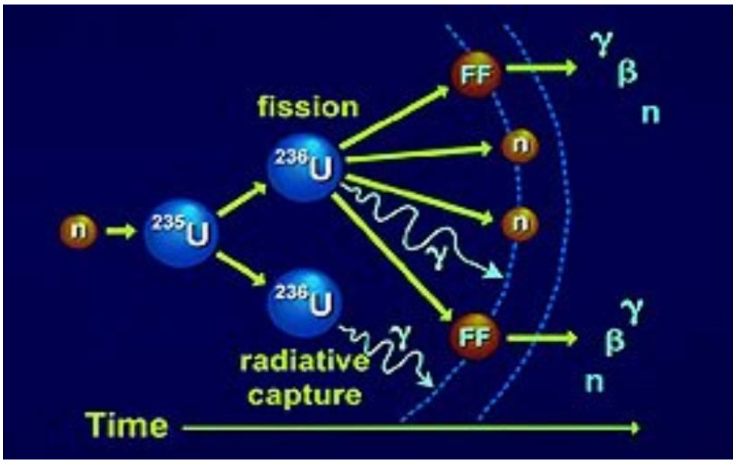


Figure 1.6 — Fission

Nuclear reaction

In a nuclear explosion, potential nuclear energy is converted into the kinetic energy of the products of a process called nuclear fission. This process causes a release of energy that ultimately gives rise to the blast and thermal effects of a nuclear explosion, effects that are many orders of magnitude greater than those of a chemical explosion.

In a nuclear power plant, the same fission reaction is used to produce electricity. But in the case of power production, the fission reaction is controlled so that the energy is not released as an explosion. Nuclear power plants are designed so that a «nuclear explosion» is not possible (figure 1.7).

Figure 1.7 — Nuclear reaction and energy production

Mechanisms of radioactive decay

There are several forms of radioactive decay depending on the original state of the unstable nucleus, i.e. whether it is neutron deficient or proton deficient.

Alpha particle

The alpha particle is a completely ionized helium nucleus. That is, a helium nucleus with no orbital electrons. It consists of two neutrons and two protons, is massive (approximately 8000 times as massive as an electron), and carries a strong, double-positive charge. Therefore, it is directly ionizing.

Alpha decay only occurs in very heavy elements, i.e. $Z > 83$, such as uranium, thorium and radium. The nuclei of these atoms are very «neutron rich» (i.e. have a lot more neutrons in their nucleus than they do protons) which makes emission of the alpha particle possible. After an atom ejects an alpha particle, a new parent atom is formed which has two less neutrons and two less protons. Thus, when Uranium-238 (which has a Z of 92) decays by alpha emission, Thorium-234 is created (which has a Z of 90) (figure 1.8).

Decay may be represented as:

$${}^{A}_{Z}X \rightarrow - \; {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

e.g. ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

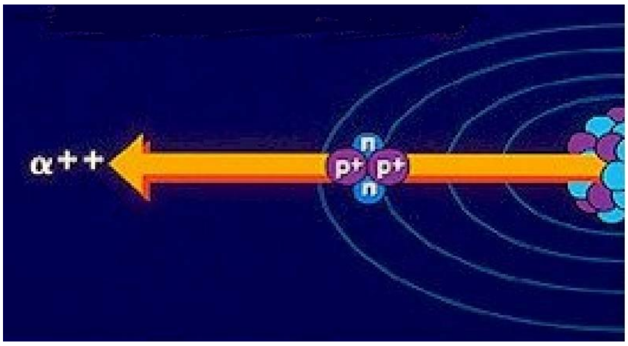


Figure 1.8 — Alpha (α^{++}) decay

$${}^{A}_{Z}\mathbf{X} \longrightarrow {}^{A-4}_{Z-2}\mathbf{Y} + {}^{4}_{2}\mathbf{He}$$

e.g. $${}^{238}_{92}\mathbf{U} \longrightarrow {}^{234}_{90}\mathbf{Th} + {}^{4}_{2}\mathbf{He}$$

Beta particle

Beta particles are identical to atomic electrons but, like alpha particles, they are ejected from a nucleus when the nucleus rearranges itself into a more stable configuration.

Beta decay occurs when a nucleus has too many neutrons i.e. it is proton deficient and it transforms a neutron into a proton plus an electron known as a beta minus particle and a neutrino.

The total energy released is shared between the electron and the neutrino. The neutrino has no mass or charge. The mass number remains unchanged. The decay may be described as:

$n \rightarrow p + e- + \upsilon$.

This may also be represented as:

$\mathbf{{}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} + \upsilon}$ **e.g.** $\mathbf{{}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + e^{-} + \upsilon}$

The daughter product is a different element to the parent. as it has an atomic number increased by 1. Beta-particles are emitted with a continuous energy spectrum ranging from zero to a maximum value depending on the radionuclide. The average energy of the beta particle is $E = E_{max}/3$.

Beta particles have only a very short range in tissue before being absorbed.

Some beta emitting radionuclides may leave the daughter nucleus in an excited energy state and the stable state is reached by the immediate emission of one or more gamma rays e.g ^{131}I (figure 1.9).

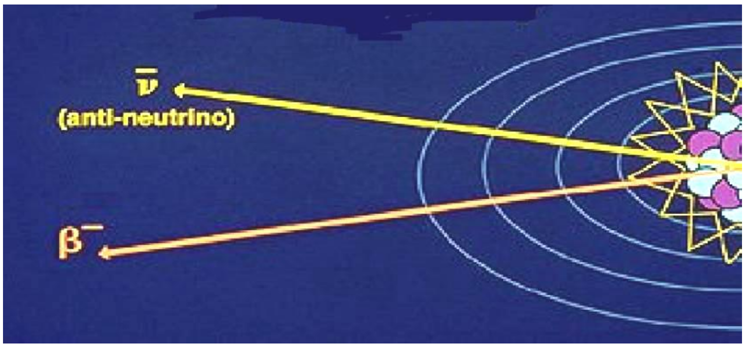


Figure 1.9 — Beta (β^{-}) decay

$\mathbf{n \longrightarrow p + e^{-} + \upsilon}$

$\mathbf{{}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} + \upsilon}$ **e.g.** $\mathbf{{}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + e^{-} + \upsilon}$

Beta plus or positron decay

This occurs when a nucleus has too many protons, i.e it is neutron deficient and it transforms a proton into a neutron plus a positron (β+), and a neutrino. The mass number A remains unchanged:

$\mathbf{p \rightarrow n + e^{+} + \upsilon}$

This may also be represented as:

$\mathbf{{}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^{+} + \upsilon}$ **e.g.** $\mathbf{{}^{18}_{9}F \rightarrow {}^{18}_{8}O + e^{+} + \upsilon}$

Like beta particles, positrons are emitted in a continuous spectrum up to a maximum energy (figure 1.10).

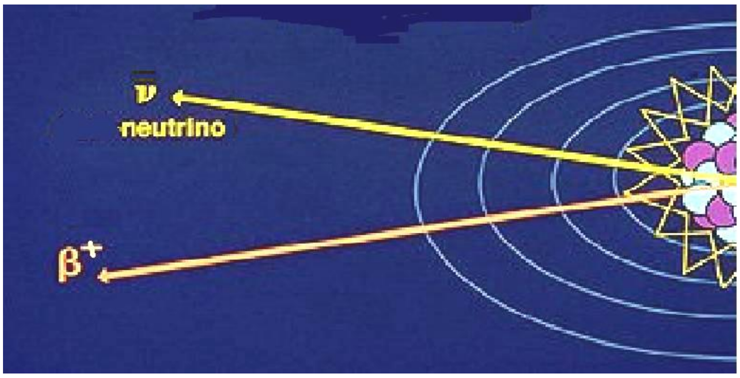


Figure 1.10 — Positron (β^+) decay

$$p \longrightarrow n + e^+ + \upsilon$$
$${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^+ + \upsilon \quad \text{e.g. } {}^{18}_{9}F \rightarrow {}^{18}_{8}O + e^+ + \upsilon$$

If the nucleus does not have sufficient energy to decay by positron emission, the excess protons may be reduced by electron capture. In this case, an orbital electron is ***«captured»*** by the nucleus and a proton transforms into a neutron plus a neutrino.

$$p^+ + e^- \rightarrow n + \upsilon$$
$${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \upsilon$$
$${}^{125}_{53}I \rightarrow {}^{125}_{52}Te + \upsilon$$

This leaves a vacancy in an orbital electron shell, most probably the K shell, and so characteristic X-rays will be emitted. Thus electron capture decay will be accompanied by a characteristic X-ray of the daughter radionuclide and in some cases, when excess energy is remaining, also a gamma-ray (figure 1.11).

$$p^+ + e^- \rightarrow n + \upsilon$$
$${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \upsilon$$
$${}^{125}_{53}I \rightarrow {}^{125}_{52}Te + \upsilon$$

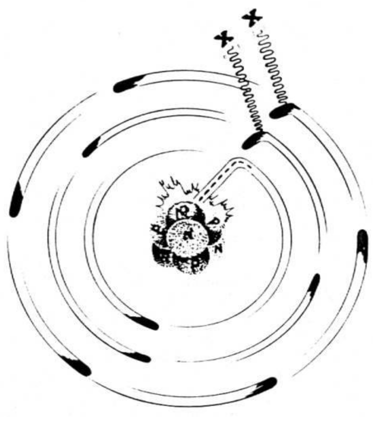


Figure 1.11 — Electron capture

Gamma (γ) emission (figure 1.12)

The release of energy as a gamma ray (γ) may be as a part of another decay process, such as alpha or β^-.

For example, the emission of gamma rays from cobalt-60 actually follows a beta decay.

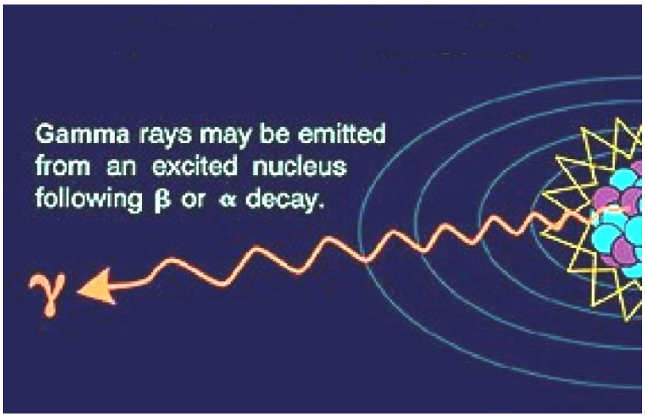


Figure 1.12 — Gamma (γ) emission

Gamma ray emmision represents a mechanism for an excited nucleus to release energy.

When energy is added the nucleus, but not enough to cause particle emission, the nucleus may merely be raised to another energy state. Actually, both the protons and the neutrons have their own set of discrete energy levels to which either nucleon can be raised if sufficient energy is supplied to the nucleus. A nucleus is in its *ground state* when all of its lower energy levels are filled.

In the figure, an *excited state* of the nucleus is represented in which a nucleon has been raised to an excited level. When this occurs, the nucleus instantaneously returns to ground state and releases energy corresponding to the energy differential. This energy release is known as ***gamma radiation*** (figure 1.13).

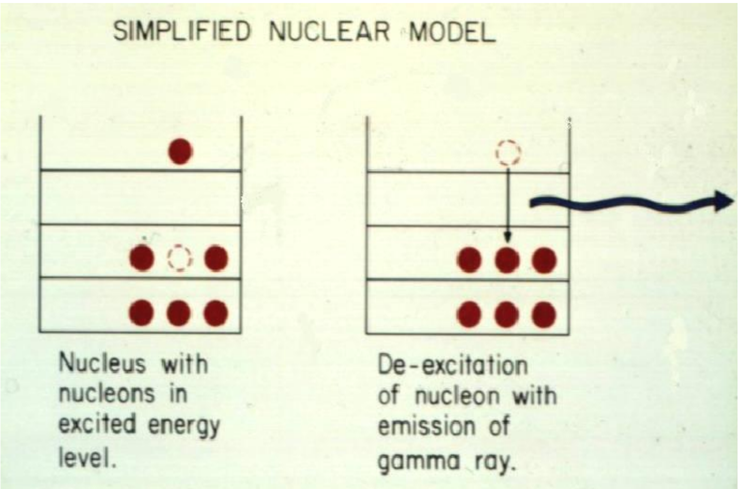


Figure 1.13 — Nuclear energy levels:gamma radiation

How does radiation interact with matter?

The interaction of radiation with matter brings about changes in its physical chemical and biological behaviour. The transfer of kinetic energy from alpha or beta particles or from gamma photons to atoms or molecules leads to ionization or excitation of these atoms or molecules.

Excitation is a process of absorbing small amounts of energy temporaily in the outer electron structure of an atom. Energy from a passing charged particle or from an interaction with electromagnetic radiation causes a short-lived or metastable excitement of an outher electron to a slightly higher energy level. The outher electron is not removed from the atom, and therefore no ionization occurs. Typically, excitation is very short lived and the atom spontaneously gives up the extra energy in the form of electromagnetic radiation (figure 1.14).

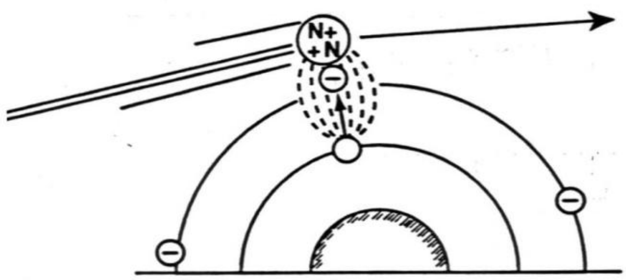


Figure 1.14 — Excitation

Ionization of an atom results from the collision of radiation with the electron structure of an atom. Ionization occurs only when there is sufficient energy from the radiation to completely remove an electron from its orbit. The energy must therfore be larger than the binding energy of the particular orbital electron. For example, if the binding energy of an electron were 54 keV and the incident energy were 78 keV, the electron would be ejected from the atom with 24 keV of kinetic energy (figure 1.15).

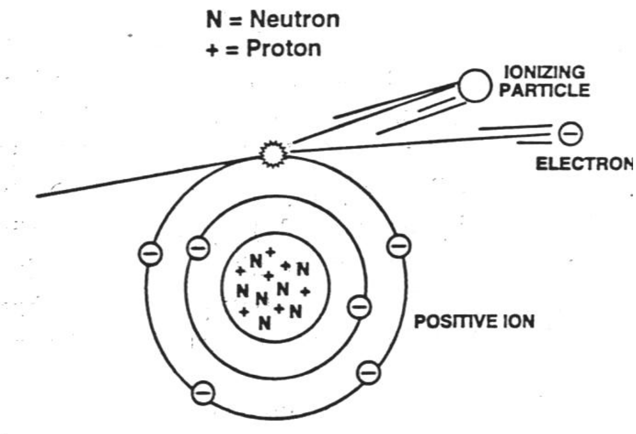


Figure 1.15 — Ionization (electron removal by ionization)

Alpha particles interact strongly with atomic electrons because of their strong positive charge. They exert coulombic forces on the electrons over great distances (on the scale of atoms), ripping electrons from their orbits as they pass by. Because alpha particles interact so strongly with atomic electrons, they have a short range. They travel in a straight line, deposit all their energy quickly, and are what is known as a *densely ionizing radiation* (figure 1.16).

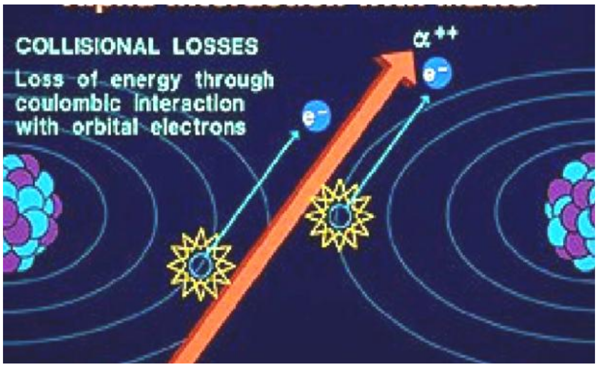


Figure 1.16 — Alpha particle interaction

The energy of these relatively heavy, positively charged particles is fully absorbed within the first 20 micrometers of an exposed tissue mass. If the source of the radiation is external, all the alpha radiation is absorbed in the superficial layers of dead cells within the stratum corneum. If anything, even tissue paper, is interposed, the alpha particles will be absorbed, and not reach the skin. Because of this, alpha radiation is not an external hazard.

Interaction of alpha radiation with living matter: external deposition (figure 1.17):

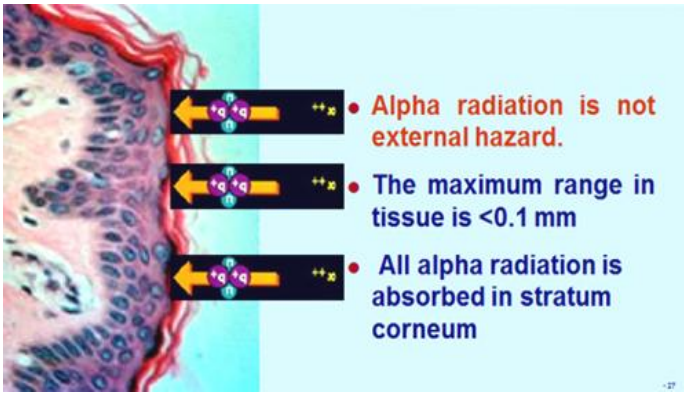


Figure 1.17 — Interaction of alpha radiation with living matter: external deposition

If alpha-emitting material is internally deposited, all the radiation energy will be absorbed in a very small volume of tissue immediately surrounding each particle. Alpha radiation has such limited penetrating ability that the maximum range for the highest energy alpha particle in tissue is less than 0.1 millimeter. Thus, while extremely high radiation doses may be deposited in the few cells immediately surrounding a source of alpha radiation, regions outside this irradiated spherical volume are not affected. Beyond a radius of about 0.02 millimeters, the deposition of energy is very small. The high radiation doses within this critical radius are lethal to the cells immediately adjacent to the source. They are then removed by phagocytosis or replaced by fibrosis. Relatively little damage to the intact organism results, unless these cells are themselves highly critical. Although internal alpha radiation can be lethal to individual cells, the overall acute hazard is small. Internal deposition of alpha particles is of importance on a long-term basis in terms of causing radiation injury.

Many alpha emitting materials also emit gamma radiation, and this gamma radiation may cause significant injury, even though the total alpha energy exceeds the total gamma energy and the ratio of gamma emissions per alpha is very small. This follows from the fact that the penetrating power of gamma radiation is many times greater than that for alpha radiation so that the total volume of tissue exposed to damaging radiation is much greater (figure 1.18).

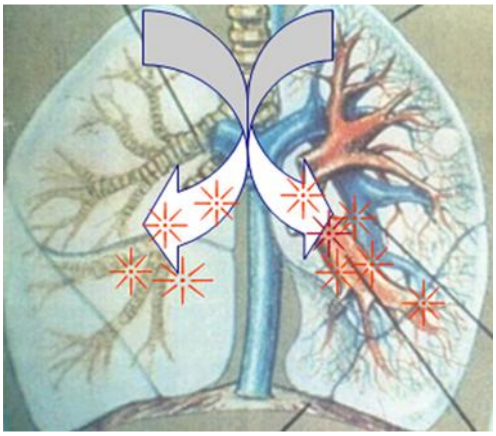


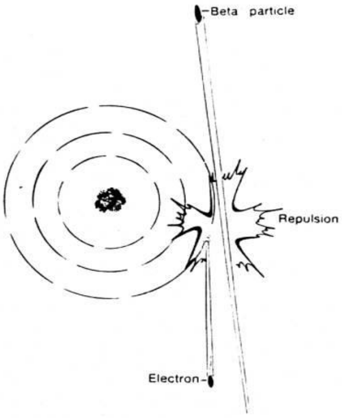
Figure 1.18 — Interaction of alpha radiation with living matter: internal deposition

Prime danger is inhalation and ingestion of alpha emitter

Beta particles also possess the ability to excite or ionize atoms or both. The method of ionization, however, is somewhat different from the ionization of alpha particles. An alpha particle attracts an orbital electron and thus creates an ion pair. The beta particle repels the orbital electron from its energy shell to create an ion pair. Each ion pair produced by the beta particle represents a loss of energy by the beta particle. These processes of excitation and ionization continue until the beta particle loses all its kinetic energy.

If these beta particles are ejected with enough energy, they can travel through the medium, causing additional ionization.

Beta particles, with their smaller mass, higher velocity and single charge, deposit their energy over a much greater range than alpha particles of comparable energy. Since its mass is equal to that of an electron, a large deflection can occur with each interaction, resulting in many path changes or scattering (figure 1.19).



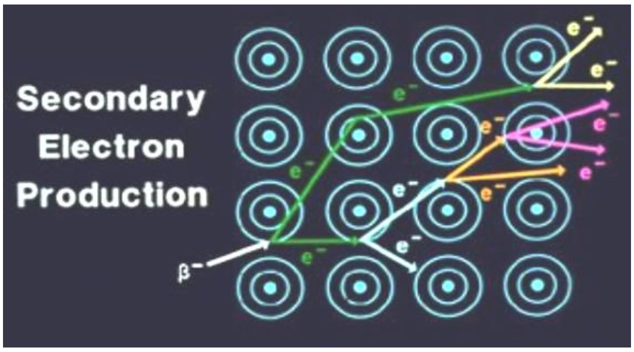


Figure 1.19 — Beta interaction with matter

Beta rays can only penetrate a few millimeters of tissue. Beta particle ranges are considerably greater than those of alpha particles. Unlike the interaction of alpha particles with matter, the path of beta particles through matter is not in a straight line. While beta particles may only penetrate a short distance into a medium, their mean path length (the average distance that a beta particle would travel in a medium if its path were straightened out) can be quite long.

In addition to a difference in range when compared with alpha radiation, there is also a significant difference in the pattern of energy deposition.

If the beta emitting material is on the surface of the skin, the resulting beta irradiation causes damage to ***the epithelial basal stratum***. The lesion is similar to a superficial thermal burn. However, if the isotope is incorporated internally, the beta radiation can cause much more significant damage. The damage will be in spheres of tissue around each fragment or source of radioactive material. The total damage is a function of the number of incorporated sources, the activity and distribution of the radionuclides within the body. The distribution pattern is determined by the chemical nature of the compound containing the radioisotope.

The density of energy deposited is much less for beta irradiation than for alpha, and as a result, the target cells may be damaged rather than killed outright. Damaged cells may be of greater significance to the total organism than killed cells, particularly if they become malignant or otherwise malfunction. Killed cells are replaced quickly in most tissues with any degree of reserve capacity and do not cause significant overall clinical effects unless the individual cells involved are highly critical or the fraction of cells killed in a given organ is large (figure 1.20).

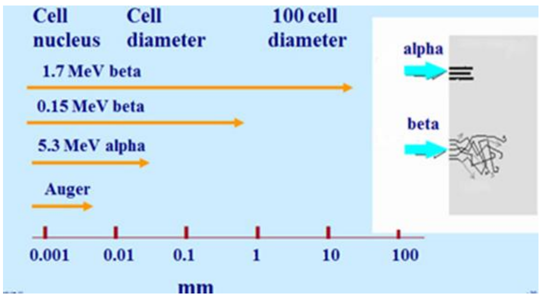


Figure 1.20 — Interaction of beta radiation with living matter

Neutrons are electrically neutral and interact with matter by either collisions with or absorption by an atomic nucleus. Collisions with atomic nuclei slow down — or thermalize — a neutron so it may undergo nuclear capture.

In nuclear capture, the incident neutron is actually absorbed into the nucleus. This can make the nucleus unstable and, therefore, radioactive. An unstable nucleus will shed its excess energy through radioactive decay and will emit particulate radiation and/or gamma rays. Nuclear capture is how objects, people, soil, etc., become radioactive after a nuclear detonation (figure 1.21).

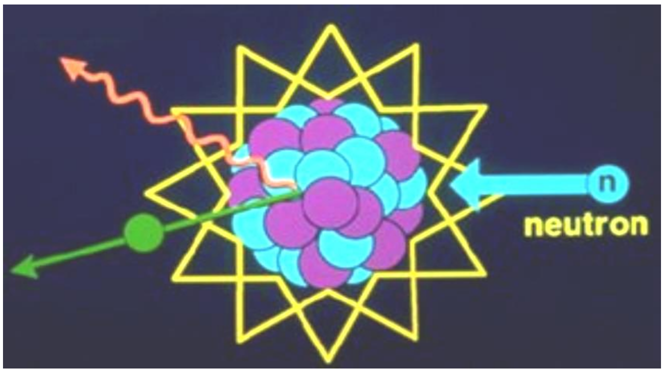


Figure 1.21 — Neutron interaction

Neutron activation is responsible for some of the delayed radiation from a nuclear detonation. In this process, an atom absorbs a neutron, placing the original atom in an «excited state», which means that the atom has excess energy. Atoms in this condition are unstable, and the primary mechanism by which they return to a stable condition is through the emission of nuclear radiation, usually in the form of or accompanied by a gamma ray.

${}_0n^1 + {}^A{}_ZX \rightarrow {}^{A+1}{}_ZX$ + gamma

${}_0n^1 + {}_{27}Co^{59} \rightarrow {}_{27}Co^{60}$ + gamma 1.3 MeV

In the illustration, an isotope of cobalt, cobalt-59, absorbs a neutron and becomes cobalt-60, which is unstable and achieves stability through the emission of a 1.3-MeV gamma ray.

Various biological materials have been used or suggested for measurements in connection with accidental exposure to neutrons. P-32 activity in body hair has been employed in the evaluation of exposures to neutrons. Both blood and whole body measurements of Na-24 activity are also important in the more accurate assesment of absorbed dose.

A large number of neutrons escape the area of an explosion without interacting with the fuel; they then cause activation of the materials in the soil immediately beneath the burst. This area is known as the induced area.

In terms of ionization, gamma radiation interacts with matter in three main ways:

1. Photoelectric effect.
2. Compton scattering.
3. Pair production.

Gamma interaction by photoelectric effect

This describes the case where a gamma photon interacts with and transfers all of its energy to an orbiting electron, ejecting that electron from the atom. The kinetic energy of the resulting photoelectron is equal to the energy of the incident gamma photon minus the binding energy of the electron. The photoelectric effect is thought to be the dominant energy transfer mechanism for X-ray and gamma ray photons with energies below 50 keV, but it is much less important at higher energies (figure 1.22).

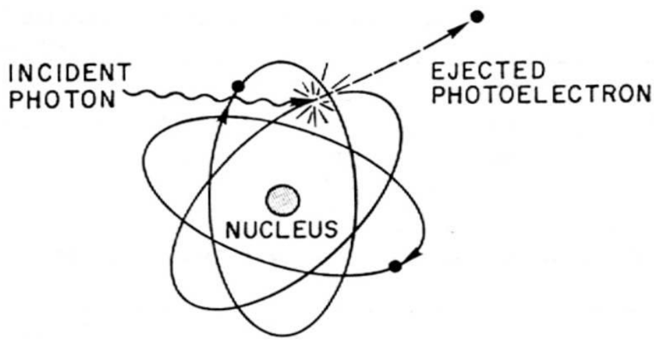


Figure 1.22 — Gamma interaction by photoelectric effect

Gamma interaction by compton scattering

This is an interaction in which an incident gamma photon loses enough energy to an orbital electron to cause its ejection, with the remainder of the original photon's energy being emitted as a new, lower energy gamma photon with an emission direction different from that of the incident gamma photon. The probability of Compton scatter decreases with increasing photon energy. Compton scattering is thought to be the principal absorption mechanism for gamma rays in the intermediate energy range 100 keV to 10 MeV, an energy spectrum which includes most gamma radiation present in a nuclear explosion. Compton scattering is relatively independent of the atomic number of the absorbing material (figure 1.23).

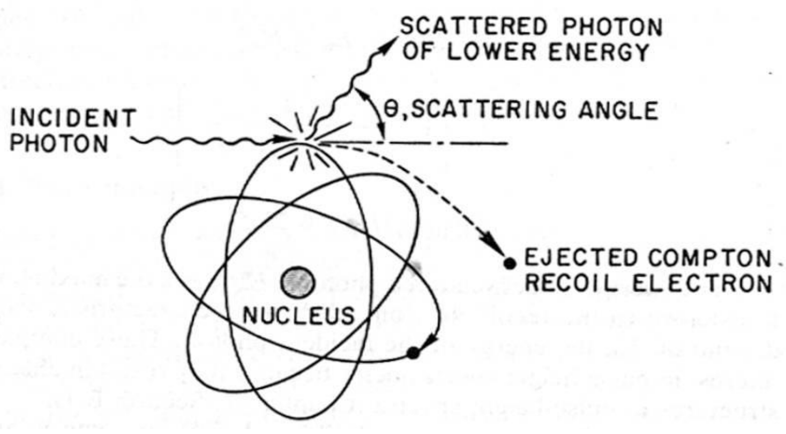


Figure 1.23 — Gamma interaction by Compton scattering

Pair production

By interaction in the vicinity of the coulomb force of the nucleus, the energy of the incident photon is spontaneously converted into the mass of an electron-positron pair. A positron is a positively charged electron. Energy in excess of the equivalent rest mass of the two particles (1.02 MeV) appears as the kinetic energy of the pair and the recoil nucleus. The electron of the pair, frequently referred to as the secondary electron, is densely ionizing. The positron has a very short lifetime. It combines in 10^{-8} seconds with a free electron (annihilation reaction). The entire mass of these two particles is then converted two gamma photons of 0.511 MeV energy each, according to Einstein's equation $E = mc^2$ (figure 1.24).

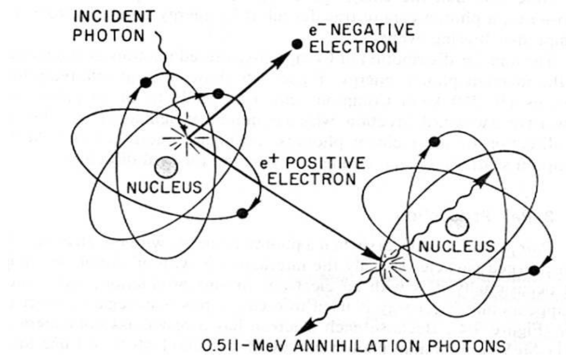


Figure 1.24 — Pair production

1. Typical condition of a problem on calculation of predicted quantity of radionuclides after emergency emission

As a result of failure on ChNPS it has been thrown out in environment 8, $7*10^{16}$ Bq Cs-137. Calculate, what percent of initial quantity radionuclide remained (has broken up) for 26.04.2009.

The solution: calculation is made according to the formula:

$$N_t = N_o \times e^{-\frac{0,693 \times t}{T_{1/2}}},$$

where: N_0 — initial quantity of radioactive atoms; N_t — quantity of active atoms after disintegration time t; $T_{1/2}$ — a half-life period; e — the basis of the natural logarithm.

From the moment of Chernobyl failure passed: 2009–1986 = 23 years. Half-life period Cs-137 — 30 years. Calculation begins with an exponent of the basis of the natural logarithm:-0,693 × 23 г: 30 years = -0, 5313; then we count **e** in degree-0,5313, it is equal 0,5874. Taking it into account N_t is calculated:

$$N_t = 8,7\times10^{16} \text{ Bq} \times 0,5874 = 5,11\times10^{16} \text{ Bq}.$$

Then we count percent of the quantity of the radionuclides which remained: $8,7\times10^{16}$ – 100 % $5,11\times10^{16}$ – x % so x = 58,74 %. Hence, the number of those decayed: 100 – 58, 74 = 41,26 %.

2. Typical problem on calculation the time necessary for achievement by the given environmental objects their activity

After Chernobyl nuclear power station disaster water has activity Cs-137 — 30 Bq/l. Time, after which the activity of the water on ^{137}Cs will not exceed Republican admissible levels (AEL) -99.

The solution: calculation is made according to the formula:

$$t = \frac{T_{1/2} \times \ln \frac{A_0}{A_t}}{0,693},$$

where: A_0 — activity of foodstuff and wate; A_t — activity of foodstuff and water on AEL-99; $T_{1/2}$ — a half-life period; ln — the natural logarithm.

According to AEL-99 activity of water on Cs-137 should be not above 10 Bq/l.

Calculation begins with definition of size of the natural logarithm:

$$\ln \frac{A_0}{A_t} = \ln \frac{30}{10} = 1,098.$$

Half-life period Cs-137 - 30 years. C the account of it t = 30×1,098/0,693 = 47, 56 years.

3. Calculation of the capacity of an exposition dose.

Calculate an annual effective dose (AED) external irradiation because of Chernobyl radionuclide emissions for inhabitants of village N., if average capacity of an exposition dose in the given settlement is equal 25 mkR/h (before failure on CAES the average level of gamma radiation background in the given village is equal 0,008 mR/h).

The solution: AED external irradiation because of Chernobyl radionuclide emissions is defined by a following parity:

$$\mathbf{AED = K_{gen.} \times K_{prot} \times (X - X_o)},$$

where AED — an annual effective dose of an external irradiation, mSv/year;

K_{gen} — a generalised factor of transition from capacity of an exposition dose (ED) in air at the height of 1 m to an annual effective dose of external irradiation of a man's body (table), equal 0,053 mSv × h / (year × mcR);

$K_{prot.}$ — a dimensionless factor characterising seasonal fluctuations of level ED, various modes of behaviour and protective properties of workers and premises of critical group of the population (foresters, machine operators, agriculturists, housing and communal services, etc.). Values K_{prot}. For different types of settlements: village — 0,41; urban-type settlement — 0,30; a city — 0,24 (table);

X — an average ED in a settlement, mcR/h;

X_o — an average level of gamma radiation background in a settlement before failure on ChNPS, mcR/h. As it's unknown the background activity before failure is accepted equal 10 mcR/h.

AED = 0,053 × 0, 41 × (25 - 8) = 0, 37 (mSv/year).

4. If a nucleus such as ^{226}Ra that is initially at rest undergoes alpha decay, which of the following statements is true?

(a) The alpha particle has more kinetic energy than the daughter nucleus.
(b) The daughter nucleus has more kinetic energy than the alpha particle.
(c) The daughter nucleus and the alpha particle have the same kinetic energy.

The solution

(a). Conservation of momentum requires the momenta of the two fragments be equal in magnitude and oppositely directed. Thus, from $KE = p^2/2m$, the lighter alpha particle has more kinetic energy that the more massive daughter nucleus.

5. Which of the following are possible reactions?

(a) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\left(^{1}_{0}n\right)$

(b) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{132}_{50}Sn + ^{101}_{42}Mo + 3\left(^{1}_{0}n\right)$

(c) $^{1}_{0}n + ^{239}_{94}Pu \rightarrow ^{127}_{53}I + ^{93}_{41}Nb + 3\left(^{1}_{0}n\right)$

The solution

(a) and (b). Reactions (a) and (b) both conserve total charge and total mass number as required. Reaction (c) violates conservation of mass number with the sum of the mass numbers being 240 before reaction and being only 223 after reaction.

6. Nuclear reactions: Determine the product of the reaction. What is the Q value of the reaction?

The solution

In order to balance the reaction, the total amount of nucleons (sum of A-numbers) must be the same on both sides. Same for the Z-number.

Number of nucleons (A):

7 + 4 = X + 1 => X = 10

Number of protons (Z):

3 + 2 = Y + 0 => Y = 5

Thus, it is B, i.e.

$_3{}^7Li + _2{}^4He \Rightarrow _5{}^{10}B + _0{}^1n$

The Q-value is then

$Q = (m)c^2 = (m_{7Li} + m_{4He} - m_{10B} - m_n)c^2 = 2{,}79$ MeV

7. If the *Q* value of an endothermic reaction is -2.17 MeV, the minimum kinetic energy needed in the reactant nuclei if the reaction is to occur must be:

(a) equal to 2.17 MeV;
(b) greater than 2.17 MeV;
(c) less than 2.17 MeV, or (d) precisely half of 2.17 MeV.

The solution

To conserve both momentum and energy, incoming particles must have a minimum amount of kinetic energy, called the *threshold energy:*

• m is the mass of the incoming particle;
• M is the mass of the target particle.

If the energy is less than this amount, the reaction cannot occur:

(b). In an endothermic reaction, the threshold energy exceeds the magnitude of the *Q* value by a factor of (1 + *m/M*), where *m* is the mass of the incident particle and *M* is the mass of the target nucleus.

8. Task

To what isotope of an element turns $^{239}_{94}Pu$ after beta disintegration?

The solution

According to the scheme a beta minus disintegration:

$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + e^{-}$

So the scheme of disintegration of plutonium:

$^{239}Pu \rightarrow ^{239}Am + e^{-}$
94 95

9. Task

Define a disintegration constant ^{131}I, if its half-life period (T 1/2) is equal 8, 06 days.

The solution

The disintegration constant is defined by the following parity:

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

where: λ — a disintegration constant; c^{-1}, T 1/2 — a half-life period; $\lambda = 0{,}693 / 8{,}06 = 0{,}086\ sut^{-1}$

Tasks for the solution:

Task 1

What isotopes of an element are formed from $\frac{40}{19}$ K.

1) a beta minus; 2) K-capture? How many protons and neutrons do they contain?

Task 2

What kernel of an element is formed after five consecutive alpha transformations $^{234}_{92}U$?

Task 3

After absorption of a neutron kernel $^{235}_{92}U$ was divided into two radionuclides: $^{137}_{52}Te$ and $^{97}_{40}Zr$.

Formed affiliated kernel $^{137}_{52}Te$ went through four consecutive beta-minus-disintegrations and has turned into a stable isotope. What chemical element does it belong to?

Task 4

The constant of disintegration $^{137}_{55}Cs$ is equal 0.023 years^{-1}. Define its half-life period.

Task 5

Define a constant of disintegration $^{131}_{55}I$ if its half-life period is equal 8.06 days.

Task 6

Define weight of source $^{226}_{88}Ra$ if its activity is equal 3.7×10^{10} Bq?

TEST CONTROL

1. A nuclear charge equal to the ...

a) number of protons in the nucleus;
b) number of neutrons in the nucleus;
c) sum of the number of protons and neutrons in the nucleus.

2. The nucleus of an atom of potassium-40 atom contains 19 protons and 21 neutrons. What is the atomic number of this item?

a) 19;
b) 40;
c) 21.

3. The term «nucleon» belongs to ...

a) beta particles;

b) proton;

c) alpha-particles.

4. Isotopes are ...

a) atoms with different atomic number, but an equal number of neutrons in the nucleus;

b) atoms with different atomic number and mass number

c) atoms with one and the same atomic number but with different mass numbers.

5. To the term «radionuclide» refers to...

a) the nucleus of a radioactive element;

b) the particle, part of the nucleus;

c) the nucleus of the stable atom.

6. A unit of radioactivity is ...

a) Gy;

b) Bq;

c) R.

7. The Law of the Republic of Belarus «On radiation safety» stated that the basic principles of radiation safety practices are:

a) a optimization principle;

b) the principle of limiting doses of external and internal exposure of the population because of Chernobyl radionuclides release;

c) the principle of noninterference.

8. The law of radioactive decay characterizes ...

a) the reduction in the number of active atoms in time;

b) the type of decay of radioactive nuclei;

c) the mode energy release of radioactive nuclei.

9. During the process of alpha decay is ...

a) formed daughter nucleus with a mass less than 4 and with a charge less than 2 than in the mother nucleus;

b) nucleus is ejected from a heavy nucleus of a hydrogen atom;

c) formed a new nucleus with the mass and charge less for 2 than that of the mother nucleus.

10. By calculating of the equivalent dose using radiation weighting factor should be taken into account:

a) the radiosensibility of the tissue to this type of radiation;

b) the lethality of this type of radiation compared to a standard X-rays;

c) the probability of stochastic effects of irradiation.

11. The equivalent dose is ...

a) the radiation dose equal to the product of the absorbed dose weighting factor for the tissue of the body;

b) the radiation dose equal to the product of the exposure dose by a factor of the quality of ionizing radiation;

c) the radiation dose equal to the product of the absorbed dose by a factor of the quality of this type of ionizing radiation.

12. Tissue weighting multiplicator is used to calculate an ...

a) exposure dose;
b) equivalent dose;
c) effective dose.

13. Unit of absorbed dose corresponds to the ...

a) rad;
b) J;
c) Sv.

14. A dose of 1 Gy corresponds to the absorption of ...

a) 1 J energy 1g of substance;
b) 1 J energy 1 kg of substance;
c) 1 meV energy 1kg of substance.

15. Gray is a unit of an ...

a) absorbed dose;
b) equivalent dose;
c) exposure dose.

16. To the unit of equated dose corresponds to ...

a) R;
b) Ci ;
c) Sv.

17. One rad is equal to ...

a) 10 mSv;
b) 10 mGy;
c) 0,01 R.

18. Sievert is a measure unit of an ...

a) absorbed dose;
b) equivalent dose;
c) exposure dose.

19. The unit of effective dose is ...

a) rad;
b) mrGy;
c) mSv.

TOPIC 2
BACKGROUND RADIATING OF THE EARTH. LOADING OF EXPOSURE DOSES ON THE POPULATION OF BELARUS

The motivational characteristic of the theme

Studying the principles of formation exposure doses because of various components of background radiating and the radionuclides cores of Chernobyl emission is necessary for a choice of adequate actions for lessening the beam effects on a human body.

The general time of employment: 4 hours

The employment purposes:

1. To give the characteristic to the basic components of background radiating of the Earth and irradiation of the population.
2. To analyse the levels of irradiation of the person from natural and artificial sources of radiation.
3. To draw the attention of students to value of radon in formation exposure doses on the population.
4. To get the students acquainted with features of migration of radionuclides in biosphere.

Employment problems:

1) to disassemble the basic components of natural background radiating of the Earth;
2) to acquire the basic components of anthropogenic changed background radiating of the Earth and their contribution to formation exposure doses on the population;
3) to acquire value of nuclear fuel cycle in formation of exposure doses on the population and principles of decrease in the given doses.

Requirements to initial level of knowledge

For the development of the theme of employment the knowledge of the basics of physics, the general chemistry, biochemistry, general physiology, the general hygiene is necessary. Mastering the material of practical employment at a high level is impossible without learning the adequate concepts as «background radiating», «natural radionuclides», knowledge of chemical properties of radon, features of inhalation xenobiotic way of reception to a human body, physical and chemical characteristics of aerosol particles.

Control questions on the employment theme:

1.The background radiating of the Earth: components of background radiating and their contribution to the formation of an annual effective dose of the population irradiation.

2. The Natural background radiating, the characteristic of its components. Space radiation and cosmogeneous radionuclides.

3. Radionuclides of radioactive numbers forming basic exposure doses on a human body: U-238, Th-232, Ra-226, PH-222, Po-210, Pb-210, Bi-210.

4. Radon and the levels of irradiation of the population: the basic sources of radon and the condition of elimination radon from them; the conditions promoting formation of the maximum dose on respiratory organs. Optimisation of the exposure doses on a human organism because of radon and products of its disintegration.

5. Natural radionuclides with no radioactive numbers. Value K-40 in formation of exposure doses on the population of Belarus. Radiating conditions in Belarus till 1986.

6. Anthropogenic influence changed background radiating, its components and their contribution to formation of doses of population irradiation.

7. The contribution of medical sources of ionizing radiation to formation of irradiation doses of inhabitants of Belarus.

8. The development of nuclear power in Belarus. The characteristic of the basic types of reactors, radionuclides, created during operating of the nuclear reactor.

9. The nucleo-fuel cycle (**NFC**): a concept, the stages.

Additional information to topic

Historical background

Although humans have evolved in an environment of ionizing radiation contributed to by cosmic rays, radon, and other terestrial radionuclides, the effects of ionizing radiation were not known until human-made sources were developed.

The age of radiation began in 1895 when Roentgen announced the discovery of «a new kind of ray» that could penetrate the human body and reveal broken bones. The first radiograph was taken in January 1896 (figure 2.1).

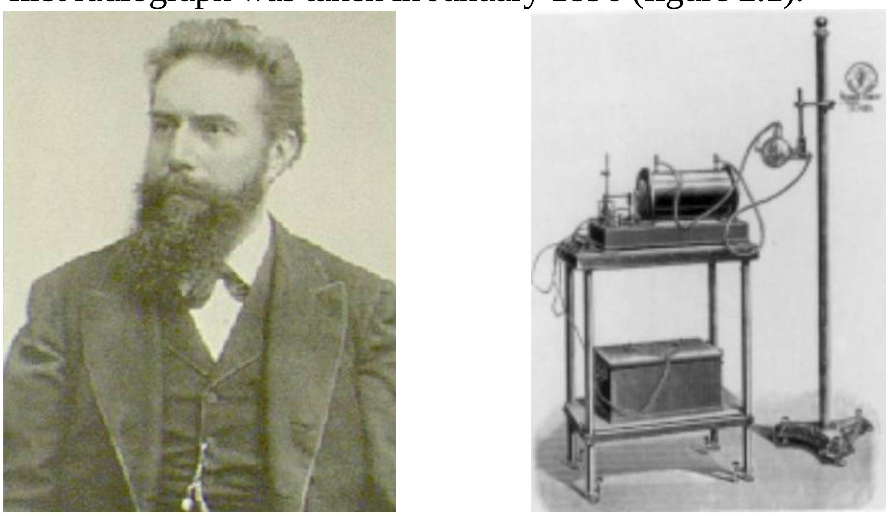


Figure 2.1 — Wilhelm Conrad Röntgen and its invention (the first x-ray device)

Antoine Henri Becquerel discovered the natural radioactivity of uranium (1896), for which he shared the 1903 Nobel Prize for physics with Marie and Pierre Curie.

In 1901, the first harmful effect of radiation was reported: a nasty skin burn was attributed to the vial of radium, obtained from Madame Curie, and carried in Becquerel's vest pocket.

The first radiation-induced skin cancer was reported in 1902 on the hand of a roentgenologist.

The first radiation induced leukemia was described in 1911.

In the 1920s, bone cancer was linked with ingestion of large quantities of radium by women who painted dials on watches and clocks.

In the 1930s, Thorotrast, a colloid solution of thorium dioxide, was commonly used as a diagnostic contrast agent, particularly for cerebral angiography. Thorotrast remains in the body, accumulates in liver and has resulted in liver cancer and leukemia.

The first reports of excess leukemia among radiologists appeared in the 1940s and excess cancer attributable to medical radiation were reported in analytical studies in the 1950s.

Unfortunately, both Madame and Irene Curie died of leukemia as a result of prolonged exposure of radiation during their studies:

- Bergonié and Tribondeaus' 'law' (1906);
- the most 'radiosensible' cells are;
- actively proliferating/dividing at the time of exposure;
- undifferentiated (non-specialized in structure and function).

According to the Bergonié-Tribondeau law (1906), radiosensibility of tissues depends on a number of factors. According to these early radiobiologists, radiation response in tissue was a function of:

- a high number of undifferentiated cells in the tissue;
- a high number of actively mitotic cells;
- the length of time the cells remain in active proliferation.

It is not clear why lack of differentiation of the cell results in radiosensibility. It has been shown that undifferentiated cells or cells in the process of differentiation are easily killed by radiation. The length of time that cells remain in active proliferation relates to the number of divisions between the most immature stage and the final mature stage. The longer cells remain in active proliferation, the greater their sensitivity to radiation.

Background radiating (BR) of the Earth

BR — it is accepted to understand ionizing radiation as a background radiating from natural sources of a space and terrestrial origin, and also from artificial radionuclides, disseminated in biosphere as a result of activity of the person.

The background radiating influences the globe population, having rather constant level.

The BR has 2 components:

— Natural BR.

— Antropogenous changed by the BR.

Both components of the BR participate in formation of effective doses of an irradiation of the person both because of external, and because of an internal irradiation.

Natural background radiating (NBR) — set of ionizing radiation from natural sources of an extraterrestrial and terrestrial origin.

Natural sources of ionizing radiation of a terrestrial origin are presented of radionuclides of 2 groups:

A. Radionuclides, entering into radioactive numbers.

B. Radionuclides, not entering into radioactive numbers.

Radionuclides of radioactive numbers

A radioactive number is a sequence of radionuclides, formed as a result an alpha- or beta disintegration of the previous element. The most long-living isotopes are called initial for each of radioactive numbers.

There are 4 radioactive numbers and, accordingly, 4 their ancestors:

A thorium number: the most long-living isotope — thorium-232 (Th-232), a half-life period — 1.4·1010 years;

2 uranium numbers:

The most long-living isotope — uranium-238 (U-238), a half-life period — 4.5·109 years;

The most long-living isotope — uranium-235 (U-235), a half-life period — 7·108 years;

Neptunium number: the most long-living isotope — neptunij-237 (Np-237), a half-life period — 2.2·106 years.

Anthropogenic changed of background radiating

It is formed for the account:

1 — sources of the ionizing radiation used in medicine;

2 — global emissions of radionuclides;

3 — building materials;

4 — television;

5 — aircraft.

1. The sources used in medicine, are the basic source of artificial irradiation and exceed the influence of all other artificial sources.

The value of an individual equivalent dose of irradiation of all body owing to medical procedures (the main contribution diagnostics gives) is 0.44–1.0 mSv/year; in some countries it’s from 50 to 100 % NBR.

2. Global emissions ph have 2 components:

Global emissions PH from tests of the nuclear weapon;

Global emissions PH from the enterprises of a nuclea-fuel cycle.

Global doses of radionuclides, found far from the emission site, i.e. practically in every spot on the globe. It occurs, when PH get to the top layers of troposphere (PH can be there to 30 days) and a stratosphere (PH in a stratosphere are late long — about several months or years). These PH are dropping out for long time in various quantities on various sites of the Globe surface.

A. The contribution of the expected collective EED (Collective effective equivalent dose) irradiations of the population from the nuclear explosions, the exceeding 1 %, give only 4 PH: C-14, Cs-137, Zr-95, Sr-90.

B. One more source PH, forming global emissions, enterprises NFC (the nucleo-fuel cycle) are. NFC includes following stages:

1 — extraction of uranium ore;

2 — its processing in enriched U-235 nuclear fuel;

3 — manufacture ***fuel element (FE)*** which consist of uranium in metal, carbide or oxide form, the prisoner in a cover from zirconium, a magnesian alloy or stainless steel;

4 — use FE on the nuclear power station (normal operation of the nuclear power station);

5 — processing of the fulfilled nuclear fuel (for the subsequent use of the taken sharing material — take basically uranium and plutonium);

6 — processing and a burial place of a formed radioactive waste.

It is necessary to remember transportation of radioactive materials for maintenance of all these stages.

Pollution of environment by PH occurs at all stages FE, but the greatest contribution bring:

Processing of the fulfilled nuclear fuel at ***radiochemical factories (RCF)***; RN C-14, Zr-95, H-3, I-129 have major importance;

Normal operation of the nuclear power station; at normal work of the reactor in the environment leave (after passage of system of clearing) gaseous, partially aerosol and liquid waste; major importance have PH I-131, radioactive inert gases, Cs-137 and 134, Sr-90.

Now EED because of use of nuclear power is estimated per a 0.1mSv/year.

Estimating danger of normal work of the nuclear power station to the person, one can state that living near to coal telectrostation capacity 1000 MVt taking into account emissions natural radionuclides (K-40, U-238, Th-232, Pb-210, Po-210) and chemical carcinogens (benzpyrene = carcinogenic hydrocarbons), in hundreds times more dangerously, than residing near to the nuclear power station of similar capacity.

3. Building materials: H = 0.1 mSv/year.

If the person is in a premise, the dose of an external irradiation changes under the influence of 2 opposite operating factors:

— Shielding of external radiation by a building;

— Radiation natural PH, being in materials of which the building is constructed.

Depending on concentration K-40, Ra-226 and Th-232 in various building materials capacity of a dose in houses changes from 4×10^{-8} to 12×10^{-8} Gy/h (0.04–0.12 mGy/h). On the average, in brick, concrete buildings capacity of a dose in 2–3 times more than in wooden houses and in houses from synthetic materials where it usually makes 0.04–0.05 mGy/h.

Here it is necessary to note, what of more production wastes has gone on building material manufacturing, its specific activity can be that above.

4. Television. H = 0.01 mSv/year.

Source of soft X-ray radiation.

Capacity H of irradiation of all body from the colour TV from the distance:

L = 250 sm from the screen = $2{,}5\times10^{-3}$ mSv/h;

L = 5 sm from the screen = 100 mSv/h.

5. Aircraft. H = 0.05 mSv/year.

During the flight on board a plane capacity of an equivalent dose of irradiation of all body makes: at the height of:

8 km — 1.35 mSv/h;

2 km — 5 mSv/h;

20 km — 13 mSv/h.

During 25 minutes flight from New York to Paris a person receives about 50 mSv during 7 hours of transatlantic flight.

Radioactive pollution of biosphere as a result of a nuclear fuel cycle.

The radiating background in a certain measure is caused by operation of the enterprises and objects NFC (nuclear fuel cycle). Despite Chernobyl and a number of other disasters, there are steady rates of development of nuclear power in the world as immediate prospects of real alternative energy sources don’t exist at present. In the end of 1989 in 38 countries of the world more than 450 power units were maintained, 73 were under construction. Relative density of nuclear power stations in the general development of the electric power in the world makes more than 17 % (in the CIS — an order of 12 %), reaching in some countries, in particular, France — 75 %; Belgium — 60 %; Hungary — 50 %.

All NFC includes three stages:

1. *Initial* (extraction, processing, creation and transportation of nuclear fuel).

2. *The basic* (nuclear energy reception, its transformation into energy of other kinds and use).

3. *Final* (transportation of the used fuel and a waste, fuel regeneration, processing and waste disposal).

Technogenic processes at various enterprises NFC differ as they have expressed specificity. Some considerable quantity of them creates artificial radionuclides, representing high potential danger of pollution of biosphere.

Now effective dose because of use of nuclear power is estimated in

0,1 mSv/year.

Estimating the danger of normal work of the nuclear power station to the person, it is necessary to notice that residing near to coal thermal power-station (TPS) capacity 1000 mVt, taking into account emissions of natural radionuclides (K-40, U-238, Th-232, Pb-210, Po-210) and chemical carcinogens (benzpyrens), is hundreds times more dangerous, than residing near the nuclear power station of similar capacity. The situation can essentially change as a result of major accidents.

Background radiation:

• Terrestrial radioactivity.

• Cosmic radiation.

• Internal radioactivity.

Humans have always been exposed to background levels of ionizing radiation caused by:

1. Terrestrial radiation from the presence of naturally ocurring radioactivity in the soil, primarily due to uranium and its by-products.

2. Cosmic radiation that results from the interaction of particles from outer space with the atmosphere and high energy photons from outher space.

3. Internal radioactivity due to naturally occurring radioactivity deposited in the body.

Naturally occuring background levels of radiation can typically range from 1.0 to 3.5 mSv a year and in some places can be much higher. The highest known level of background radiation is in Kerala and Madras States in India where a population of over 100,000 people receive an annual dose rate which averages 13 millisieverts.

As shown in this slide, the average doses from natural sources of radiation vary throughout Europe. Radiation doses in the United Kingdom and the Netherlands are the lowest at around 2 to 3 mSv per year whereas in Sweden and Finland the annual doses are around 6 to 7 mSv.

Radiation dose limitation

The benefits of the use of radiation have been recognized for over a century. The potential for harm was also recognized shortly after radiation was first used for medical and therapeutic uses. Various advisory groups exist to review the use of radiation, evaluate the risk, and make recommendations on safe use, including exposure levels for personnel and the general population. The most prominent international organization is the *International Commission on Radiological Protection (ICRP)*.

According to ICRP recommendations, occupational exposure to radiation should not be higher than 50 mSv in any one year, and the annual average dose over five years must not exceed 20 mSv.

The dose limits for the general public are lower than those for workers. The ICRP recommends that the public should not be exposed to more than an average of 1 mSv per year.

Special limits are needed for women workers who become pregnant. It is important that a woman declare her pregnancy as early as possible; the ICRP recommends that the embryo or foetus should be protected by applying a more restrictive dose limit for the remaining time of the pregnancy. The objective of management once a pregnancy is declared is to ensure that the embryo or foetus is afforded the same broad level of protection as is required for members of the public.

Radiation protection. Basic principles and primary methods

The primary aim of radiological protection is to provide appropriate standards of protection for humans from practices involving radiation exposure, without unduly limiting the benefits of these practices. The system of radiological protection for proposed and continuing practices is based on the following general principles:

• *The justification of a practice.* No practice involving exposure to radiation should be adopted unless it produces sufficient benefit to the exposed individual or to society to offset the radiation detriment it causes.

• *The optimization of protection*. All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account

• *Individual dose limits.* The dose equivalent to individuals shall not exceed the recommended dose limits.

Basic methods of protection against exposure to ionizing radiation

Three basic factors:

• Time.
• Distance.
• Shielding.

Time

The amount of exposure an individual accumulates is directly proportional to the time of exposure. The longer the time spent exposed to radiation the greater the potential for absorbing a dose of radiation. It is therefore important to minimize the time near radioactive sources. Never sit, chat, read or hold telephone conversations in the presence of radioactive materials.

Distance

In the same way that heat from a fire is less powerful the further away you are, the intensity of radiation decreases the further you are from the source.

Distance effect

It is very important to recognize how rapidly exposure falls off with distance from the source. The relationship between distance and exposure follows the inverse square law — the intensity of the radiation exposure decreases in proportion to the inverse of the distance squared. For example, in contact with a 37 MBq vial of sodium 22, the exposure rate is about 150 mSv/hr. At only 50 cm from the source, the exposure is reduced to only 0.06 mR/hr. It is therefore advisable to stand as far as away as possible from radioactive sources. Carrying boxes, forceps and remote handling tools should be used for manuplating sources.

Shielding

Shielding alpha and beta particles

Due to the fact that alpha and beta particles deposit so much energy over such a short distance they are very easy to shield. Alpha particles require little or no shielding as they travel only a very short distance in air.

For beta-emitting radioisotopes, low atomic number material such as plastic is recommended. Plastic will adequately shield the betas and keep bremsstrahlung production to a minimum. The thickness of the shield will depend on the range of the beta in the chosen material. A 3/8" plexiglass shield is recommended when working with P-32 (figure 2.2).

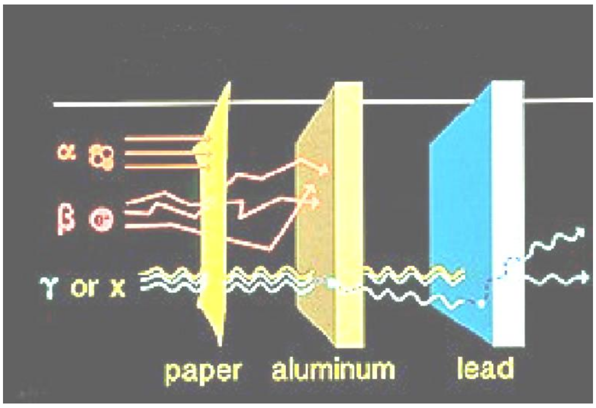


Figure 2.2 — Shielding

X and gamma rays are diminished in intensity by any absorber but not completely stopped. Materials having a high atomic number can absorb more photons than lighter elements. For X and gamma emitters, shielding is usually lead. The thickness will depend on the half value layer of the photon in the chosen material.

The ability of shielding material to attenuate radiation is generally given as half value layer. This is the thickness of the material which will reduce the amount of radiation by 50 %.

An example of a photon emitters in the lab is Cr-51. For chromium, shielding is usually lead. It takes about 3.5 mm of lead to attenuate one half of the chromium photons.

There is a potential for internal exposure if radionuclides are taken into the body. Entry into the body can occur by inhalation, ingestion, or absorption through the skin.

Control of inhalation is accomplished by working with volatile compounds in a fume hood. Iodinations are the most common work involving volatile radioactivity. Iodinations may be performed only if approved as a special condition on the laboratory license and may be performed only in fume hoods that have been approved by the Radiation Safety Office and have effluent air sampling systems installed.

Each worker must register at the Radiation Safety Office before iodinating and receive monthly thyroid bioassays.

Control of ingestion and absorption through the skin is accomplished by following safe work habits, identifying radiation use areas, controlling contamination, and laboratory monitoring. No eating, drinking, smoking, storage of food or mouth pipetting is permitted in areas where radiation is used or stored.

Lab coat and gloves must be worn when handling radioactive material or when working in a labelled radiation work area. Safety glasses or other appropriate splash shields should be used when handling radioactive material.

Hands should be washed thoroughly after working with radioactive material.

Medical exposure Relative effective dose and equivalent period of exposure to natural background radiation

The effective dose of X-ray and nuclear medicine investigations mainly lies between 0.5 mSv and 10 mSv. In general, doses from individual radiological investigations are seldom greater than 10 mSv, most being of the order of 2-3 mSv, which is comparable with individual doses received from natural sources over one year. The X-ray investigations with the highest effective dose are CT of the chest and abdomen, and barium enema (approximately8 mSv). X-ray fluoroscopy is another procedure which can result in comparatively large radiation exposure to both patients and staff. In nuclear medicine the most commonly used procedure, the Tc-99m bone scan, results in an effective dose of less than 4 mSv (table 2.1).

Table 2.1 — Medical exposure. Relative effective dose and equivalent period of exposure to natural background radiation

	Effective dose (mSv)	Equivalent period of natural radiation
Radiography		
Chest	0.02	3 days
Pelvis	1.0	6 months
IVP	4.6	2.5 years
Barium studies	9.0	4.5 years
CT (Chest, Abdomen)	8.0	4 years
Nuclear Medicine		
Thyroid imaging	1.0	6 months

Bone imaging	3.6	1.8 years

Radon

Radon-222 is a radioactive gas released during the natural decay of thorium and uranium, which are common, naturally occurring elements found in varying amounts in rock and soil. Odorless, invisible, and without taste, radon cannot be detected with the human senses.

Radon-222 decays into radioactive elements, two of which — polonium-218 and polonium-214 — emit alpha particles, which are highly effective in damaging lung tissues. These alpha-emitting radon decay products have been implicated in a causal relationship with lung cancer in humans (figure 2.3).

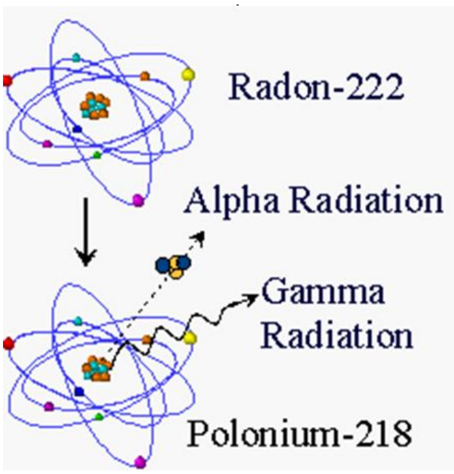


Figure 2.3 — Radon decay products (polonium-218 and polonium-214, stable form)

If inhaled, radon decay products (polonium-218 and polonium-214, stable form), unattached or attached to the surface of aerosols, dusts, and smoke particles, become deeply lodged or trapped in the lungs, where they can radiate and penetrate the cells of mucous membranes, bronchi, and other pulmonary tissues. The ionizing radiation energy affecting the bronchial epithelial cells in the lungs is believed to initiate the process of cancer causing process.

Sources of radon

Outdoors, where it is diluted to low concentrations in the air, radon poses significantly less risk than indoors. In the indoor air environment, however, radon can accumulate to significant levels. The magnitude of radon concentration indoors depends primarily on a building's construction and the amount of radon in the underlying soil. The soil composition under and around a house affects radon levels and the ease with which radon migrates toward a house. Normal pressure differences between the house and the soil can create a slight vacuum in the home that can draw radon gas from the soil into the building.

Radon gas can enter a building from the soil through cracks in concrete floors and walls, floor drains, sump pumps, construction joints, and tiny cracks or pores in hollow-block walls. Radon levels are generally highest in basements and ground floor rooms that are in contact with the soil. Factors such as the design, construction, and ventilation of the home affect the pathways and sources that can draw radon indoors. Another source of radon indoors may be air released by well water during showering and other household activities. Compared to radon entering a building home through soil, radon entering a building through water will in most cases be a small source of risk.

Radon is measured in picoCuries per liter of air (pCi/L), a measurement of radioactivity.

It should always be remembered that radon is a radioactive substance.

Though radon is most prominent in homes, the workplace is also affected.

In addition to geographic location, the level of ventilation in the workplace is an important indicator. Radon levels are generally low in workshops and other well ventilated workplaces. However, problems have been found in more confined workplaces such as shops, offices and public buildings where rates of ventilation are relatively low. Building construction is also an important indicator because radon is often drawn into the building through cracks in floors and gaps around pipes, cables, drains etc. Finally, high radon levels are rarely found above the ground floor of buildings but can be most severe in cellars and basements (figure 2.4).

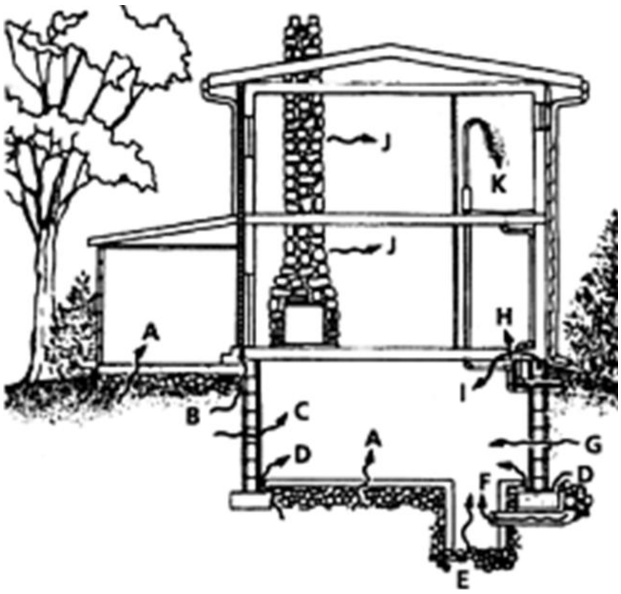


Figure 2.4 — How radon enters a building

Radon can enter a building in various ways. It can enter through:

A. Cracks in concrete slabs.

B. Spaces behind brick veneer walls that rest on uncapped hollow-brick foundation.

C. Pores and cracks in concrete blocks.

D. Floor-wall joints.

E. Exposed soil, as in a sump.

F. Weeping (drain) tile, if drained to open sump.

G. Mortar joints.

H. Loose fitting pipe penetrations.

I. Open tops of block walls.

J. Building materials such as some rocks.

K. Water (from some wells).

There are several methods that a contractor can use to lower radon levels in your home. Some techniques prevent radon from entering your home while others reduce radon levels after it has entered. EPA generally recommends methods which prevent the entry of radon.

Reducing radon entry by:

• Collecting it prior to entry into the building and discharging it to a safe location.

• Modifying building pressure differentials or sealing entry points.

Methods that reduce radon concentrations after entry by:

• Dilution with increased ventilation.

• Filtering radon from the air.

Radon is able to dissolve in water and accumulate in water from underground sources (called ground water), such as wells. When water that contains radon is used in buildings, the radon gas escapes from the water and goes into the air, raising the room's radon content.

Each year, 183 people die from exposure to radon in drinking water. Most of the cancer risk from radon in drinking water arises from the transfer of radon into indoor air, and exposure through inhalation, although there is some risk from ingesting water containing radon.

The primary health risks from radon in drinking water are lung cancer, from inhaling radon discharged from water used in the home, and stomach cancer, from ingesting radon in drinking water.

Radon can be removed from water by using one of two methods: aeration treatment or granular activated carbon (GAC) treatment.

Aeration treatment involves spraying water or mixing it with air, and then venting the air from the water before use. Aeration is more efficient than GAC; but it requires annual cleaning to maintain effectiveness and to prevent contamination. The system must also be carefully vented. These systems usually remove 95–99 % of the radon.

GAC treatment filters water through carbon. Radon attaches to the carbon and leaves the water free of radon. The carbon may need special handling in its disposal if it is used at a high radon level or if it has been used for a long time. The tank may need a radiation shield around tank to protect against the radon decay buildup. These systems usually remove 85–99 % of the radon.

Territory of Belarus are in the third group of the countries on radon danger, however considering failure consequences on ChNPS and non-uniformity of distribution of radonic potential on RB territory, it is necessary to define radiating conditions in RB territory, defined by radon presence.

Typical tasks and their solution:

Task 1

Calculate an annual effective dose (AED) an external irradiation because of Chernobyl emissions of radionuclides for inhabitants of village N if average power exhibition dose (PED) in the given settlement makes doses 25 mcR/h. Before failure on ChNPS the gamma background average level was equal in the given village 8 mcR/h.

The solution:

AED external training because of Chernobyl emissions is defined by a following parity:

$$AED = Kgeneral \times K\ protective \times (X-X0),$$

where: AED — an annual effective dose of an external irradiation, mSv/year;

Kgeneral — generalized factor of transition from PED in air at height of 1 m to AED an external irradiation of a body of the person, equal 0,053 mSv × H/year × mcR;

Kprotective — the dimensionless factor characterizing seasonal fluctuations of level PED, various modes of behaviour and protective properties of workers and premises of critical group of the population (foresters, machine operators, agriculturists, and housing and communal services, etc.).

Values of Kprotective for different types of settlements: village — 0,41; township — 0,30; a city — 0,24.

X — average MED in settlement, mcR/h;

X0 — The average level background scale in settlement before failure on ChNPS, mcR/h. At unknown value before accident a background it is accepted equal 10 mcR/h.

$$AED = 0,053 \times 0,41 \times (25 - 8) = 0,37\ mSv/year.$$

In the absence of measurements PED in settlement for calculation AED use indicators of density of pollution in the ratio:

$$AED\ Kgen \times Kd\ (density) \times S\ (Cs),$$

where: AED — an annual effective dose of an external irradiation, mSv/year;

Kgen — the generalised factor of transition from PED in air at height of 1 m to AED an external irradiation of a body of the person, equal 0,053 mSv×h/year×mcR;

S (Cs) — density of pollution of territory of settlements 137Cs, kBq/cm^2 or Cu/km^2;

Kd — average factor of transition from density of pollution of soil 137Cs to PED, calculated according to TLD (termo luminescent dosimeter) — MEASUREMENTS for settlements of different type:

Kd = $4,7 \times 10^{-2}$ at use of values S (Cs) in kBq/м^2;

Kd = 1,75 at use of values S (Cs) in Cu/km^2.

For example, if the density of pollution of territory of settlement makes 10 Cu/km^2.

$$AED = 0{,}053 \times 17{,}75 \times 10 = 0{,}92 \text{ mSv/year.}$$

From NRS (norms of rad.safety)-2000 we know that dose limit (DL) for the population it is equal 20 mSv. Hence, the received equivalent dose does not exceed dose limit (0, 0041 Sv: 0, 02 Sv = 0,205)

Task 2

To define the effective period of semideducing (Tef) iodine-131 from an organism of the adult person.

The solution:

The effective period of semideducing of Tef - time for which activity of the radioactive substance saved up in an organism decreases twice. Tef is under the following formula:

$$Tef = T1/2 \times Tb \,/\, (T1/2 + Tb),$$

where: T 1/2 — a half-life period of radionuclide; Tb — the period of biological semideducing — time during which because of biological processes of a live organism half of radioactive substance which have got to it is deduced approximately.

For iodine — 131 T 1/2 = 8, 04 days.

Tb = 138 days.

$$Tef = 8{,}04 \times 138 \,/\, (8{,}04 + 138) = 7{,}59 \text{ days}$$

Task 3

Define factor of easing by a premise of a background irradiation of the person on open district.

PED on open district — 20 mcR/h, indoors — 10 mcR/h.

The solution: K w (weakening) = PED open district / MEDindoors = 20 mcR/h / 10 mcR/h = 2, i.e. the premise weakens an external irradiation of the person in 2 times.

Task 4

What dose from value of capacity of an exposition dose 20 mcR/h will be received by the person who is in the street 5 hours a day.

The solution:

20 mcR/h × 5 h = 100 mRem, since Rem — a biological equivalent of a X-ray.

Task 5

Calculation on density of pollution of territory by radionuclides of caesium-137.

Calculate an annual effective dose (AED) external irradiation because of Chernobyl emissions of radionuclides for inhabitants of the village N., if the density of pollution of territory of settlement makes 5 Cu/km2.

The solution: in this case for calculation AED the following parity is used:

$$AED = Kgen \times Kd \times S\ (Cs),$$

where: AED — an annual effective dose of external irradiation, mSv/year;

Kgen — the generalised factor of transition from PED in the air at the height of 1 m to an annual effective dose of external irradiation of a body of the person (table), equal 0,053 mSv×h / (year×mcR);

Kd — an average factor of transition from the density of soils pollution Cs-137 to PED, calculated according to TLD (termo luminescent dosimeter) measurements for a great number of settlements of different type (table). Kd = 0, 047 at use of values S (Cs) in kBq/m^2; Kd = 1, 75 at use of values S (Cs) in Cu/km^2.

S (Cs) — density of pollution of territory of settlement Cs-137, kBq / m^2 or Cu/km^2.

AED = 0,053 × 1, 75 × 5 = 0, 46 (mSv/year)

Task 6

What fraction of a radioactive sample has decayed after two half-lives have elapsed? (a) 1/4(b) 1/2(c) 3/4 (d) not enough information to say.

The solution:

(c). At the end of the first half-life interval, half of the original sample has decayed and half remains. During the second half-life interval, half of the remaining portion of the sample decays. The total fraction of the sample that has decayed during the two half-lives is:

$$\frac{1}{2}+\frac{1}{2}\left(\frac{1}{2}\right)=\frac{3}{4}$$

Task 7

Calculate ED (mSv) to red bone marrow adult due to internal exposure when used with a diet of milk with a specific activity of cesium-137, 370 Bq / kg.

Annual consumption of milk to accept equal 399 kg.

The solution:

Calculation is made according to the formula:

$$H = A \times B \times I,$$

where: H — an equivalent dose in Sv;

A — specific activity of radionuclide in the given foodstuff in Bq/kg;

B — dose factor of an internal irradiation at oral administration of radionuclide in an organism equal.

$$1{,}3 \times 10^{-8} \text{ Sv/Bq},$$

where: I — the use of the given foodstuff in kg/year.

If specific activity of a product on a task is given in Cu/kg it is necessary to translate it in system units, i.e. in Bq/kg.

For calculation ED (in a mSv/year) it is multiplied dose factor by specific activity and annual consumption of a product:

H = 1,3 × 10^{-8} Sv/Bq × 370 Bq×399 kg/year = 0,001919 Sv/ year = 1,919 mSv/year.

Task 8

Calculate annual ED (in mSv) because of an internal irradiation for the 6-year-old child at the use with food of milk with specific activity on caesium-137 of 370 Bk/kg. The annual use of milk to accept equal 85 kg.

The solution:

Similarly to the previous problem, except that it is necessary to make an amendment to the frequency rate of doses excess with a child К=2, 28 (on tab.), value dose factor can be found in the table B = 1, 4 × 10^{-8} Sv/Bq:

H = B × K × A × I

H = 1,4 × 10^{-8} Sv/Bq × 370 Bq/kg × 85 kg/year × 2,28 = 0,001004 Sv/year or 1,004 mSv/year.

Task 9

Calculate annual ED (in Sv) on a thyroid gland of the child at the age of 10 years if mid-annual volume activity of atmospheric air on iodine-131 is equal 3,0 × 10^{-13} Cu/l (receipt ways - through breath bodies).

The solution:

Calculation is made according to the formula:

$$H = V \times A \times B \times K,$$

where: H (Sv/year) — an equivalent dose (or an effective equivalent dose);

A (Bq/m^3) — volume activity of radionuclide in air;

B (Sv/Bq) — dose factor of internal irradiation at inhalation receipt radionuclide in an organism; K — factor of frequency rate of excess of doses with a child of 10 years (3, 01).

Volume of breath of the 10-year-old child — 15 m^3/day (tab.). Hence,

V = 5475 m^3/year.

Dose factor of internal irradiation at inhalation receipt in an organism of iodine-131 for thyroid gland B = 2, 9 × 10^{-7} Sv/Bq (tab.).

We move volume activity of the air in system units.

3, 0 ×10^{-12} Cu/l = 3, 0 × 10^{-12} × 3, 7 × 10^{10} × 10^{3} = 111 Bq/m^{3}.

We count annual ED:

H = 5475 m^{3} × 111 Bq/m^{3} × 2, 9 × 10^{-7} Sv/Bq × 3, 01 = 0, 53048 Sv/years.

Tasks for the solution:

Task 1

As a result of a short-term receipt of iodine-131 in an organism of the adult person specific activity of its thyroid gland has reached 200 MBq/kg. To define weight of the iodine-131 incorporated in a thyroid gland. After what time will the maintenance of radioactive iodine in a thyroid gland of this person decrease in 2 times? 5 times? 100 times?

Task 2

After what time will that activity of the caesium-137 incorporated in the body of the inhabitant injured after the disaster on ChNPS decrease in 5 times if he lives in «a pure» zone? 10 times? 100 times?

Task 3

Define annual absorbed and equivalent doses of external background gamma radiation of inhabitants in Bragin in the Gomel region in 1990, if to consider that they on the average spent 5 hours per day in the open air. Average capacity of an exposition dose in this settlement on distance 1m from, to an earth surface in 1990 was approximately equal 270 mcR/h, in buildings — 30 mcR/h.

Task 4

Calculate an annual effective dose (in mSv) of external irradiation because of Chernobyl emissions radionuclides for inhabitants of village N., if average PED is equal in the given settlement 90 mcR/hour (before failure on ChNPS the average level of a background of gamma radiation was equal 12 mcR/hour in the given village).

Task 5

Calculate an annual effective dose (in mSv) of external irradiation because of Chernobyl emissions radionuclides for townsmen M if average PED is equal 0.065 mR/hour in the given settlement.

Task 6

Calculate an annual effective dose (in mSv) of external irradiation because of Chernobyl emissions of radionuclides for inhabitants of the village G if average PED is equal 65 mcR/hour in the given settlement. Before the failure on ChNPS the average level of a background of gamma radiation was equal 5 mcR/hour in the given village.

Task 7

For 1 year a person receives 2 mSv from a natural irradiation. Define a dose received by during 50 years.

Task 8

Because of the sources of space radiation the person receives in a year 0.315 mSv, including the influence of external irradiation 0.3 mSv/year and because of internal — 0.015 mSv/year. Define how much does the person receive during 50 years from the sources of space radiation, including because of the influence of external and internal irradiation.

Task 9

Capacity of an exposition dose in Gomel makes 14 mcR/h. What dose from this background is received by the person for a year which is in a premise of 80 % of time of days?

Task 10

Calculate, how many times does the annual effective dose of external irradiation because of emissions of radionuclides after the disaster on ChNPS exceed a dose limit if it is known that average PED in village A at the moment — 0,073 mR/hour.

Task 11

Calculate an annual effective dose (rem) of external irradiation because of Chernobyl emission of radionuclides, received by inhabitants of a settlement of city type if average PED is equal 0,07 mR/hour in the given settlement. Before failure on ChNPS the gamma background average level was equal 9 mcR/hour in the given village.

Task 12

Calculate an annual effective dose (mcSv) of external irradiation because of Chernobyl emissions of radionuclides, received by townsmen N if average PED is equal 0, 035 mR/hour in the given settlement.

Task 13

Calculate an annual effective dose (rem) of external irradiation because of Chernobyl emissions of radionuclides for inhabitants of the village N if the average density of territory pollution of the given settlement by Cs137 is equal 15 Cu/km^2.

Task 14

Calculate an annual effective dose (мSv) of external irradiation because of Chernobyl emissions of radionuclides for inhabitants of village N if the average density of territory pollution of the given settlement by Cs137 is equal 610 kBq/m^2.

Task 15

Calculate, in how many time the annual effective dose of external irradiation because of emissions of radionuclides after failure on ChNPS exceeds a dose limit if it is known that average PED in the village N at the moment is 0,074 mR/hour. Before the failure on ChNPS the gamma background average level was equal 0,009 mR/hour.

TEST CONTROL

1. A nuclear charge equal to the ...

a) number of protons in the nucleus;

b) number of neutrons in the nucleus;

c) sum of the number of protons and neutrons in the nucleus.

2. The nucleus of an atom of potassium-40 atom contains 19 protons and 21 neutrons. What is the atomic number of this item?

a) 19;

b) 40;

c) 21.

3. The term «nucleon» belongs to ...

a) beta particles;

b) proton;

c) alpha-particles.

4. Isotopes are ...

a) atoms with different atomic number, but an equal number of neutrons in the nucleus;

b) atoms with different atomic number and mass number

c) atoms with one and the same atomic number but with different mass numbers.

5. To the term «radionuclide» refers to ...

a) the nucleus of a radioactive element;

b) the particle, part of the nucleus;

c) the nucleus of the stable atom.

6. A unit of radioactivity is ...

a) Gy;

b) Bq;

c) R.

7. The Law of the Republic of Belarus «On radiation safety»stated that the basic principles of radiation safety practices are:

a) a optimization principle;

b) the principle of limiting doses of external and internal exposure of the population because of Chernobyl radionuclides release;

c) the principle of noninterference.

8. The law of radioactive decay characterizes ...

a) the reduction in the number of active atoms in time;

b) the type of decay of radioactive nuclei;

c) the mode energy release of radioactive nuclei.

9. During the process of alpha decay is ...

a) formed daughter nucleus with a mass less than 4 and with a charge less than 2 than in the mother nucleus;

b) nucleus is ejected from a heavy nucleus of a hydrogen atom;

c) formed a new nucleus with the mass and charge less for 2 than that of the mother nucleus.

10. By calculating of the equivalent dose using radiation weighting factor should be taken into account:

a) the radiosensibility of the tissue to this type of radiation;

b) the lethality of this type of radiation compared to a standard X-rays;

c) the probability of stochastic effects of irradiation.

11. The equivalent dose is ...

a) the radiation dose equal to the product of the absorbed dose weighting factor for the tissue of the body;

b) the radiation dose equal to the product of the exposure dose by a factor of the quality of ionizing radiation;

c) the radiation dose equal to the product of the absorbed dose by a factor of the quality of this type of ionizing radiation.

12. Tissue weighting multiplicator is used to calculate an ...

a) exposure dose;

b) equivalent dose;

c) effective dose.

13. Unit of absorbed dose corresponds to the ...

a) rad;

b) J;

c) Sv.

14. A dose of 1 Gy corresponds to the absorption of ...

a) 1 J energy 1g of substance;

b) 1 J energy 1 kg of substance;

c) 1 meV energy 1kg of substance.

15. Gray is a unit of an ...
a) absorbed dose;
b) equivalent dose;
c) exposure dose.

TOPIC 3
THE RADIO ECOLOGICAL SITUATION IN BELORUS AFTER CHERNOBYL ACCIDENT

The motivational characteristic of the theme

The knowledge of the characteristics of the radionuclides cores dose from Chernobyl emission, radionuclides ways migration in biosphere, principles of calculation of doses of external irradiation at residing on polluted radionuclide territory is necessary for the estimation of the exposure doses and carrying out of preventive actions for decrease in doses of external and internal irradiation.

The general time of employment: 4 hours

The employment purposes:

1) to acquire formation principles of exposure doses on the population after the failure on ChNPS;

2) to acquire principles of calculation of doses of external irradiation of a person while living on the territories polluted by radionuclides.

Employment problems:

1) to learn the features of radiating conditions in Belarus after the failure on ChNPS;

2) to acquire the characteristic of Chernobyl emission, its dynamics in time and space; migration ways of radionuclides in biosphere;

3) to learn the characteristics of the radionuclides cores dose coming from Chernobyl emission;

Requirements to initial level of knowledge

High-level mastering of the material of practical employment is possible when students acquire adequate knowledge of the laws of substances circulation in nature (biology), physical and chemical properties of elements of the first, second, seventh and eighth groups of periodic system of elements of Mendeleyev (the general and biological chemistry). For full mastering of the theme it is necessary for students to repeat the concept and the basic properties of biogene macro — and microcells (bioorganic and biological chemistry).

Control questions on the employment theme:

1. The disaster on ChNPS, dynamics of emission in time and space.
2. The influence of radionuclide ways from Chernobyl emission on the population of the republic and their participation in formation of effective doses of irradiation of the population at various times after failure.
3. Migration of radionuclides in biosphere: local and global emissions, features of radionuclides accumulation in hydrosphere and lithosphere; properties of radionuclides, defining features of their migration.
4. The comparative characteristic of oral and inhalation ways of radionuclides receipt in a human body.
5. The general laws of radionuclides distribution in a human body. Distribution types of radionuclides in a human body.
6. The characteristics (physical and chemical characteristic, receipt, distribution and deducing from an organism, possible biological effects) of the cores radionuclides of Chernobyl emission: Cs-134, Cs-137, Sr-89, Sr-90, H-3, I-131, 132, 133, 135, Pu-239, 240, Pu-241, Am-241, «hot particles». The role of various radionuclides in formation of the doses of the population in different terms after radioactive emission.
7. The international scale of nuclear events. Criteria of classification. Maintenance of radiating safety of the personnel and the population during radiating failures.
8. The concept of the population protection during radiating failures on the nuclear power station, including carrying out of blockade of a thyroid gland.
9. Radiometry. Direct and indirect radiometry. Radiometry objects of environment, foodstuff and water.

The additional information to the topic

Formation of radioactive pollution of RB (the Republic of Belarus) has begun right after reactor explosion since the radioactive cloud moved with air streams in northwest and northern directions. About 70 % of the radioactive substances which were thrown out from the destroyed reactor in atmosphere, as a result of dry and damp sedimentation fell out on territory of Belarus. Thus 23 % of territory of Belarus (46,5 thousand km^2) with 3221 settlements, including 27 cities, where lived 2,2 million persons (more than 400 000 children), were polluted by caesium-137 more than 37 kBq/m^2 (1 Cu/km^2). For comparison: in Ukraine the zone with the level of pollution more than 37 kBq/m^2 occupies the 28, 5 thousand space km^2 (5 %, 1599 settlements), in Russia-35, 2 of thousand km^2 10, 6 %, 1088 settlements).

Radioactive pollution extended on all areas of republic. It has non-uniform «spotty» character which is caused by the dynamics of emission and constantly changing meteoconditions.

Pollution maximum levels have been found out in a 30-kilometre zone round the nuclear power station:

— on caesium-137 — 18500 kBq/m^2 (500 Cu/km^2);

— to strontium-90 — more than 455 kBq /m^2 (more than 12 Cu /km^2);

— on plutonium-239,240 — nearby 150 kBq /m^2 (about 4 Cu /km^2).

However even outside alienation zone sites with high levels of pollution are revealed (Chydiany the Mogilyov area — 5402 kBq /m^2). There are cases when within one settlement there is a big distinction of levels of pollution of soil caesium-137. For example, in v. Veprin the Mogilyov area in east part of pollution 37 kBq /м^2 (1 Cu /km^2), in western — 2035 kBq /m2 (55 Cu /km^2); in v. Koliban the Gomel area pollution of soil from 174 to 2424 kBq /m^2.

The areas which have suffered from Chernobyl accident the most of Belarus are: Gomel, Mogilyov and Brest. In the Brest region considerable radioactive pollution is in Stolinsky, Pinsk, Luninetsky, Drogichinsky, Berezovsky and Baranovichsky areas. In the Minsk, Grodno and 4 settlements of Vitebsk region the caesium-137 maintenance in soil exceeds 37 kBq/m^2 (1 Cu /km^2). On the territory of Belarus levels of pollution of soil caesium-137 also before the accident the quantities only in northwest areas of Vitebsk area were comparable to global emissions.

There were thrown out into the environment:

1. Flying radioactive inert gases.
2. Hundreds the fragmental fission products which have collected in a zone of the reactor.
3. Isotopes of the induced radio-activity because of substances which dumped on the reactor.
4. Parts of nuclear fuel.

Right after failures radiating conditions in republic and formation of exposure doses on the population were defined by action of short-lived radionuclides: molybdenum, technetium, lanthanum, barium, noble inert gases, iodine-131 radioisotopes, 132, 133, 134, 135, 123, 125, 126. Under the settlement data, in environment 50–60 % of the radioisotopes which have collected in the reactor of iodine were emitted.

Levels of radioactive pollution of short-lived iodine radionuclides in many regions of republic were so great that the irradiation of millions people caused by them is qualified by experts as the period of **«*iodic blow*».**

Allocate some the basic types of influence of radionuclides of Chernobyl failure for a human body:

1. External gamma irradiation from a radioactive cloud.

It was short and proceeded before formation of the radioactive trace on district and objects of environment. Its contribution to the dose formation to the first afterwreck year made 2, 5 %.

2. Inhalation radionuclides received by a human body.

They constitute 4, 5 % of the dose because of internal irradiation of an organism. Aerosol pollution of atmospheric air can be divided into 2 stages:

1 Rather short-term which lasts from the moment of emission a gas-aerosol stream in atmospheric air, formation and carrying over of radioactive clouds till the moment of their sedimentation on the surface of the earth, water, objects of environment, i.e. inhalation receipt of radionuclides from a radioactive cloud;

2 Continuous — secondary pollution of atmosphere because of wind lifting of a dust.

Pollution of the ground layer of atmosphere as a result of the wind soil erosion is the additional factor of the territory pollution by radionuclides. The smallest aerosol parts are transferred with the air to the long distances owing to slow sedimentation. In some cases carrying over of radioactive dust caused repeated pollution of the deactivated territories. Secondary pollution of atmosphere by radionuclides due to the wind lifting of the dust represents special danger for the population constantly living and working in polluted territory.

3. External gamma radiation resting on the soil surface and the objects of environment of the radionuclides (deposits also intensively wash away radioactive substances from atmosphere).

The irradiation of an organism from settled radionuclide the long and intensive. It forms about 50–60 % of the dose which the population aqcuired.

The given type of the influence is caused, basically, by gamma radiation of caesium-137 and others gamma radiating radionuclides.

The major factors reducing external gamma radiation, are:

1. Natural disintegration of radionuclides;
2. Radionuclide migration deep into soils.

Now the dose in a human body is formed because of long-living radionuclides caesium-137 with a half-life period of 30 years; strontium-90 — 29, 1 years; tritium — 12 years; carbon-14 — 5730 years; plutonium-239 — more than 24000.

As results of the researches carried out on the polluted territories show, radionuclide migration deep into soils is insignificant. The caesium-137 great bulk later 12 years after failure is concentrated in the top 5-centimetric soil layer. In impoverished humus sod-podzol sandy soils the maximum of concentration of radio caesium is on depth 3,5–4, 5 Most intensively vertical migration see proceeds in peatbogs. The basic part of radio strontium (51–78 %) is in blankets (0–1 sm) soils, and 2–5 % — soluble. The nearest and long-term (50 years) forecasts show that self-cleaning of soils owing to vertical migration of radionuclides will occur extremely slowly.

Finding radionuclides in root-inhabited layer, and also increase in relative quantity of exchange strontium in the layers of soils long time will cause intensive radionuclide migration on food chains.

4. The penetration of radionuclide to an organism in food chains.

For our republic this type of influence of radionuclide has special value. It is connected with features of soils, mainly in Belarus Polesye.

Among the sites polluted by radionuclide more than half the soils of Belarus make soils with easy granulometric structure, absorption characterised by low capacity, the small maintenance humus and secondary clay minerals. In light soils of the republic radionuclides caesium-137 and strontium-90 it is abnormal are mobile, i.e. badly communicating soil particles and consequently the probability of their transition in plants is the high. Well fixed radionuclides are in humus, clay soil, and in Belarus Polesye soil which is sandy, podsolic, turfary, i. e. light.

The specified features of Polesky region have basic value and define high levels of radionuclide accumulation in local foodstuff and high exposure doses on organisms of the population living there. A bright example is the Lelchitsky area of the Gomel area on the territory of which there are the soils different in structure and on density of pollution by caesium 137.

Special danger is represented by the penetration of radioactive substances in a human body. Their concentration in this or that body of a body of the person can exceed many times that in environment. Behaviour of radionuclides in an organism — ways and ways of receiption, distribution in bodies and systems (including selective accumulation), speed and deducing ways depend on their chemical properties.

There are three basic ways of the penetration of radioactive isotopes to an organism:

Inhalation way — at inhalation of air polluted by radioactive aerosols.

Alimentary — through a gastroenteric path with water and food.

Through a skin — damaged and intact.

Distinguish some types of radionuclides distribution in an organism:

Uniform (Cs-137, C-14, H-3, Ru-106).

Skeletal (Sr-90, Zr-95, Ce-144, Pu-239, Am-241, Ra-226, Pb-210).

Thyroid (I-131).

Reticuloendothelial (Pu-239, Am-241, Zn-65, Fe-55).

Nephritic (U-238, Pb-210, Be-7).

Radio toxicity — the ability of radioactive isotopes to cause the big or smaller pathological changes when they penetrate an organism. Radio toxicity is caused by a number of factors: 1) a kind of radioactive transformation; 2) average energy of one certificate of disintegration; 3) the scheme of radioactive disintegration; 4) receipt radionuclides ways in an organism; 5) distribution type of radionuclide in an organism; 6) stay time of radionuclide in an organism; 7) duration of time of receipt in a body of the person.

The effective period (Teff) — time during which activity of an isotope in an organism decreases twice. The effective period can be calculated according to the following formula:

$$Teff = \frac{T_{1/2} \times T_b}{T_{1/2} + T_b},$$

where: $T_{1/2}$ — a half-life period;

T_b — the period of biological semideducing.

Transuranium elements — the chemical radioactive elements located in Periodic system of elements of D.I.Mendeleyev after uranium-238 that is with atomic number (Z) more than 92. Transuranium elements by bombing of heavy elements (uranium, thorium or protactinium) are received by neutrons. There are known 14 transuranium elements synthesised by means of nuclear reactions. With increase Z the half-life period of transuranium elements sharply decreases.

«Hot» particles are an aerosol of dispers nuclear fuel. They have various size, activity and radionuclide structure.

After the failure «hot» particles were carried by atmospheric air on considerable distances, but their great bulk has concentrated in the zone of alienation and the Gomel area.

«Hot» particles represent danger to all livingcreatures because of high concentration of radionuclides of different kinds radiations in them.

The feature of irradiation doses formation of the population living in polluted territories, is:

1) the prolonged external and internal irradiation due to the long-living radionuclides (Cs, Sr, Pu) in addition to the doses generated at an early stage of failure because of the short-lived radiation , especially iodine radioisotopes;

2) a certain part of the population is compelled to live on polluted by radionuclides territories, eating food products of local manufacture which form the basic exposure doses on an organism (more than 80 %). Thus countrymen receive much larger doses, than city.

The principles put in a basis of carrying out of all protective actions, are reduced to the following:

1. It is necessary to exclude any possibility of occurrence at the radiation sickness population.

2. The risk of the remote effects of radiation on a man's health should be lowered as much as it is possible.

According to the Law «About a legal regime of territories, exposed of radioactive pollution as a result of accident on ChNPS» (11/12/1991) all polluted by radionuclides territory of RB is divided into the *zones*:

Evacuation zone (alienations, a 30-kilometre zone).

The zone of the primary moving out — pollution density of radionuclides caesium-137 more than 40 Cu/km^2.

The zone of the subsequent moving out — with the density of pollution of territory of 15–40 Cu/km^2.

The zone with the right for moving out — with superficial activity 5–15 Cu/km^2.

The zone of periodic radiating control — with the density of pollution of 1–5 Cu/km^2.

The practical task.

Measurement minimum of effective dose, MED by means of dosimeter DKS — AT3509 indoors and on open district with the subsequent hygienic estimation of the received results.

TEST CONTROL

1. The main part of the dose from radon exposure is formed ...

a) by the expense of the radon;
b) due to radon decay products adsorbed on aerosol particles;
c) by themselves radon decay products.

2. The main dose load on the lungs is caused by ...

a) sorbed on aerosols of alpha-emitting decay products of radon;
b) sorbed on aerosols of beta-emitting decay products of radon;
c) sorbed on aerosols, of gamma-emitting decay products of radon.

3. Chernobyl release radionuclides, emerging now the primary dose load on the human body are:

a) iodine-131;
b) Cs-137;
c) ruthenium-106.

4. Emission Chernobyl radionuclides that have predominantly skeletal type of distribution in the human body are:

a) iodine-131;
b) strontium-90;
c) tritium.

5. On the territory of the pollution density with cesium-137 less than 5 Cu/km^2 the greatest importance in shaping the dose on the human body has:

a) irradiation for ingestion of radionuclides to the body;
b) irradiation with inhalation of radionuclides to the body;
c) exposure from deposition of radionuclides on the environment objects.

6. Most short-term impact of the Chernobyl release radionuclides on the human body has ...

a) irradiation for ingestion of radionuclide;
b) irradiation with inhalation of radionuclides;
c) irradiation from a radioactive cloud.

7. Chernobyl release radionuclides with a uniform type of distribution in

human organism are:

a) Cs-137;
b) plutonium-239;
c) iodine-131.

8. Immediately after the Chernobyl accident the bulk of the radiation dose at the population was formed by ...

a) cesium-137;
b) cesium-134;
c) iodine-131.

9. As a result of the Chernobyl release the greatest part of the territory of Belarus polluted with ...

a) strontium-90 and strontium-89;
b) plutonium-240 and plutonium-240;
c) cesium-134 and cesium-137.

10. Immediate resettlement zone corresponded to the territory of the Republic with contamination density of cesium-137 is ...

a) more than 40 Ci/km²;
b) 15–40 Ci/km²;
c) 1–5 Ci/km².

11. The contamination density of the Republic territory of Cs-137 from 15 to 40 Ci/km² corresponds to zone ...

a) with the right to resettlement;
b) of periodic radiation control;
c) of subsequent resettlement.

12. Absorption of strontium-90 in the gastrointestinal tract of an organism decreases ...

a) during lactation;
b) in childhood;
c) by using calcium-rich food.

13. To formation of «spotted» contamination of the Republic territory as a result of the Chernobyl accident contributed ...

a) a high-activity;
b) release of the duration and a uneven ejection time;
c) abnormally high temperatures.

14. Chernobyl release radionuclides with long-term biological half-life of an organism are:

a) americium-241;
b) tritium;
c) cesium-134.

15. Radionuclide enters the body primarily through the gastrointestinal tract thanks due to ...

a) a high-energy radiation;
b) the high degree of accumulation in the body;
c) a good solubility.

16. Mainly by inhalation to the organism enters ...

a) cesium-137;
b) strontium-90 ;
c) americium-241.

TOPIC 4
RADIOSENSIBILITY. RADIATION EFFECTS ON A PERSON

The motivational characteristic of the theme

The knowledge of mechanisms of radiosensibility at various levels of the organization of living matter and the features of radiation injuries developping of people in different age groups is necessary for the further practical activities of the doctor for the purpose of carrying out adequate treatment-and-prophylactic actions for supression of damaging effect of ionizing radiation.

The general time of lesson: 4 hours

The employment purposes:
To learn the features of radial damages occurring of a human body.

Employment problems:

1) to learn about the factors definingradiosensibility at different levels of the organization of living matter;
2) to learn about possible consequences of irradiation of a person;
3) to learn about the connection between an exposure dose and the degree of expression of clinical syndromes;
4) to learn about the algorithm of measurement of power of an air dose and the received results estimation;

To fix skills of work with the scientific literature.

Requirements to initial level of knowledge

For the development of the theme and the employment of the knowledge of the basics of physics, general chemistry, biology, biochemistry, normal physiology, general hygiene is necessary. High-level mastering of the material of practical employment is possible if students have adequate notions of cell structure, genome organization levels, about the critical periods of organogenesis, normal indicators of the maintenance of the elements of peripheric blood and the duration of their life, hemopoiesis stages.

Control questions on the employment theme:

1. Radiosensibility problem — the central problem of bioradiology and radiative medicine.
2. Molecular bases of radiosensibility. The factors defining radiosensibility at cellular level.
3. The factors defining radiosensibility at tissue level. Rule Bergone-Tribondo.
4. Individual and age differences in radiosensibility. Radiation action on embryos and a foetus.
5. Radiosensibility updating.
6. The factors defining a lesion of an organism. Concept of «a critical organ».
7. Radiative syndromes: osteo-brain, gastroenteric, cerebral, and their dependence on a dose.
8. The characteristic of an osteo-brain syndrome: a pathogenesis, phases, causes of death of an organism.
9. The characteristic of a gastroenteric syndrome: a pathogenesis, causes of death of an organism.
10. The characteristic of a cerebral syndrome: a pathogenesis, causes of death of an organism.

The additional information to the topic

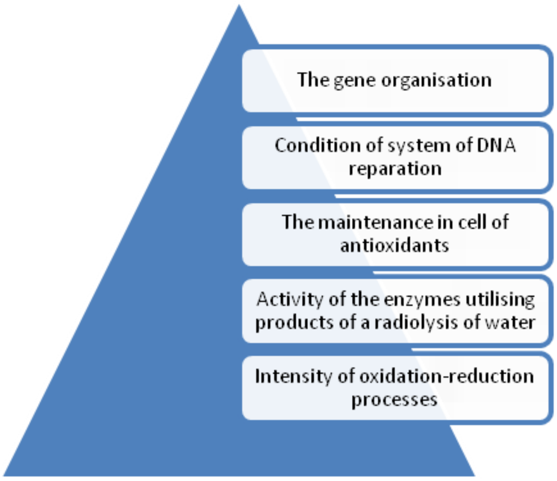
Radiosensibility is the relative susceptibility of cells, tissues, organs, organisms, or other substances to the injurious action of radiation.

In general, it has been found that cell radiosensibility is directly proportional to the rate of cell division and inversely proportional to the degree of cell differentiation. In short, this means that actively dividing cells or those not fully mature are most at risk from radiation.

Alternative concepts — a ***radioresistance.***

Correctly to estimate consequences of an irradiation of a human body, it is necessary to estimate radiosensibility at various levels — cellular, tissue, organ, organismic.

At cellular level of the radiosensibility depends on a number of factors:



At tissue level ***rule Bergonie and Tribondeau*** is carried out: the tissue radiosensibility is directly proportional to proliferative activity and inversely proportional to the degree of the differentiation of cells making it.

«X-rays are more effective on cells which have a greater reproductive activity».

At the organ level radiosensibility depends not only on the radiosensibility of tissues that make up the body, but also on its functions.

The radiosensibility problem is the central problem of radio biology. For example, the lethal dose of IR (ionizing radiation) for the person of 6 Gy corresponds to the absorbed energy in 1 J on kg of weight of a body that can cause body heating on 0,01 degrees or corresponds to the energy concluded in a glass of warm tea. This effect named the basic paradox of radio biology, can be caused emissions of small portions of energy in minute volumes that leads to a considerable local warming up and damage of sensitive biological structures. It is possible to offer one more interpretation: interaction occurs at nuclear and molecular levels, its result are ionization or excitation of atoms or molecules of biological structures which then enter various chemical reactions, causing damages.

Now there is no the uniform theory offering a full and universal explanation of biological effects of IR. We will define the basic scientific theories and the hypotheses explaining now biological effects of IR.

1. *The theory of targets and a principle of hits* is offered by Dessauer in 1922. This classical representation based on carrying over of mechanisms of interaction of IR with substance on biological structures. The cage has sensitive structures — of «target», for example, DNA molecule hit in which leads to fatal defeat. The theory well explains the results received in experiments on cultures of cages and simple organisms.

2. *The stochastic hypothesis* arisen and successfully developed with introduction of mathematical methods in radio biology. Consists in mathematical modelling of a cellular cycle and distribution of its stages on radio sensitivity. The hypothesis is capable to describe more difficult and thin radio biological effects.

3. *The structurally-metabolic hypothesis* was extended in the middle of 20th century after experimental reception of specific substances — of products of an irradiation, so-called radio toxins. Introduction of radio toxins in not irradiated healthy cage caused the reactions similar to the irradiated cell. In a hypothesis basis it is put specified structure of cell, it differentiation and that fact that the cell is elementary object of a metabolism According to a hypothesis, by absorption energy of IR there are the metabolic shifts causing synthesis of low-molecular connections — of toxins which lead to a cell poisoning. Advantage of a hypothesis is the explanation of effects of defeat lipid (cellular membranes) and durations of display of biological effects.

Most often as a radiosensibility measure it is used LD50 — the dose of the irradiation causing destruction of 50 % of irradiated organisms for various time after an irradiation (depending on a kind of live organisms).

At cellular level radiosensibility depends on a number of factors:

1. The organisation genom.
2. A condition of system of a reparation of DNA.
3. The maintenance in a cage of antioxidants.
4. Activity of the enzymes utilizing products of water radiolysis.
5. Intensity of oxidation-reduction processes.

Critical bodies are vitals and systems which are damaged by the first in the given of dose range that causes destruction of an organism in certain terms after an irradiation.

Depending on critical body allocate 3 basic radiating syndromes: **Radiation Sickness**

Radiation Sickness is a form of damage to organic tissue due to excessive exposure to ionizing radiation.

A radiological accident is defined as an unforeseen event involving over-exposure or contamination of persons/the environment by radioactive material.

Acute Radiation Syndrome (ARS) (sometimes known as radiation toxicity or radiation sickness) is an acute illness caused by irradiation of the entire body (or most of the body) by a high dose of penetrating radiation in a very short period of time (usually a matter of minutes).

The latest major nuclear and radiological accidents have contributed to the diagnosis, monitoring and treatment of radiation injuries:

Explosion of the vapour at the Chernobyl Nuclear Power Plant in April 1986 resulted in the hospitalization of 237 patients identified as overexposed persons. 134 of them developed ARS. Of these 134 exposed persons, 28 eventually died of ARS associated injury with extensive radiation burns.

In September 1987, a shielded radioactive caesium-137 source was removed from the protective housing of an abandoned teletherapy machine in Goiânia, Brazil. Subsequently, the source was ruptured. As a result, many people incurred large doses of radiation by both external and internal contamination. Four of the casualties ultimately died, and 28 people developed local radiation injuries.

In 1989, a radiological accident occurred at an industrial sterilization facility in San Salvador, El Salvador. The accident occurred when the cobalt-60 source became stuck in the open position. Three workers were exposed to high radiation doses and developed ARS. The immediate acute effects were limited by specialized treatment. Nonetheless, two of the men were so seriously injured that their legs had to be partly or completely amputated. The most highly exposed worker died 6.5 months later, his death attributed to residual lung damage and other injuries.

Radiation Sickness sometimes known as *Acute Radiation Syndromes* has three classes:

1. Hematopoietic Syndrome.
2. Gastrointestinal Syndrome.
3. Cardiovascular / Central Nervous System Syndrome.

Hematopoietic syndrome —the full syndrome will usually occur with a dose between 0.7 and 10 Gy (70–1000 rads) though mild symptoms may occur as low as 0.3 Gy or 30 rads.

The survival rate of patients with this syndrome decreases with increasing dose. The primary cause of death is the destruction of the bone marrow, resulting in infection and hemorrhage.

Gastrointestinal (GI) syndrome — the full syndrome will usually occur with a dose between 10 and 100 Gy (1000–10,000 rads) though some symptoms may occur as low as 6 Gy or 600 rads.

Survival is extremely unlikely with this syndrome. Destructive and irreparable changes in the GI tract and bone marrow usually cause infection, dehydration and electrolyte imbalance. Death usually occurs within 2 weeks.

Cardiovascular (CV)/ Central Nervous System (CNS) syndrome — the full syndrome will usually occur with a dose greater than 50 Gy (5000 rads) though some symptoms may occur as low as 20 Gy or 2000 rads.

Death occurs within 3 days. Death is likely due to collapse of the circulatory system as well as increased pressure in the confining cranial vault as the result of increased fluid content caused by edema, vasculitis and meningitis.

Radiation Sickness Stages

• Prodromal stage (N-V-D stage) — The classic symptoms for this stage are nausea, vomiting and diarrhea that occur from minutes to days following exposure. The symptoms may last (episodically) for minutes up to several days.

• Latent stage — In this stage the patient looks and feels generally healthy for a few hours or even up to a few weeks.

• Manifest illness stage — In this stage the symptoms depend on the specific syndrome (see Appendix) and last from hours up to several months.

• Recovery or death — Most patients who do not recover will die within several months of exposure. The recovery process lasts from several weeks up to two years.

On the level of population radiosensibility depends on the following factors:

1. Features of a genotype (10–12 % of people possess the raised radiosensitivity).
2. Physiological (dreaming, vivacity, weariness, pregnancy) or patophysiological organism condition (chronic diseases, burns, traumas).
3. Level of radiosensibility (men possess high radiosensibility).
4. Age (people of middle age are the least sensitive).

Features of radiosensitibility in the pre-natal development period are revealed in high radiosensibility tissue of a fetus. A little different is irradiation of pregnant women which has four classical effects at posterity:

— embryonic, neonatal and afternatal destruction of a fetus;
— Congenital developmental anomalies;
— Infringement of growth and physical development;
— Infringement of the central nervous system functions.

Sharp radiation sickness (SRS)

As radiation sickness of the person displays a complex of amazing action of ionizing radiation on an organism. The variety of displays depends on a number of factors:

— An irradiation kind — local or the general, external or internal (from incorporated radionuclides).
— Irradiation time — unitary, prolonged, chronic.
— Spatial factor — uniform or non-uniform.
— Volume and localization of the irradiated site.

Sharp radiation sickness at a unitary external uniform irradiation is the most typical example of radiating injury of the person. A threshold dose for display SRS — 1 Gy. At external unitary irradiation in a dose of 0, 25 Gy appreciable deviations in the state of health irradiated are not marked. The irradiation in a dose from 0, 25 to 0, 5 Gy can cause insignificant time deviations as a part of peripheral blood, from 0, 5 to 1 Gy — symptoms vegetative disregulation and unsharply expressed decrease in quantity platelet and leukocytes (A. K. Guskova, etc., 1985) (table 4.1).

Allocate four basic clinical forms of SRS:

1. Osteo-brain (a dose of 1–10 Gy).
2. Intestinal (a dose of 10–20 Gy).
3. Toxemic (a dose of 20–80 Gy).
4. Cerebral (a dose more than 80 Gy).

Table 4.1 — Clinical forms and severity levels of sharp radiation sickness

Clinical forms	Severity level	An irradiation dose ± 30 %, Gy	The Forecast	Duration of the latent period	Terms		
					obligatory hospitalisation	treatments in a hospital	approaches of deadly outcomes
Osteo-brain	I — easy	1–2	favorably	4–5 weeks	Usually is not required	—	—
	II — average weight	2–4	predominant favourable	2–3 weeks	20-s days	2–3 month	5-s weeks
	III — rough	4–6	doubtful				
	IV — extreme rough	6–10		1,5 weeks	8-s days	3–4 months	3–4-s weeks
Intastinal	The same	10–20	The same	1–2 days	The same	—	1–1,5-s weeks
Toxemic	The same	20–80	absolutely unfavorable	—	The same	—	3–6-s day
Cerebral	The same	80 and more	The same	—	The same	—	to 48 hours

Radiosensibility updating is made by means of special chemical preparations — of radio protectors, and also the products, containing antioxidants, vitamins and the preparations strengthening immunity. Efficiency of application of modifying means can reach 2 and more times.

PRACTICAL PART

Typical tasks and their solution:

Task 1

Calculate, in how many times does the basic dose exceed the limit (LD) of the equivalent dose on a thyroid gland of the adult woman if the mid-annual volume activity of atmospheric air on iodine-131 is equal $2{,}0 \times 10^{-13}$ Cu/l (a receipt way — through breath bodies).

The solution:

Calculation is made according to the formula:

$$H = V \times A \times B,$$

where: H (Sv/year) — an equivalent dose;

V (m^3/year) — annual volume of breath;

A (Bq/m^3) — volume of radionuclide activity in the air;

B (Sv/Bq) — dose factor of internal irradiation at inhalation receipt of radionuclide in an organism.

Volume of breath of the adult woman — 21 m^3/day (tab.). Hence, for a year:

$V = 21 \times 365 = 7665$ m^3/year.

We move volume activity of air in system units:

$2,0 \times 10^{-13}$ Cu/l = 7, 4 Bq/m^3;

UNDER the table it is found dose factor of an internal irradiation at inhalation receipt I-131 for a thyroid gland,

$B = 7,2 \times 10^{-8}$ Sv/Bq

For calculation H we multiply quantity of the past through lungs of air (V) on дозовый factor (B) and by volume activity of air (A):

$H = 7.2 \times 10^{-8}$ Sv/Bqk × 7665 m^3 × 7, 4 Bq/m^3.

Tasks for the solution:

Task 1

Calculate an annual effective dose (mkSv), received by the young man during 17 years because of eating potatoes with specific activity on ^{90}Sr equal $2,1 \times 10^{-10}$ Cu/kg. Annual consumption of potatoes is 80.

Task 2

Define the effective period of semideducing of iodine-131 from an organism of an adult person.

Task 3

Define the effective period of semideducing of strontium-90 from an organism of an adult person.

Task 4

Define the effective period of semideducing of caesium-137 from an organism: of an adult person; a teenager; a newborn.

Task 5

Calculate an annual effective dose (mcSv), received by the child during 14 years because of internal irradiation if the average volume activity of atmospheric air on Cs_{137} is equal $2,8 \times 10^{-14}$ Cu/l (a way of receipt Cs_{137} — inhalation).

Task 6

Calculate an annual effective dose (mcSv), received by the adult person because of drinking milk with specific activity on I_{131} equal $2,5 \times 10^{-11}$Cu/kg. Annual consumption of milk — 150 kg.

Task 7

Calculate an annual effective dose (mcSv), received by the adult person because of eating potatoes with specific activity on Cs_{137} equal $1,8 \times 10^{-10}$Cu/kg. Annual consumption of potatoes — 80 kg.

Task 8

Calculate ED (in mSv) on a red bone brain of the adult person because of internal irradiation due to eating the food and drinking milk with specific activity on Cs-137 370 Bq/kg.

Annual consumption of milk is equal 399 kg.

Calculation is made according to the formula:

$$H = A\times B\times I,$$

where: H — ED in Sv;

A — specific activity of radionuclide in the given foodstuff in Bq/kg;

B — dose factor of an internal irradiation at per oral absorption of radionuclide in an organism is equal: 1.3×10^{-8} Sv/Bq,

where I — the use of the given foodstuff in kg/year?

Task 9

Calculate an annual effective dose (mSv), received during 16 years by the young man because of internal irradiation, if average volume activity of atmospheric air on Cs_{137} is equal $4{,}7\times10^{-14}$ Cu/l (the way of receiving Cs_{137} is by inhalation).

Task 10

Calculate, in how many times does the basic dose received by the adult person exceed the limit if volume activity of atmospheric air on Sr_{90} is equal $9{,}0\times10^{-14}$ Cu/l (the way of receiving Sr_{90} — is by inhalation).

Task 11

Calculate, in how many times does the basic dose received by the adult person exceed the limit if volume activity of atmospheric air on Cs_{137} is equal $1{,}2\times10^{-12}$ Cu/l (the way of receiving Cs_{137} — is by inhalation).

Task 12

Activity of the iodine-131 incorporated in a thyroid gland of the adult person at the moment of its evacuation on May, 15th, 1986 in a «pure» zone after failure on ChNPS, has made 2.8 MBq. Calculate an equivalent dose of an internal irradiation of a thyroid gland of this person by iodine-131, after evacuation for the next 10 days; 20 days; 60 days; 1 year; 5 years.

Task 13

The maximum absorbed dose of internal irradiation iodine-131 of a thyroid gland of the child at its constant residing at a «pure» zone after evacuation from Narovljansky area of the Gomel area was 10 Gy. Find out the weight and activity of the iodine-131 incorporated in a thyroid gland of the child at the moment of its evacuation from polluted as a result of failure on area ChNPS. (Weight of a thyroid gland of the child of 15 gramme).

TEST CONTROL

Bergognie-Tribondorule is formulated as:

a) the radiosensibility of tissues is directly proportional to the proliferative activity and inversely proportional to the degree of differentiation of its constituent elements;

b) the radiosensibility of tissues is directly proportional to the degree of differentiation of its elements and is inversely proportional to their proliferative activity;

c) radiosensibility of tissues is directly proportional to the proliferative activity and degree of differentiation of its elements.

High radiosensibility has ...

a) endocrine system;
b) bone;
c) red bone marrow.

An exception to the Bergognie-Tribondo rule are ...

a) leukocytes;
b) nerve cells;
c) lymphocytes.

The transmutation effect is connected with ...

a) formation of thymine dimmers;
b) transformation in the nucleic bases C-14 in to the stable nitrogen;
c) decay of radioactive iodine in the thyroid gland.

In the dose range of 1–10 Gy develops ...

a) cerebral syndrome;
b) medullary syndrome;
c) gastrointestinal syndrome.

Cerebral radiation syndrome develops at doses of ...

a) 10 Gy;
b) about 50 Gy;
c) over 100 Gy.

The intestinal form of acute radiation disease occurs at a dose of ...

a) 1–10 Gy;
b) 10–20 Gy;
c) 10–40 Gy.

Third degree of severity of acute radiation sickness corresponds to the dose of ...

a) 1–2 Gy;
b) 4–6 Gy;
c) 6–10 Gy.

To deterministic effects of radiation exposure is related to ...

a) leukemia;
b) reproductive disorders;
c) skin cancer.

To the stochastic effects of radiation exposure is related to ...

a) non-neoplastic lesions form of blood;

b) ray cataract;
c) skin cancer.

The mechanism of irradiation deterministic effects occurrence is based on ...
a) radiation block mitosis;
b) excess of the number of dead cells over the number of survivors;
c) mutations in the germ cells.

Threshold dose (the threshold of clinical effect) could be related to ...
a) deterministic effects of radiation exposure;
b) stochastic effects of radiation exposure;
c) genetic effects of radiation exposure.

As small doses for given type of organism are called doses ...
a) of 2magnitude orders lower than the LD50;
b) of order magnitude lower than the LD50;
c) equal to LD50.

TOPIC 5
THE DETERMINISTIC AND STOCHASTIC EFFECTS CONSEQUENCES OF A RADIATION EXPOSURE

The motivational characteristic of the theme

The knowledge of medical and biologic consequences of irradiation of a human body, structure of the diseases of the population of Belarus after accident on ChNPS, who suffered from radiation exposure, is necessary for the further practical activities of the doctor for the purpose of carrying out adequate timely treatment-and-prophylactic actions for decreasing the damaging effect of ionizing radiation.

The general time of employment: 4 hours

The employment purpose

To acquire medical and biologic consequences of irradiation of a human body.

Employment problems:
1) to fix practical skills;
2) an ability to express method of definition of the incorporated radio cae-

sium in a human body device SRP-68-01; to estimate the received results;

3) to acquire knowledge about indications of the necessity of inspection carried out to find the radioactive caesium in an organism, periodicity of carrying out of inspections and an estimation of the received results.

Requirements to the initial level of knowledge

For development of the theme via employment of the knowledge of bases of biology, biochemistry, normal physiology, the general hygiene is necessary.

Control questions on the employment theme:

1. The general characteristic of the determined consequences of irradiation: concept, development terms, pathogenesis, dependence on a dose.
2. Kinds of the determined effects: communication with a dose of an irradiation, a development condition.
3. The contribution of the incorporated radio caesium to the formation of a dose of internal irradiation of an organism.
4. Indications of the necessity of inspection carried out to find the radioactive caesium in an organism, periodicity of carrying out of inspections.
5. Types and the characteristics of stochastic consequences of irradiation.
6. The comparative characteristic of the determined and stochastic consequences of irradiation.
7. Concept of small doses of ionising radiation.Affect of small doses of ionising radiation on a human body. Radiating hormesysis.
8. The state of health of the population of Belarus after the disaster on ChNPS.

Additional information to topic

In the development of radiating damages it is possible to find 4 phases: three short ones, connected with infringements at molecular level and the fourth one is long during which changes at the level of cells, fabrics, body and an organism develop. In its turn, the consequences generated on 4th phase share the time for the nearest either early and kept away or late, and on character of display — on determined (earlier designated as not stochastic), stochastic and genetic.

Radiation effects may appear:

— early (i.e. within three months)

— late (after 3 months, usually in years).

Early effects result from high dose radiation to partial body or whole body. They are all of deterministic type. Among the local effects the most frequent is the radiation induced skin injury. Acute exposure of the whole body is early expressed in the rather general symptoms of the acute radiation syndrome (ARS) or acute radiation disease. It leads to death — without treatment — in 3–6 weeks if the radiation absorbed in the whole body dose is above 5 Gy. The $LD_{50/60}$ dose is about 3.5 Gy when there is no possibility of specialized treatment. However, with specialized haematological treatment and provision of sterile conditions, the effects of doses even twice as high can be cured and the patient can be saved.

Among the ***late effects*** we can distinguish deterministic effects, such as dermatitis, cataracta or teratogenic effects. They develop if the cumulative absorbed dose is above of a cumulative threshold dose required for the given effect. Thus, teratogenic damage may only develop if the absorbed dose in the foetus is above 0.1 Gy. The stochastic late effects are cancer and genetic (hereditary) effects, usually appearing after many years.

Early deterministic effects after whole body irradiation

- **<0.1 Gy** — no detectable difference in exposed or non-exposed patients.
- **0.1–0.2 Gy** — detectable increase in chromosome aberrations, clinical signs or symptoms.
- **0.12 Gy**– sperm count decreases to minimum about day 45.
- **0.3 Gy** — detectable temporary sterility for man.
- **0.5 Gy** — detectable bone marrow depression with lymphopenia.
- Below 0.1 Gy, whole body(WB), there is no detectable difference in exposed vs non-exposed patients.
- Detectable increase in chromosome aberrations by cytogenetic dosimetry is found in whole body doses greater than 0.1–0.2 Gy but still there are no clinical signs or symptoms.
- Sperm count decreses to minimum about day 45 at doses more than 0.12 Gy WB.
- Bone marrow depression with lymphopenia can be detected at doses 0.5 Gy WB.

Human Dose Response

The $LD_{50/30}$ or $LD_{50/60}$ is defined as the dose necessary to cause death in 50 % of an irradiated population in 30 and 60 days, respectively. For an exposed worker population, the dose for 5 % mortality may differ from the dose for 95 % mortality by only 2–3 Gy. Therefore, an increase in dose by only a factor of 2 may represent the difference between total survival of an irradiated population and essentially total mortality. *$LD_{50/60}$* may increase above 5.4 Gy with advanced therapy modalities.

Factors decreasing $LD_{50/60}$

- Coexisting trauma combined injury.
- Chronic nutritional deficit.
- Coexisting infection.
- Contribution of high LET radiation

As with many other clinical phenomena, a patient's response to radiation may not conform to the anticipated. Therefore, the relationship between a particular radiation dose level and an expected effect should be considered approximate at best. Individual response to and ability to recover from radiation injury is related to:

- total dose and quality of radiation;
- dose rate;
- portion of the body exposed;
- comparative intrinsic genetic cellular radio sensibility;
- uniformity of exposure;
- age and health of the victim;
- presence of coexisting injuries or illnesses.

Deterministic effects have a threshold of irradiation under which they do not appear and are the necessary cosequence of irradiation. The damage they cause depends on the dose: they are sublethal from 0, 25 to 2 Sv, lethal from 2 to 5 Sv (a certain percent of population dies within 60 days), above 5 Sv the majority of people die within 60 days and above 6 to 7 all people die. Of course, these effect depend also on many other factors, like age, sex, health etc.

Stochastic effects are coincidental and cannot be avoided. They don't have a threshold. These can be divided into **somatic** and **genetic**. Among the somatic effects, secondary cancer is the most important. It develops because radiation causes DNA mutations directly and indirectly. Direct effects are those caused by ionizing particles and rays themselves, while the indirect are those that are caused by free radicals, generated especially in water radiolysis and oxygen radiolysis. The genetic effects confer the predisposition to cancer to the offspring. The process is not well understood.

Stochastic effects of radiation exposure:

1. Frequency proportional to dose.
2. No threshold dose.
3. No method for identification of appearance of effect of ionizing radiation in individuals.
4. Increase in occurrence of stochastic effects provable only by epidemiological method.
5. Stochastic effects observed in animal experiments.
6. Dose-effect relationship for humans can be studied only in human population groups.
7. Dose-effect relationship in low dose range (below 100 mSv) not yet verified.
8. Extrapolation down to zero excess dose accepted only for radiation protection and safety.

Carcinogenic effects:

1. *Carcinogenic effects* have been known practically since the discovery of radioactivity and since the first case of radiation-induced cancer was described in 1902.

2. The epidemiological assessment was made from over 575 cancers and leukaemias for the 80,000 survivors irradiated at Hiroshima and Nagasaki, and about 2,000 cancers of the thyroid in children in the Chernobyl region.

3. The actual data does not enable us to show a risk of cancer at greater than 0,1 Gy by acute irradiation.

Nevertheless, it is considered that risk of cancer and the relationship dose/risk remains linear for doses below 0,1 Gy.

- If cells are exposed to high dose at high dose rate, they are killed by radiation and eliminated.
- If cells are exposed to low dose at low dose rate, they are normally repaired and return to normal cell cycle. However, if the repair occurs with certain mistakes, i.e. mutations, the cells remain viable but mutated and may not perform the usual functions of the given cell line.

These mutated cells form the pre-cancer that has no clinical or laboratory signs at all. When a second factor (physical, chemical or viral) affects these cells, the pre-cancer stage may be promoted to minimal cancer (still without any clinical signs).

With a new effect of any cancer inducing agent, the minimal cancer may progress to clinically manifest cancer, which may lead to metastasis of malignant cells into other organs (spreading via lymph or blood flow).

This multistage-multifactorial theory of cancer induction is the most commonly accepted one today.

One of paradoxical effects of small and midget doses is the effect ***radiating hormesysis***. The term radiating hormesis has been offered in 1980 to T. D. Lakki and means favorable influence of small doses of an irradiation. The mechanism radiating hormesis at level of a cell of warm-blooded animals consists in initiation of synthesis of fiber, activation of a gene, DNA reparation in reply to stress — influence of a small dose of an irradiation (close to value of a natural radioactive background of the Earth). This reaction finally causes activation membrane receptors, proliferation of splenocytes and stimulations of immune system. Small doses of activate immune system at different kinds of animals and the key membran-connected enzymes, in particular adenylate cyclase, activate reparation systems and raise stability of cages and an organism to the subsequent higher doses of an irradiation.

Task

Define factor of weakening relaxation by a premise of a background irradiation of the person on open district.

PED (power effective dose) on open district — 20 mcR/h, indoors — 10 mcR/h.

The solution

Кeas=PEDopen/PEDind=20/10=2, i.e. the premise weakens an external irradiation of the person in 2 times.

Tasks for the solution:

Task 1

What is the time the inhabitant injured because of the accident on ChNPS should live in «a pure» zone so that activity of the caesium-137 incorporated in its body decreased in 100 times?

Task 2

Average capacity of the dose in rural settlement is 20 mcR/h.

What dose will a person receive in a year:

— The bookkeeper while 8 hour of stay in a brick building, 12 hours in a wooden building and 4 hours in the open air;

— The agriculturist while 12 hour stay in the open air and 12 hours in the wooden house. Factor of protection of the wooden house — 2, brick one — 8.

Task 3

The equivalent annual dose at which it is necessary to resettle is 20 mSv/year. Deicide between 2 settlements: 1 — with the capacity of an exposition dose 500 mcR/hour; 2 — with the capacity of an exposition dose — 100 mcR/hour. An average factor of protection of the population in premises is 1,5.

Task 4

During a photoroentgenography procedure an absorbed dose of a thorax makes 3 mGy, thus the dose is distributed as follows: in lungs of 25 %, in bone brain — of 10 %, in bone tissue of 25 %, in muscles — of 35 % in the skin — of 2 %, in the gullet — of 3 %. Define an effective dose of irradiation on an organism.

Task 5

Limit of the dose for workers of the nuclear power station is 50 mSv/year. How many days in a week can the metre man work if his shift is 12 hours during 45 weeks of work in a year. Average capacity of an exposition dose on the worker’s place is 3mR/hour.

Task 6

Define an effective equivalent dose of irradiation in mSv if the skin and red marrow are irradiated by beta particles with the absorbed dose of 0,1 Gy and 0,05 Gy accordingly, the lungs and the liver by alpha particles with the absorbed dose 4 mGy and 20 mGy, accordingly, a stomach — x-ray radiation with the absorbed dose 8 mGy.

Task 7

The population of the Gomel region is 1, 5 million persons, 500 thousand of them live in Gomel, 500 thousand — in cities and settlements, 500 thousand — in countryside. Owing to disaster on ChNPS the average annual effective dose influencing the inhabitants of Gomel is 0,2 mSv/year, cities — 0,4 mSv/year, the rural population — 0,6 mSv/year. Define the collective dose of the population of the Gomel region.

Task 8

Calculate an annual effective dose of internal irradiation of the organism of a 5-year-old child because of milk with specific activity of caesium-137 of 10 Bq/l. Daily consumption of milk is 0, 5 l. The factor of strengthening of a dose for children till 7 years is 2.3.

Task 9

Calculate a total annual effective dose of internal irradiation on the bone marrow and the red marrow of a teenager of 13 years old because of drinking milk with specific activity of strontium-90 of 5 Bq/l. In the bone marrow there are 90 % of the strontium-90 which is in the organism. Annual consumption of milk — of 150 l. The factor of strengthening of a dose for children of 7–15 years is 3.

Task 10

Calculate an annual effective dose of internal irradiation.

Inhalation reception of americium-241 with volume activity of air 0,1 mcBq/l in an organism of the adult person is 150 m^3 daily.

Task 11

Calculate in how many times does the value of an admissible dose of irradiation exceed the limit if a dose generated in an organism of the adult man because of the consumption of milk with specific activity of caesium-137 of 3×10^{-8} Cu/kg. Annual consumption of milk is 400 kg.

Task 12

Calculate an annual effective dose of internal irradiation in an organism of the adult woman while inhalation of caesium-137 with volume activity of 5×10^{-13} Cu/l. Daily inhalation of air is 8 m^3.

Task 13

The adult person in average receives a dose of irradiation from space radiation 0,315 mSv/year, from that 0,3 mSv/year — a dose of external irradiation, 0,015 mSv/year — a dose of internal irradiation. Define, what dose of the external and internal radiation will be (separately received by the person for life (70 years).

Task 14

Calculate in how many times does the value of an admissible dose of irradiation exceed the limit after radiating failure (20 mSv/year) if a dose generated during the consumption of milk with specific activity of iodine-131 of 400 Bq/kg. Daily consumption of milk is1 of kg. Effect of radioactive disintegration and biological deducing can be not taken into consideration.

Task 15

Calculate an annual effective dose of internal irradiation in an organism of the adult person during inhalation of plutonium-239 with volume activity 0,2 mcBq / l. Average frequency of breath is 20 breaths minute, volume of a breath is of 5 l.

TEST CONTROL

1. Cerebral radiation syndrome develops at doses of ...

a) 10 Gy;
b) about 50 Gy;
c) over 100 Gy.

2. The intestinal form of acute radiation disease occurs at a dose of ...

a) 1–10 Gy;
b) 10–20 Gy;
c) 10–40 Gy.

3. Third degree of severity of acute radiation sickness corresponds to the dose of ...

a) 1–2 Gy;
b) 4–6 Gy;
c) 6–10 Gy.

4. To deterministic effects of radiation exposure is related ...

a) leukemia;
b) reproductive disorders;
c) skin cancer.

5. To the stochastic effects of radiation exposure is related...

a) non-neoplastic lesions form of blood;
b) ray cataract;
c) skin cancer.

6. The mechanism of irradiation deterministic effects occurrence is based on ...

a) radiation block mitosis;
b) excess of the number of dead cells over the number of survivors;
c) mutations in the germ cells.

7. Threshold dose (the threshold of clinical effect) could be related to ...

a) deterministic effects of radiation exposure;
b) stochastic effects of radiation exposure;
c) genetic effects of radiation exposure.

8. As small doses for given type of organism are called doses ...

a) of 2 magnitude orders lower than the LD50;
b) of order magnitude lower than the LD50;
c) equal to LD50.

9. Radiation hormesis is ...

a) a beneficial effect of radiation trace doses;

b) a enhancing phenomenon of ionizing radiation negative effect in the low dose range;

c) increasing of the stochastic effects risk in exposed persons.

10. Stochastic effects of radiation exposure are characterized by:

a) the presence of a threshold dose;

b) absence of threshold dose;

c) evident in any event at a threshold dose.

11. Deterministic effects of radiation exposure include:

a) radiation cataract;

b) neoplastic thyroid disease;

c) increased incidence of somatic disorders.

12. LD50 for a man is ...

a) 10 Gy;

b) 4 Gy;

c) 0, 4 Gy.

13. Genetic effects of radiation exposure are characterized by ...

a) evidence in any case at a threshold dose;

b) rate expression depending on the collective dose;

c) a threshold dose.

TOPIC 6
CONTROL OF RADIATING SAFETY

The motivational characteristic of the theme

The knowledge of principles and methods of maintenance of radiating safety is necessary for the further practical activities of the doctor for the purpose of carrying out of actions for restriction of an irradiation of the population, including in the conditions of radiating failure, for maintenance of radiating safety of the personnel at operation of technogenic sources of radiation.

The general time of employment: 4 hours

The employment purposes:

1) to acquire the knowledge of the main principles of maintenance of radiating safety of the population;

2) to acquire the knowledge of the principles of the organization and carrying out of individual radiation control.

Employment problems:

1. To acquire the basic requirements on maintenance of radiating safety;

2. To acquire main principles of the organisation of work with sources of ionising radiation.

Requirements to initial level of knowledge

For the development of the theme of employment the knowledge of bases of physics, the general chemistry, biology, biochemistry, the general hygiene, factory hygiene is necessary. High-level mastering of the material of practical employment is possible if the students have adequate notions of the terms "risk" and «safety», the knowledge of the principles of a substantiation of admissible levels of the influence, the principles of the organization of works in harmful working conditions.

Control questions on the employment theme:

1. The international and national bodies of regulation and management in the field of maintenance of radiating safety.
2. The general characteristics of the basic documents regulating maintenance of radiating safety of the population: Law of the RB «About radiating safety of the population», NRS-2000, the basic sanitary rules of maintenance of radiating safety.
3. Ways of maintenance and an estimation of a condition of radiating safety of the population: the main principles of maintenance of radiating safety, the categories of irradiated people and basic dose limits corresponding to them; classes of specifications.
4. The closed sources of ionizing radiation, methods of protection against an external irradiation.
5. Open sources of ionizing radiation, methods of protection against an external and internal irradiation; protection of environment against radioactive pollution.
6. Ways of maintenance of radiating safety of the personnel and the population. Radiating control at work with the sources of ionizing radiation used in medicine. Individual dosimetry.
7. The concept of radiating failures. Criteria for decision-making on population protection at radiating failures.

The additional information to topic

Radiating safety is a condition of security of the present and the future generations of people from harmful influence of ionizing radiation. Maintenance of radiating safety of the population provides carrying out of a complex of actions (administrative, technical, sanitary-and-hygienic and others), various categories of the population limiting an irradiation within admissible thresholds and providing decrease in radioactive environmental contamination to the lowest levels reached by means comprehensible to a society (taking into account social and business factors).

Radiating safety is provided with the state with use of following positions:

1. Legislatively — standard base RB.
2. All-round and universal radiating control.
3. Protection against radiation.

The basic document regulating irradiation of various categories of the population in Belarus — the Law «About Radiating Safety of the population» № 122-3 from January, 5th, 1998 with respective alterations and additions. It defines the bases of legal regulation in the field of maintenance of radiating safety of the population; it is directed on creation of the conditions providing protection of life and health of people from harmful influence of ionizing radiation.

The law of the RB «About Radiating Safety of the population» proclaims three main principles of radiating safety:

1) Not to excess the admissible limits of individual doses of irradiation of the person from all sources of radiation (a rationing principle);

2) The acceptation of any unreasonable irradiation: prohibition of all kinds of activities which use the sources of radiation giving it to the society, only if they do not exceed the limit of the risk of the possible harm caused by an additional irradiation (a substantiation principle);

3) Lessening of the dose of radiation to lowest possible level: maintenance at lowest possible and achievable level taking into account economic and social factors of individual doses of irradiation and the number of irradiated persons due to the usage of any source of radiation (an optimization principle). The dose should be as low as it is possible and is achievable taking into account social and economic and scientific potential of the country.

Rationing of radiating influence is carried out for different categories of irradiated persons.

The category of irradiated persons is the conditionally allocated group of the population different in the degree of contact to ionizing radiation.

According to the law of the RB «About radiating safety of the population» are divided into *2 categories of irradiated persons:*

1. The personnel (professional workers), i.e. persons who constantly or temporarily work directly with source of ionizing radiation (SIR) (an example: the doctor-radiologist, the laboratorian of radio isotope laboratory).
2. All population, including persons from the personnel, out of sphere and conditions of their industrial activity.

Dose limit *(DL)* — the size of an annual effective or equivalent dose of a technogenic irradiation which should not be exceeded in the conditions of normal work. Observance of a limit of an annual dose prevents occurrence of the determined effects, and the probability of stochastic effects remains thus at comprehensible level.

Limit of annual receipt (LAR) — an admissible level of receipt given radionuclide in an organism within a year which at monofactorial influence leads to an irradiation of the conditional person the expected dose equal to corresponding limit of an annual dose.

Level control — the value of controllable size of a dose, capacity of a dose, radioactive pollution etc., established for operative radiating control, for the purpose of fastening of the reached level of radiating safety, maintenance of the further decrease in an irradiation of the personnel and the population, radioactive environmental contamination. Test objective levels are established by administration of establishment and consider the level of radiating safety reached in establishment and provide conditions at which radiating influence will be below admissible. The test objective levels accepted in establishment, always below admissible levels (table 6.1).

Requirements of «Norms» do not extend on the sources of radiation creating under any conditions of the reference with them:

Individual annual effective dose is no more than 10 mcSv;

Individual annual equivalent dose is in a skin no more than 50 mSv and in a crystalline lens no more than 15 mSv;

Collective effective annual dose is no more than 1 person-Sv (Sievert) or when at a collective dose more than 1 person-Sv the estimation by an optimisation principle shows inexpediency of decrease in a collective dose.

Table 6.1 — The basic limits of doses

Normalised sizes*	Limits of doses	
	the personnel	the Population
Effective dose	**20 mSv in a year** on the average for any consecutive 5 years, but no more than 50 mSv in a year	**1 mSv in a year** on the average for any consecutive 5 years, but no more than 5 mSv in a year
Equivalent dose for a year in an eye crystalline lens ** to the Skin *** Brushes and stops	 150 mSv 500 mSv 500 mSv	 15 mSv 50 mSv 50 mSv

Notes:

* the simultaneous irradiation to the specified limits on all normalised sizes Is supposed.

** Concerns the dose on depth of 300 mg/sm^2.

*** Concerns an average the area with 1 sm2 to value in basal layer of the skin in the thickness of 5 mg/sm^2 under an integumentary layer in the thickness of 5 mg/sm^2. On palms a thickness of an integumentary layer — 40 mg/sm^2. The specified limit presupposes irradiation of all skin of the person provided that within an average irradiation of any of the area of a skin of 1 sm^2 this limit will not be exceeded. The dose limit at a face skin irradiation provides not excess a dose limit on a crystalline lens from beta particles.

The basic safety requirements at work with ionizing radiation sources depend on type of a source used at the enterprise: ***closed or opened SIR***.

The closed source — a radioactive source, which device excludes the reception of radioactive substances which are contained in the environment.

Open source — a radioactive source at which the reception of radioactive substances which are contained in the environment is possible.

The radiating dosimetric control (control over observance of admissible levels of an irradiation and an individual radiation control) is spent by service of radiating safety, or specially allocated person.

To radiating control are subject:

— Radiating characteristics of the sources of radiation, emissions in atmosphere, a liquid and firm radioactive waste.

— The radiating factors created by technological process on workplaces and in environment.

— Radiating factors in the polluted territories and in buildings with the raised level of a natural irradiation.

— Levels of an irradiation of the personnel and the population from all sources of radiation on which action NRS-2000 extends.

The basic controllable parametres are:

— Annual effective and equivalent doses.

— Receipt radionuclides in an organism and their maintenance in an organism for an estimation of annual receipt.

— Volume or specific activity of radionuclides in air, water, foodstuff, building materials and others.

— Radioactive pollution of integuments, clothes, footwear, working surfaces.

— Dose and capacity of a dose of external radiation.

— Density of a stream of particles and photons.

PRACTICAL WORK

Fill the table: «the Comparative characteristic of the determined and stochastic effects»

Sign	The Determined effects	Stochastic effects
Definition synonym		
The occurrence mechanism		
Time of occurrence of effect		
Doses limit		
Clinical displays		

Tasks for the solution:

Task 1

The worker from the personnel is 40 years old. He started working with the sources of ionizing radiation when he was 25 years old. Define the maximum equivalent dose which it could receive for the time of work.

Task 2

What maximum equivalent dose could the operator receive for the time of work, if his age is 25 years?

Task 3

Is it necessary to show special measures of protection and requirements to placing of installation with the closed source of γ radiation if the distance from accessible parts of installation in working position and in position of storage is 1 m and does not exceed capacity of an equivalent dose 1 mcSv/h?

Task 4

During the performance of thorax radiography the patient has received an effective dose 0, 15 mSv at picture performance in a posterior-anterior projection and 0,37 mSv in a lateral projection. Estimate the risk and the damage for the patient during thorax radiography.

Task 5

As a result of radiation control the doctor-radiologist received a dose of 35 mSv during a year. Estimate the received dose and what measures is it necessary to undertake?

Help material

Definition of an effective dose of irradiation of patients at radiological researches.

Measurement of a product of a dose in the area by the results of measurements by the dosimeters using as the detector through passage ionization chamber, established on a x-ray radiator.

$$E = F \times Kd, \text{ [mcSv]},$$

where: F — the measured size of product of a dose on the area, sGy×sm^2;

Kd — dose factor for the given research and the patient of the given age, (mcSv/sGy×sm^2)

TEST CONTROL

1. Chernobyl release radionuclides, emerging now the primary dose load on the human body are:

a) iodine-131;

b) Cs-137;

c) ruthenium-106.

2. Emission Chernobyl radionuclides that have predominantly skeletal type of distribution in the human body are:

a) iodine-131;
b) strontium-90;
c) tritium.

3. On the territory of the pollution density with cesium-137 less than 5 Cu/km² the greatest importance in shaping the dose on the human body has:

a) irradiation for ingestion of radionuclides to the body;
b) irradiation with inhalation of radionuclides to the body;
c) exposure from deposition of radionuclides on the environment objects.

4. Most short-term impact of the Chernobyl release radionuclides on the human body has ...

a) irradiation for ingestion of radionuclide;
b) irradiation with inhalation of radionuclides;
c) irradiation from a radioactive cloud.

5. Chernobyl release radionuclides with a uniform type of distribution in human organism are:

a) Cs-137;
b) plutonium-239;
c) iodine-131.

6. Immediately after the Chernobyl accident the bulk of the radiation dose at the population was formed by ...

a) cesium-137;
b) cesium-134;
c) iodine-131.

7. As a result of the Chernobyl release the greatest part of the territory of Belarus polluted with ...

a) strontium-90 and strontium-89;
b) plutonium-240 and plutonium-240;
c) cesium-134 and cesium-137.

8. Immediate resettlement zone corresponded to the territory of the Republic with contamination density of cesium-137 is ...

a) more than 40 Ci/km²;
b) 15–40 Ci/km²;
c) 1–5 Ci/km².

9. The contamination density of the Republic territory of Cs-137 from 15 to 40 Ci/km² corresponds to the zone ...

a) with the right to resettlement;
b) of periodic radiation control;
c) of subsequent resettlement.

10. Absorption of strontium-90 in the gastrointestinal tract of an organism decreases ...

a) during lactation;
b) in childhood;
c) by using calcium-rich food.

TOPIC 7
THE DOSE IRRADIATION LOWERING

The motivational characteristic of the theme

For development of the theme and its employment the knowledge of bases of the general chemistry, biology, biochemistry, normal and pathological physiology, the general hygiene, hygiene of a food is necessary. High-level mastering of the material of employment is possible if the students have the knowledge of influence of modes of impellent activity and food on the level of health of the population, the principles of the healthy way of life.

The general time of employment: 4 hours

The employment purpose

To acquire the knowledge of the main principles of decrease of exposure doses on the population.

Employment problems:

1. To acquire the basic methods and actions for decrease in beam loadings on the population in the conditions of chronic low dose irradiations;
2. To fix knowledge of radionuclides metabolism in a human body;
3. To seize practical skills of an estimation of radiating influence on the population at the expense of an internal irradiation at residing on polluted radionuclides territories.

Requirements to the initial level of knowledge

For development of a theme of employment the knowledge of bases of the general chemistry, biology, biochemistry, normal physiology, the general hygiene, hygiene of a food is necessary.

Control questions on the employment theme:

1. Formation principles of dose loaded on the population after radiating failure.
2. The complex of actions for decreasing the doses formed due to external irradiation.
3. The complex of actions for decreasing the doses formed due to internal irradiation:
4. The actions made at the state level;
5. The actions made at individual level, including the ways of decreasing the reception and deducing acceleration radionuclides from an organism.
6. Principles of residing of the population on the territories polluted by radionuclides.

The additional information to topic

All actions for decreasing the exposure doses on population at the territories polluted radionuclides can be divided on two groups:

I. THE ACTIONS AT NATIONAL LEVEL UNDERTOOK BY THE STATE

1. The system of radiating control.

In the course of radiating control the following parameters are measured:

— the capacity of an exposition dose;

— the density of the stream of particles;

— the concentration of radionuclides in water, air, soil, foodstuff, a human body.

According to the law of the RB «About the legal regime on the territories, pass to radioactive pollution as a result of Chernobyl accident» (1991) are defined by *3 levels of radiating control*:

— The state.

— The departmental.

— The public.

Radiating control is realized in the following territories (zones):

Zone A — the territory polluted as a result of Chernobyl failure.

Zone B — the territory of probable radiating influence of emissions of the nuclear power station (30-kilometre zones round the Ignalin and Chernobyl nuclear power station).

Zone C — other territories of the republic.

The territory accessible to this or that zone defines frequency rate and volume of researches of foodstuff and water on the radionuclides maintenance.

Foodstuff and raw materials in they are produced on the territory of radioactive pollution, they should have the certificate with the instructions on production and the radionuclides maintenance. The radionuclides maintenance during the production should not exceed the Republican admissible levels (RAL) the radionuclides maintenance caesium and strontium in foodstuff and potable water which regularly are reconsidered and affirm the Main state health officer of RB and Chairman NCRP (national commission of radiation protection) and Council of Ministers of RB.

II. THE ACTIONS UNDERTOOK INDEPENDENTLY

Actions for radionuclides reception level decreasing in an organism.

Restriction and/or starting a diet consisting of the foodstuff less accumulating radionuclides in significant amounts.

It is known that plants in different degrees accumulate radionuclides. The greatest accumulation the plants can have is revealed in those ones the root system of which is located superficially, as the basic quantity of radionuclides contained in them is in superficial layer — 1–5 centimetric (about 95 % from all radioactive substances contained in soil).

Culinary and technological processing of foodstuff.

Restriction of the use of «local» products, especially grown in the wood: mushrooms and berries.

The actions limiting absorption of radionuclides in an organism:

It is possible to reduce the action of radionuclides which got to an organism, having limited their absorption. For this purpose there are the following principles:

Principle of competitive replacement.

Radionuclides on the chemical properties and, accordingly, metabolism ways are similar to some stable elements — caesium with potassium and rubidium; strontium with calcium; plutonium with trivalent iron. At introduction of the products containing these stable elements to a diet, they will compete radioactive elements, and reduce them absorption.

Principle of radionuclides linkage in a gastroenteric path.

For the population living on polluted radionuclides territories, the use of the products rich in pectins, phytats, anticyonats which connect radionuclides in gastrointestinal tract is recommended.

The actions directed for acceleration of radionuclides reducing from an organism.

Strengthening intestines peristalsis which is provided by the use of the products rich with food fibres, including cellulose:

— Bread of a rough grinding.

— Vegetables (cabbage, a beet, carrots).

— Fruit (prunes).

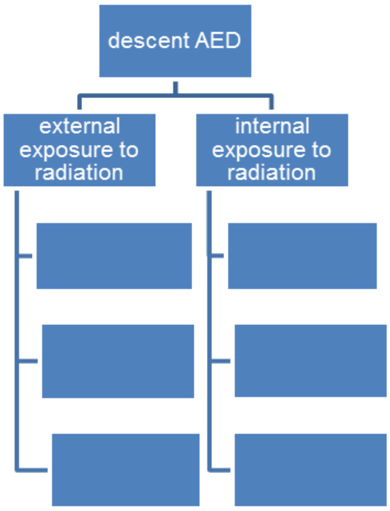
— Groats (buckwheat, porridge, millet).

Recommended consumption of food fibres — 30/days 10 gr on 1000 kcal of a daily diet.

PRACTICAL TASKS

Task 1

Schematically list main principles of decrease in an annual effective dose of internal and external irradiation:



Task 2

1) Distribute the following mushrooms to the following groups:

Groups	The Name of mushrooms
Mushrooms-accumulators	Champignon, the Polish mushroom, a birch mushroom, cep, oyster mushroom, yellow boletus, orange-cap boletus, puff-ball, agaric honey, russule, milk mushroom, saddle fungus, chanterelle.
Strongly accumulating radionuclides	
Middle accumulating radionuclides	
Radionuclides discriminators	

2) Recommend actions for culinary and technological processing for concentration radionuclides decrease in mushrooms before the usage for eating.

Task 3

Of the list of vegetables you got place them in ascending order according to the ability to accumulate Cs-137: onions, cucumbers, a sorrel, beans, vegetable marrows, a string bean, carrots, cabbage, peas, a beet, garlic, a garden radish, a potato, tomatoes, pepper.

TEST CONTROL

1. To formation of «spotted» contamination of the Republic territory as a result of the Chernobyl accident contributed ...

a) a high-activity;

b) release of the duration and a uneven ejection time;

c) abnormally high temperatures.

2. Chernobyl release radionuclides with long-term biological half-life of an organism are:

a) americium-241;

b) tritium;

c) cesium-134.

3. Radionuclide enters the body primarily through the gastrointestinal tract thanks due to ...

a) a high-energy radiation;

b) the high degree of accumulation in the body;

c) a good solubility.

4. Mainly by inhalation to the organism enters ...

a) cesium-137;

b) strontium-90 ;

c) americium-241.

5. Bergognie-Tribondo rule is formulated as:

a) the radiosensibility of tissues is directly proportional to the proliferative activity and inversely proportional to the degree of differentiation of its constituent elements;

b) the radiosensibility of tissues is directly proportional to the degree of differentiation of its elements and is inversely proportional to their proliferative activity;

c) radiosensibility of tissues is directly proportional to the proliferative activity and degree of differentiation of its elements.

6. High radiosensibility has ...

a) endocrine system;

b) bone;

c) red bone marrow.

7. An exception to the Bergognie-Tribondo rule are ...

a) leukocytes;

b) nerve cells;

c) lymphocytes.

8. The transmutation effect is connected with ...

a) formation of thymine dimmers;

b) transformation in the nucleic bases C-14 in to the stable nitrogen;

c) decay of radioactive iodine in the thyroid gland.

9. In the dose range of 1–10 Gy develops ...
a) cerebral syndrome;
b) medullary syndrome;
c) gastrointestinal syndrome.

10. Cerebral radiation syndrome develops at doses of ...
a) 10 Gy;
b) about 50 Gy;
c) over 100 Gy.

11. The intestinal form of acute radiation disease occurs at a dose of ...
a) 1–10 Gy;
b) 10–20 Gy;
c) 10–40 Gy.

12. Third degree of severity of acute radiation sickness corresponds to the dose of ...
a) 1–2 Gy;
b) 4–6 Gy;
c) 6–10 Gy.

13. To deterministic effects of radiation exposure is related ...
a) leukemia;
b) reproductive disorders;
c) skin cancer.

14. To the stochastic effects of radiation exposure is related ...
a) non-neoplastic lesions form of blood;
b) ray cataract;
c) skin cancer.

15. The mechanism of irradiation deterministic effects occurrence is based on ...
a) radiation block mitosis;
b) excess of the number of dead cells over the number of survivors;
c) mutations in the germ cells.

16. Threshold dose (the threshold of clinical effect) could be related to ...
a) deterministic effects of radiation exposure;
b) stochastic effects of radiation exposure;
c) genetic effects of radiation exposure.

17. As small doses for given type of organism are called doses ...

a) of 2 magnitude orders lower than the LD50;
b) of order magnitude lower than the LD50;
c) equal to LD50.

18. Radiation hormesis is ...
a) a beneficial effect of radiation trace doses;
b) a enhancing phenomenon of ionizing radiation negative effect in the low dose range;
c) increasing of the stochastic effects risk in exposed persons.

19. Stochastic effects of radiation exposure are characterized by:
a) the presence of a threshold dose;
b) absence of threshold dose;
c) evident in any event at a threshold dose.

20. Deterministic effects of radiation exposure include:
a) radiation cataract;
b) neoplastic thyroid disease;
c) increased incidence of somatic disorders.

21. LD50 for a man is ...
a) 10 Gy;
b) 4 Gy;
c) 0, 4 Gy.

22. Genetic effects of radiation exposure are characterized by ...
a) evidence in any case at a threshold dose;
b) rate expression depending on the collective dose;
c) a threshold dose.

23. Radiation Safety Standards – 2000 ...
a) establish a system of fundamental limits of doses and principles of their application;
b) contain requirements for the protection of the environment from pollution by radioactive substances;
c) contain requirements for the organization of work with sources of ionizing radiation.

24. Radiation Safety Standards – 2000 subjects are related to the following types of ionizing radiation on human beings:
a) in normal operation of man-made sources of radiation;
b) to cosmic radiation at Earth's surface;

c) to internal radiation generated by natural potassium.

25. Radiation Safety Standards – 2000 set the following categories of exposed individuals:

a) staff, all people, including those from staff, outside the sphere and the conditions of their production activities;

b) the population living in territories with contamination density of Cs-137 over 1 Ci / km²;

c) population receiving further from anthropogenic change of the background more than 1 mSv per year.

26. According to the Law of the Republic of Belarus «On radiation safety of the population» exposure of the population and staff due to the content of radon and natural gamma-emitting radionuclides in residential and industrial buildings ...

a) is not regulated;

b) should not exceed the established standards;

c) do not take into account at assessing the dose of background radiation.

27. In the Law of the Republic of Belarus «On radiation safety» there is followed a definition of a radiation accident:

a) loss-ionizing radiation source which could lead or has led to the exposure of people or radio-active contamination of the environment beyond the established norms;

b) is any situation involving the improper actions of staff which could lead or has led people to radiation or radioactive contamination of the environment in excess of established norms;

c) control loss of ionizing radiation source caused by malfunction, damaged equipment, improper actions of employees (staff), natural disasters or other causes that could lead or has led people to radiation or radioactive contamination of the environment beyond the established norms.

28. By the Law of the Republic of Belarus «On radiation safety of population»in case of radiation accidents ...

a) increased exposure of citizens engaged for rescue and decontamination is not regulated;

b) increased exposure of citizens engaged for rescue and decontamination is allowed at time period of their lives with free consent;

c) increased exposure of citizens engaged for rescue and decontamination is not considered.

29. Introduction to the diet of stable micro elements which compete with radionuclides allows to ...

a) speed removal of radionuclides from the body;
b) reduce the absorption of radionuclides in the gastrointestinal tract;
c) bind radionuclides in the gastrointestinal tract.

30. For the radiation dose reduction and prevention of adverse effects in conducting pregnant women radiological examinations ...
a) a conduct radiological diagnostic should be strictly prohibited;
b) preventive studies should be carried out according to strict clinical indications;
c) dose to the fetus should not exceed 0,01 Sv.

TESTS FOR SELF-CHECKING KNOWLEDGE OF STUDENTS

1. A nuclear charge equal to the ...
a) number of protons in the nucleus;
b) number of neutrons in the nucleus;
c) sum of the number of protons and neutrons in the nucleus.

2. The nucleus of an atom of potassium-40 atom contains 19 protons and 21 neutrons. What is the atomic number of this item?
a) 19;
b) 40;
c) 21.

3. The term «nucleon» belongs to ...
a) beta particles;

b) proton;
c) alpha-particles.

4. Isotopes are ...
a) atoms with different atomic number, but an equal number of neutrons in the nucleus;
b) atoms with different atomic number and mass number;
c) atoms with one and the same atomic number but with different mass numbers.

5. To the term «radionuclide» refers ...
a) the nucleus of a radioactive element;
b) the particle, part of the nucleus;
c) the nucleus of the stable atom.

6. A unit of radioactivity is ...
a) Gy;
b) Bq;
c) R.

7. The Law of the Republic of Belarus «On radiation safety»stated that the basic principles of radiation safety practices are:
a) a optimization principle;
b) the principle of limiting doses of external and internal exposure of the population at the expense of Chernobyl radionuclides release;
c) the principle of noninterference.

8. The law of radioactive decay characterizes ...
a) the reduction in the number of active atoms in time;
b) the type of decay of radioactive nuclei;
c) the mode energy release of radioactive nuclei.

9. During the process of alpha decay is ...
a) formed daughter nucleus with a mass less than 4 and with a charge less than 2 than in the mother nucleus;
b) nucleus is ejected from a heavy nucleus of a hydrogen atom;
c) formed a new nucleus with the mass and charge less for 2 than that of the mother nucleus.

10. By calculating of the equivalent dose using radiation weighting factor should be taken into account:
a) the radiosensitivity of the tissue to this type of radiation;
b) the lethality of this type of radiation compared to a standard X-rays;

c) the probability of stochastic effects of irradiation.

11. The equivalent dose is ...

a) the radiation dose equal to the product of the absorbed dose weighting factor for the tissue of the body;

b) the radiation dose equal to the product of the exposure dose by a factor of the quality of ionizing radiation;

c) the radiation dose equal to the product of the absorbed dose by a factor of the quality of this type of ionizing radiation.

12. Tissue weighting multiplicator is used to calculate a ...

a) exposure dose;
b) equivalent dose;
c) effective dose.

13. Unit of absorbed dose corresponds to the ...

a) rad;
b) J;
c) Sv.

14. A dose of 1 Gy corresponds to the absorption of ...

a) 1 J energy 1g of substance;
b) 1 J energy 1 kg of substance;
c) 1 meV energy 1kg of substance.

15. Gray is a unit of a ...

a) absorbed dose;
b) equivalent dose;
c) exposure dose.

16. To the unit of equated dose corresponds ...

a) R;
b) Ci ;
c) Sv.

17. One rad is equal to ...

a) 10 mSv;
b) 10 mGy;
c) 0,01 R.

18. Sievert is a measure unit of a ...

a) absorbed dose;
b) equivalent dose;
c) exposure dose.

19. The unit of effective dose is ...

a) rad;
b) mrGy;
c) mSv.

20. To the effects of DNA double strand breaks are related ...

a) chromosome aberrations;
b) the formation of thymine dimmers;
c) a transmutation effect.

21. Application of the scintillation method of ionizing radiation registration is based on ...

a) gas ionization in the gas-discharge counters;
b) the photon radiation registration of some liquids and crystals that arise under the influence of ionizing radiation;
c) illumination of the films.

22. Owerly to a increasing of linear energy transfer there is ...

a) reduced oxygen effect;
b) increased the oxygen effect;
c) no change of the oxygen effect.

23. Direct (primary) type of ionizing radiation is …

a) neutron- radiation;
b) beta- radiation;
c) gamma- radiation.

24. A receptive device in apparatus based on the ionization method of ionizing radiation registration is ...

a) a scintillator;
b) Geiger-Muller counter;
c) a photographic.

25. The difference between X-ray and gamma radiation with the same energy is:

a) the penetrating power;
b) the quality factor;
c) the origin.

26. The quality factor of radiation characterizes ...

a) the striking ability of this type of radiation;
b) the penetrating ability of this type of radiation;

c) the detection efficiency of radiation.

27. The highest quality factor has ...
a) alpha radiation;
b) beta radiation;
c) gamma rays.

28. The total annual effective dose of human exposure due to different sources of radiation is ...
a) 3 mrSv/year;
b) 3 mSv/year;
c) mRem/year.

29. The main contribution to the formation of a natural background radiation make ...
a) a cosmic radiation;
b) sources of terrestrial origin;
c) a nuclear energy.

30. To the cosmogenic radionuclides are related ...
a) potassium-40;
b) Na-22;
c) radium-226.
31. The founder of the radioactive series is ...
a) lead-210;
b) radium-226;
c) uranium 235.
32. The highest dose of internal radiation is formed due to ...
a) thorium decay-series;
b) uranium decay-series;
c) neptunium decay-series.

33. Lead-210 ...
a) accumulates mainly in adipose tissue;
b) accumulates mainly in bone tissue;
c) undergoes alpha decay.

34. The main contribution to the formation of the annual effective dose of the population due to natural radionuclides which are not included in the radioactive series introduces ...
a) rubidium-87;
b) potassium-40;

c) tritium.

35. Of the components of technological-intensive radiation background the most radiation dose on the population is formed by ...

a) global fallout from nuclear weapons tests;
b) X-ray and radiodiagnostic procedure;
c) TV.

36. Global fallout of radionuclides are formed by ...

a) radioactive substances fallen within a radius of 30 km from their point of a radioactive emission;
b) radioactive substances introduced into the upper layer of troposphere and stratosphere;
c) radioactive substances scattered on the surface of the Earth's crust.

37. Of the intermediate products of uranium decay the main contribution to the formation of YED population exposure from natural background radiation makes ...

a) lead-206;
b) radon-222;
c) radium-226.

38. Radon-222 comes to the environment from ...

a) a soil and groundwater;
b) a solar cosmic radiation;
c) a car exhaust.

39. The main part of the dose from radon exposure is formed ...

a) by the expense of the radon;
b) due to radon decay products adsorbed on aerosol particles;
c) by themselves radon decay products.

40. The main dose load on the lungs is caused by ...

a) sorbed on aerosols of alpha-emitting decay products of radon;
b) sorbed on aerosols of beta-emitting decay products of radon;
c) sorbed on aerosols, of gamma-emitting decay products of radon.

41. Chernobyl release radionuclides, emerging now the primary dose load on the human body are:

a) iodine-131;
b) Cs-137;
c) ruthenium-106.

42. Emission Chernobyl radionuclides that have predominantly skeletal type of distribution in the human body are:

a) iodine-131;
b) strontium-90;
c) tritium.

43. On the territory of the pollution density with cesium-137 less than 5 Cu/km² the greatest importance in shaping the dose on the human body has:

a) irradiation for ingestion of radionuclides to the body;
b) irradiation with inhalation of radionuclides to the body;
c) exposure from deposition of radionuclides on the environment objects.

44. Most short-term impact of the Chernobyl release radionuclides on the human body has ...

a) irradiation for ingestion of radionuclide;
b) irradiation with inhalation of radionuclides;
c) irradiation from a radioactive cloud.

45. Chernobyl release radionuclides with a uniform type of distribution in human organism are:

a) Cs – 137;
b) plutonium – 239;
c) iodine – 131.

46. Immediately after the Chernobyl accident the bulk of the radiation dose at the population was formed by ...

a) cesium-137;
b) cesium-134;
c) iodine-131.

47. As a result of the Chernobyl release the greatest part of the territory of Belarus polluted whith ...

a) strontium-90 and strontium-89;
b) plutonium-240 and plutonium-240;
c) cesium-134 and cesium-137.

48. Immediate resettlement zone corresponded to the territory of the Republic with contamination density of cesium-137 is ...

a) more than 40 Ci/km²;
b) 15–40 Ci/km²;
c) 1–5 Ci/km².

49. The contamination density of the Republic territory of Cs-137 from 15 to 40 Ci/km² corresponds to zone ...

a) with the right to resettlement;
b) of periodic radiation control;
c) of subsequent resettlement.

50. Absorption of strontium-90 in the gastrointestinal tract of an organism decreases ...
a) during lactation;
b) in childhood;
c) by using calcium-rich food.

51. To formation of «spotted» contamination of the Republic territory as a result of the Chernobyl accident contributed ...
a) a high-activity;
b) release of the duration and a uneven ejection time;
c) abnormally high temperatures.

52. Chernobyl release radionuclides with long-term biological half-life of an organism are:
a) americium-241;
b) tritium;
c) cesium-134.

53. Radionuclide enters the body primarily through the gastrointestinal tract thanks due to ...
a) a high-energy radiation;
b) the high degree of accumulation in the body;
c) a good solubility.

54. Mainly by inhalation to the organism enters ...
a) cesium-137;
b) strontium-90 ;
c) americium-241.

55. Bergognie-Tribondo rule is formulated as:

a) the radiosensitivity of tissues is directly proportional to the proliferative activity and inversely proportional to the degree of differentiation of its constituent elements;

b) the radiosensitivity of tissues is directly proportional to the degree of differentiation of its elements and is inversely proportional to their proliferative activity;

c) radiosensitivity of tissues is directly proportional to the proliferative activity and degree of differentiation of its elements.

56. High radiosensitivity has ...
a) endocrine system;
b) bone;
c) red bone marrow.

57. An exception to the Bergognie-Tribondo rule are ...
a) leukocytes;
b) nerve cells;
c) lymphocytes.

58. The transmutation effect is connected with ...
a) formation of thymine dimmers;
b) transformation in the nucleic bases C-14 in to the stable nitrogen;
c) decay of radioactive iodine in the thyroid gland.

59. In the dose range of 1–10 Gy develops ...
a) cerebral syndrome;
b) medullary syndrome;
c) gastrointestinal syndrome.

60. Cerebral radiation syndrome develops at doses of ...
a) 10 Gy;
b) about 50 Gy;
c) over 100 Gy.

61. The intestinal form of acute radiation disease occurs at a dose of …
a) 1–10 Gy;
b) 10–20 Gy;
c) 10–40 Gy.

62. Third degree of severity of acute radiation sickness corresponds to the dose of ...
a) 1–2 Gy;
b) 4–6 Gy;
c) 6–10 Gy.

63. To deterministic effects of radiation exposure is related ...
a) leukemia;
b) reproductive disorders;
c) skin cancer.

64. To the stochastic effects of radiation exposure is related ...
a) non-neoplastic lesions form of blood;
b) ray cataract;

c) skin cancer.

65. The mechanism of irradiation deterministic effects occurrence is based on ...

a) radiation block mitosis;
b) excess of the number of dead cells over the number of survivors;
c) mutations in the germ cells.

66. Threshold dose (the threshold of clinical effect) could be related to ...

a) deterministic effects of radiation exposure;
b) stochastic effects of radiation exposure;
c) genetic effects of radiation exposure.

67. As small doses for given type of organism are called doses ...

a) of 2 magnitude orders lower than the LD50;
b) of order magnitude lower than the LD50;
c) equal to LD50.

68. Radiation hormesis is ...

a) a beneficial effect of radiation trace doses;
b) a enhancing phenomenon of ionizing radiation negative effect in the low dose range;
c) increasing of the stochastic effects risk in exposed persons.

69. Stochastic effects of radiation exposure are characterized by:

a) the presence of a threshold dose;
b) absence of threshold dose;
c) evident in any event at a threshold dose.

70. Deterministic effects of radiation exposure include:

a) radiation cataract;
b) neoplastic thyroid disease;
c) increased incidence of somatic disorders.

71. LD50 for a man is ...

a) 10 Gy;
b) 4 Gy;
c) 0, 4 Gy.

72. Genetic effects of radiation exposure are characterized by ...

a) evidence in any case at a threshold dose;
b) rate expression depending on the collective dose;
c) a threshold dose.

73. Radiation Safety Standards – 2000 ...

a) establish a system of fundamental limits of doses and principles of their application;

b) contain requirements for the protection of the environment from pollution by radioactive substances;

c) contain requirements for the organization of work with sources of ionizing radiation.

74. Radiation Safety Standards - 2000 subjects are related to the following types of ionizing radiation on human beings:

a) in normal operation of man-made sources of radiation;

b) to cosmic radiation at Earth's surface;

c) to internal radiation generated by natural potassium.

75. Radiation Safety Standards - 2000 set the following categories of exposed individuals:

a) staff, all people, including those from staff, outside the sphere and the conditions of their production activities;

b) the population living in territories with contamination density of Cs-137 over 1 Ci / km^2;

c) population receiving further from anthropogenic change of the background more than 1 mSv per year.

76. According to the Law of the Republic of Belarus «On radiation safety of the population» exposure of the population and staff due to the content of radon and natural gamma-emitting radionuclides in residential and industrial buildings ...

a) is not regulated;

b) should not exceed the established standards;

c) do not take into account at assessing the dose of background radiation.

77. In the Law of the Republic of Belarus «On radiation safety»there is followed a definition of a radiation accident:

a) loss-ionizing radiation source which could lead or has led to the exposure of people or radio-active contamination of the environment beyond the established norms;

b) is any situation involving the improper actions of staff which could lead or has led people to radiation or radioactive contamination of the environment in excess of established norms;

c) control loss of ionizing radiation source caused by malfunction, damaged equipment, improper actions of employees (staff), natural disasters or other causes that could lead or has led people to radiation or radioactive contamination of the environment beyond the established norms.

78. By the Law of the Republic of Belarus «On radiation safety of population» in case of radiation accidents ...

a) increased exposure of citizens engaged for rescue and decontamination is not regulated;

b) increased exposure of citizens engaged for rescue and decontamination is allowed at time period of their lives with free consent;

c) increased exposure of citizens engaged for rescue and decontamination is not considered.

79. Introduction to the diet of stable micro elements which compete with radionuclides allows ...

a) speed removal of radionuclides from the body;

b) reduce the absorption of radionuclides in the gastrointestinal tract;

c) bind radionuclides in the gastrointestinal tract.

80. For the radiation dose reduction and prevention of adverse effects in conducting pregnant women radiological examinations ...

a) a conduct radiological diagnostic should be strictly prohibited;

b) preventive studies should be carried out according to strict clinical indications;

c) dose to the fetus should not exceed 0,01 Sv.

ANSWER TO TEST

№ of question	Answer	№ of question	Answer	№ of question	Answer	№ of question	Answer
1	a	21	b	41	b	61	b
2	c	22	a	42	b	62	b
3	b	23	b	43	a	63	b
4	c	24	b	44	c	64	c
5	a	25	c	45	a	65	b
6	b	26	a	46	c	66	a
7	a	27	a	47	c	67	a
8	a	28	b	48	a	68	a
9	a	29	b	49	c	69	b
10	b	30	b	50	c	70	a

11	c	31	c	51	b	71	b
12	c	32	b	52	a	72	b
13	a	33	b	53	c	73	a
14	b	34	b	54	c	74	a
15	a	35	b	55	a	75	a
16	c	36	b	56	c	76	b
17	a	37	b	57	c	77	c
18	b	38	a	58	b	78	b
19	c	39	b	59	b	79	b
20	a	40	a	60	c	80	c

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Учебное издание

Бортновский Владимир Николаевич
Лабуда Анна Арнольдовна

РАДИАЦИОННАЯ
МЕДИЦИНА
(на английском языке)

Учебно-методическое пособие
для студентов 2 курса факультета по подготовке специалистов
для зарубежных стран медицинских вузов

Редактор *Т. М. Кожемякина*
Компьютерная верстка *А. М. Терехова*

Подписано в печать 13.10.2014.
Формат $60\times84^{1}/_{16}$. Бумага офсетная 80 г/м^2. Гарнитура «Таймс».
Усл. печ. л. 6,51. Уч.-изд. л. 7,12. Тираж 70 экз. Заказ № 366.

Издатель и полиграфическое исполнение:
учреждение образования «Гомельский государственный медицинский университет».
Свидетельство о государственной регистрации издателя,
изготовителя, распространителя печатных изданий № 1/46 от 03.10.2013.
Ул. Ланге, 5, 246000, Гомель.